Cognitive Factors Influencing Mathematics Ability in Children with ADHD

By

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Institute of Medical Science
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Abstract

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Background- Mathematics difficulty is a prevalent co-morbidity of ADHD. There is limited knowledge to explain cognitive characteristics of this co-morbidity. Objective- The study aims to investigate cognitive factors influencing mathematics performance in children with ADHD. Method- The sample consisted of 374 children with ADHD. The association between reading and mathematics ability and different cognitive factors measured by WISC-IV, Stop Signal Task and RAN was studied. Results- Inhibitory control did not have association with neither mathematics nor reading ability. Processing speed, working memory and visuo-spatial processing were predictors of mathematics score. Processing speed had differentiating role for mathematics performance. Conclusion- The lack of association between mathematics performance and inhibitory control implies possible independence of difficulties in mathematics learning from ADHD core cognitive deficits. Processing speed distinguishes mathematics from reading ability in children with ADHD. The cognitive factors influencing mathematics ability in ADHD seem to be similar to those in general population.
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CHAPTER I- INTRODUCTION AND BACKGROUND

Introduction

Attention deficit hyperactivity disorder (ADHD) is one of the most common childhood neuro-developmental disorders found in children. Prevalence estimates suggest that between 3% and 7% of school-age children are affected (Faraone, Sergeant, Gillberg & Biederman, 2003). ADHD is characterized by a triad of behavioral manifestations; these are comprised of developmentally inappropriate difficulties with attention, excess of activity, and impulsivity (American Psychiatric Association, DSM-IV, 1994; Barkley, 1998). Although they arise early in childhood (Barkley & Biederman, 1997), deficits associated with the condition typically persist over the course of a child’s development and, in many cases, into adult life (Barkley, Fischer, Smallish, & Fletcher, 2002). They are known to negatively impact social, educational, and occupational domains (Barkley 1998). Children with ADHD may experience academic underachievement, poor school performance, and repetition of the school year (Barkley et al. 2002; Arnold, Hodgkins, Kahle, Madhoo, & Kewley, 2015). A substantial part of these academic impairments are related to the high comorbidity of learning disabilities with ADHD.

In community samples, the prevalence of learning disabilities is estimated at 3-10% (WHO, 1989; Altarac, 2007; Lagae, 2008). Reading disability has been reported in 5-9% of such samples while mathematics disability is estimated to occur in 5-8% (Biederman, Newcorn & Sprich, 1991; Mazzocco & Myers, 2003; Shalev, Manor, Auerbach, & Gross-
Comparing to general population, ADHD-affected individuals show a significantly greater prevalence of learning disabilities with 20-30% of individuals with ADHD having a co-morbid learning disability. (Biederman et al. 1991), some reports have suggested the prevalence may be as high as 50% (Mayes and Calhoun, 2006). Reading disability is present in 20-40% of the ADHD population while mathematics disability appears in 11-26% (Srinivas, Roediger, & Rajaram, 1992; Monuteaux, Faraone, Herzig, Navsaria, & Biederman, 2005; Capano, Minden, Chen, Schachar, & Ickowicz, 2008).

Much like studies within the general population, most studies of children with ADHD in the area of learning have focused on reading disability. However, it is well-known that the prevalence of mathematics disability in children with ADHD far exceeds that of the general population, implying a vulnerability of children with ADHD to difficulty in mathematics learning. Problems with calculation and working with numbers can contribute to many life-long struggles which children with ADHD face. These problems can affect academic achievement, career success and even daily life. Yet it is not clear whether the predisposition of children with ADHD to mathematics disability is the result of deficits inherent of, or independent of, ADHD. There is a paucity of research on clinical aspects of co-morbidity of ADHD with mathematics disability; studies investigating the neuro-cognitive aspects of this co-morbidity are even less available. The heterogeneity in design and discrepancies in findings within the few existing studies make it difficult to reach a comprehensive understanding of the problem. In addition to these concerns,
inconsistencies are also present in the definition and measurement of mathematics learning disability. For the purpose of this study, and to avoid inaccuracy, the term Mathematics Low-Achievement (MLA) will be used to refer to our target problem with mathematics acquisition; a detailed definition of it is provided in the next chapter.

This thesis explores the cognitive factors influencing mathematics ability in children with ADHD. The study aims to provide a better understanding of whether the vulnerability of children with ADHD to mathematics difficulty is related to factors associated with ADHD or distinct from it. The literature review conducted for this thesis did not reveal any study investigating such a relationship, and this study is believed to be the first one to do so.

This study aims to explore cognitive deficits that might predispose children with ADHD to difficulty in mathematics acquisition. Also considering that reading disability is the other highly prevalent learning difficulty in children with ADHD this study contrasts the cognitive features associating with these two academic abilities in order to understand the factors that are more specific to mathematics.

To achieve the above objectives the available literature in the areas of ADHD, mathematics disability and reading disability is reviewed and is presented in Chapter II. The literature review helped the author to understand the cognitive deficiencies in ADHD, mathematics, and reading disability and the known effects in the interaction amongst these constructs.

To meet the study goals and answer the questions of the study a secondary data analysis is completed on a cross-section of children diagnosed with ADHD. The study
tests a spectrum of cognitive factors that are known to be impaired in ADHD, mathematics disability, or reading disability. The cognitive factors that are tested in this study include inhibitory control, processing speed, working memory, visuo-spatial processing and automaticity. As the first step the study isolates factors that associate with mathematics performance in children with ADHD. In a complimentary step, the full spectrum of factors will be tested for their effect on reading, and the results will be contrasted to discover factors distinguishing mathematics from reading performance in our sample of children with ADHD.

**Background on ADHD**

ADHD is a developmental neuro-biological condition characterized by pervasive symptoms of inattention, hyperactivity, and impulsivity (American Psychiatric Association DSM-IV, 1994; American Psychiatric Association, DSM-V, 2013). A child must exhibit a number of inattentive, hyperactive, and impulsive behaviors over a period of six months in order to be diagnosed with ADHD. These behaviors should be present both in school and at home and significantly impair the daily age-specific functioning of the child. For example, individuals with ADHD have difficulty taking turns. They tend to talk excessively, often appear not to be listening when spoken to, and tend to interrupt and intrude on others in games, conversations and classroom discussions (American Psychiatric Association DSM-IV, 1994). ADHD is primarily observed and diagnosed in school-age children; however the disorder exists in pre-school children (Lavigne et al. 1996; Daley et
al. 2009) and can extend through adolescence (Faigel et al. 1995; Wolraich et al. 2005) and into adulthood (Mannuzza, Klein, Bessler, Malloy, & LaPadula, 1993; Barkley, Fischer, Smallish, & Fletcher, 2002).

In addition to the core symptoms of inattention, hyperactivity, and impulsivity, individuals with ADHD often experience other co-morbid problems: 30–50% present with oppositional defiant disorder (ODD) and/or conduct disorder (CD); 20–30% present with anxiety (Biederman et al. 1991). As mentioned previously, at least 20 - 30% of children with ADHD have an associated learning disorder related to reading, spelling, writing and/or mathematics (Biederman et al. 1991; Pliszka 1998; Pliszka 2000).

Individuals with ADHD experience impairments in many aspects of life. The interaction of core ADHD symptoms with co-morbid problems predisposes children with ADHD to experience academic and educational problems (Biederman et al. 1996; Loe & Feldman 2007; Frazier, Youngstrom, Glutting, & Watkins, 2007). These children are more likely to use remedial academic services, be placed in special education classes, and to experience behavioral problems that might lead to suspension or expulsion from school (Biederman et al. 1996). Apart from their specific performance in academic settings, children with ADHD are likely to show significant academic underachievement overall, evidenced by poor grades, poor scores on standardized reading and mathematics tests, and an increased likelihood of repeating the school year (Loe and Feldman, 2007).

The relation between ADHD symptoms and school performance has been investigated in several studies. There appears to be a negative association between core ADHD
symptoms and reading, writing, and mathematics performance, regardless of clinical diagnosis of the disorder, in community samples (Merrell & Tymms, 2005; Rodriguez et al., 2007). A systematic review of studies of children with ADHD reported that ADHD symptoms predict academic problems, varying from grade repetition and need for special education, to lower scores on achievement tests (Polderman, Boomsma, Bartels, Verhulst, & Huizink, 2010). Moreover, the relation between ADHD symptoms and learning may persist into adolescence and beyond (Frazier et al., 2007). Mannuzza et al (2003) reported that men who were diagnosed with ADHD as children had completed on average 2.5 years less schooling than controls. Nearly one quarter of the ADHD group did not complete high school, compared with 2% of controls; only 12% had completed a bachelor’s degree or higher, compared with nearly half of controls; and only 1% had completed a postgraduate degree, compared with 8% of controls (Mannuzza et al. 2003). From a developmental perspective, the negative impact of ADHD symptoms on academic achievement can be seen across the lifespan.

It is not yet known whether these problems are the result of factors directly related to ADHD, such as behavioral symptoms or underlying cognitive processes, or whether they are caused by aspects not directly related to ADHD such as comorbidity with other disorders. Also, it is not well understood how intellectual abilities influence academic achievement in ADHD. Intelligence has been demonstrated to be a predictor of future achievement (Frazer et al. 2007). However, studies demonstrating a link between ADHD and academic underachievement have either controlled for IQ or matched experimental and control groups for IQ (Diamantopoulou, Rydell, Thorell, & Bohlin, 2007), suggesting
that academically, individuals with ADHD perform at a lower level than would be predicted by their IQ. While individuals with ADHD have been shown to score lower than controls on IQ tests, this may not be the primary cause of their impaired academic performance.

Children with ADHD suffer from various types of cognitive deficits, some of which, such as inhibitory control, might exercise deliberate control over characteristic behaviors and emotions (Barkley, 1997). It seems cognitive impairment generally affects academic functioning in children with ADHD (Biederman & Monuteaux, 2004). Even so, the relation between ADHD and mathematics disability is poorly understood.

**Background on Mathematics Disability**

Different terminologies are used in the literature for problems pertaining to learning achievement in mathematics. Dyscalculia, Mathematics Disability, Mathematics Learning Disorder and Mathematics Underachievement are widely used terms to address selective learning difficulties in numeracy and calculation. In spite of the absence of a uniform definition, diagnostic criteria for mathematics disability are informed by low performance on mathematics achievement tests.

Mathematics disability is a developmental problem with a roughly analogous prevalence to reading disorder (Gabrieli, 2009). Employment, job productivity and level of income are all influenced by basic competencies in mathematics beyond the contribution of reading ability and intelligence (Geary, 2010 (b)). Mathematics disability can affect learners with
normal intelligence and normal working memory (Landrel, Bevan, & Butterworth, 2004), although it often co-occurs with other developmental disorders, including reading disability (Gross-Tsur, Manor, & Shalev 1996) and ADHD (Monuteaux et al. 2005).

Researchers have tried to define cognitive patterns and deficits underlying mathematics disability. Studies of community samples show that children use a mix of strategies when solving mathematics problems. Although children with mathematics disability use similar strategies to those of their normal developing peers (Geary, 2000), the strategies used by children with mathematics disabilities are comparatively not as fully developed, and are certainly less effective. Brain imaging also confirms the involvement of similar areas of the brain between math-disabled children and their normal counterparts while working on a math problem (Davis et al. 2009).

Cognitive factors known to associate with mathematics performance range from fundamental functions in number and magnitude representational systems (Geary 2010 (a), Butterworth 2005), to domain-general deficits such as working memory and processing speed (Mabbott and Bisanz 2008, Geary 2010 (a), Swanson, 1993; Swanson & Sachse-Lee, 2001). These may also play a role in many abilities other than mathematics performance. These two groups of domain-general and domain-specific cognitive factors are discussed in detail in the literature review chapter.

In summary, the predisposition of children with ADHD to mathematics difficulty is evidenced in epidemiological studies, yet cognitive factors contributing to this vulnerability are not well known. Clinical studies have shown that psychostimulant medication can
improve mathematics performance in children with ADHD (Carlson, Pelham, Swanson, & Wagner 1991; Zentall, Tom-Wright, & Lee, 2013) but not in children with severe dyscalculia (Rubinsten, 2011). These findings suggest that mathematics disability in ADHD might be related to specific ADHD cognitive issues rather than deficits in the ability to represent and manipulate numbers and quantities. A similar pattern of response to psychostimulants has been shown in person/children with reading problems and ADHD (Zentall et al., 2013, Williamson 2014). However, no study has looked directly into the relation between core ADHD cognitive factors, as inhibitory control, and mathematics ability in affected individuals. Without understanding the underlying cognitive factors, it will be impossible to inform effective pathways to treat mathematics disability in children with ADHD.
CHAPTER II – REVIEW OF THE RESEARCH LITERATURE

The objective of the current study is to determine the cognitive factors associated with MLA in children with ADHD. Even though difficulties with mathematics are highly prevalent in children with ADHD, there is little research exploring this co-morbidity. A survey of the English language literature performed for the purpose of this study revealed a large number of studies with consistent or replicated evidence addressing ADHD independently, reading disabilities independently, and the combination of ADHD and reading disabilities. In comparison to reading, there is paucity of literature on the co-morbidity of ADHD with mathematics disability. Only one study that presents empirical evidence on the cognitive aspects of mathematics difficulty in children with ADHD was identified (Kaufmann & Nuerk, 2006). The scarcity of research in the area of focus of this dissertation is notable. However, the author has attempted to gather available information in either of the mentioned areas that could assist in defining the conceptual framework and hypothesis of this study.

Literature search

A systematic literature review using Ovid-MEDLINE and psycINFO databases was completed for this study. The primary literature scan involved all studies published in the period between 1948 and 2014, focusing on the general areas of ADHD, dyscalculia, dyslexia and cognitive deficits. The primary search identified 17000 publications. Further
screening for case control, clinical trials and review studies published in English language resulted in selecting 300 papers that were used for review of evidence for this dissertation.

**Review of the Literature**

ADHD is a neuro-developmental disorder, highly comorbid with learning disabilities. The prevalence of mathematics disability and reading disability in clinical ADHD populations is substantially higher than community populations. Majority of research in the area of learning disability and ADHD has been devoted to reading problems despite of the comparable prevalence of mathematics disability in these children. The prevalence of mathematics and reading disability in both general and clinical samples is summarised in Table.1 for comparison.

Table.1. Prevalence of Learning Disabilities in Community and ADHD Populations

<table>
<thead>
<tr>
<th></th>
<th>Community Population</th>
<th>ADHD Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning Disability</td>
<td>3-10%</td>
<td>40-50%</td>
</tr>
<tr>
<td>Reading Disability</td>
<td>5-9%</td>
<td>20-40%</td>
</tr>
<tr>
<td>Math Disability</td>
<td>5-8%</td>
<td>11-26%</td>
</tr>
</tbody>
</table>

Mathematics disability is an important area of impairment in ADHD; yet, the neurocognitive pathophysiology of this co-morbidity is not well understood.

It is evident that there are two categories of cognitive factors affecting mathematics ability; domain-specific and domain-general factors. As the term implies, domain-specific cognitive factors pertain to a single domain which is mathematics ability in this case. A cognitive factor is domain-specific if it has no application to other domains of cognitive functioning. By contrast, a domain-general cognitive factor can be deployed in unfamiliar contexts and can be applied to various domains. The current literature review proceeds by briefly describing domain-specific factors in mathematics learning such as magnitude representation and counting. The chapter then focuses on domain-general factors including inhibitory control, working memory, processing speed, visuo-spatial processing and naming speed.

Domain-Specific factors in mathematics ability

Domain-specific factors are cognitive functions that are directly related to the acquisition and maintenance of mathematics ability. Two fundamental systems appeared to be affected in persons with math disabilities; the exact representational system and the approximate magnitude representational system (Butterworth, 2005). The exact representational system refers to the representation and implicit understanding of the precise quantity of small collections of objects and symbols (e.g., Arabic numerals) that represent these quantities (e.g., “3”= ■ ■ ■ ). The approximate magnitude representational system refers to the way an individual recognizes the approximate magnitude of larger
quantities (Butterworth, 2005). These core competences play roles in different abilities necessary for resolving mathematical problems. ‘Subitize’ is the ability to understand the quantities of sets of 3 or 4 objects or actions without counting (Wynn, Bloom, & Chiang, 2002). The other ability is to use nonverbal processes or counting to quantify small sets of objects and to add and subtract small quantities to and from these sets (Levine, Jordan, & Huttenlocher, 1992; Starkey, 1992; Case & Okamoto, 1996). Another competency is to estimate the relative magnitude of sets of objects beyond the subitizing range and to estimate the results of simple numerical operations (Dehaene & Cohen, 1997), for example, implicitly knowing that adding one item to a set of items results in “more” (Wynn, 1992). These basic competencies provide the foundation for many aspects of children’s early learning of math (Geary, 2000). The ability to estimate the approximate answer to simple mathematical problems in young children may be an important foundation for learning to solve formal problems and eventually calculate the answers (Gilmore et al., 2007).

In addition, the exact representational system supports children’s initial understanding that Arabic numerals and number words represent quantities (e.g., ■■■=“3”=“three”), while the approximate system supports learning in other areas of basic math such as the number line concept (Gilmore, McCarthy, & Spelke, 2007; Geary, 2008). Children place numbers in line according to how well they understand the approximate magnitude representational system. Children who are developing normally quickly develop the number line concept in the early school years (Siegler & Booth, 2004), and are able to understand the difference between two consecutive numbers regardless of where they
lie on the number line. According to Butterwoth’s hypothesis, children with math disability may have deficits or developmental delays for both subitizing and the ability to represent approximate quantities (Geary 2010 (b); Butterworth 2005).

Counting is the other ability affected in math disability. Elementary school children with math disability or low achievement understand most of the basic counting principles, but they may become confused when faced with deviations from standard counting, such as being asked to count objects from right to left instead of the standard direction of left to right (Geary, Bow-Thomas, & Yao, 1992; Geary, Hoard, Byrd-Craven, & DeSoto, 2004).

Combinations of difficulties in such fundamental abilities such as subitizing, number line concept and counting are present in math disability. Children with math disability commit more errors in solving simple math problems (e.g., 4+3), simple word problems, and complex math problems (e.g., 745–198) compared to the same-grade typical achievers (Geary et al., 2007, 2012; Jordan, Rinne & Mazzocco, 2014). They also tend to use developmentally immature procedures when working with numbers (Geary, 1990; Jordan, Hanich, & Kaplan, 2003 (a); Raghubar et al., 2009), for example using fingers in summing procedures more frequently than their normal peers (Geary et al., 2004, 2007; Jordan et al., 2003 (a)).

The deficits become more prominent in solving complex math problems. For example, when solving a multistep problem such as 45 - 12 or 126+537 (which involves carrying or borrowing from one column to the next or keeping the partial answers), late primary school-aged children with math difficulty commit more errors than their IQ-matched
classmates. Children with math disability and low achievement have such patterns of
difficulty regardless of their reading achievement (Jordan & Hanich, 2000; Geary 2012).

Children with math disability also have difficulty with the storage of basic math facts to
long-term memory or retrieving them once they are saved (Barrouillet, Fayol, & Lathuliére,
1998; Jordan et al., 2003 (a); Barrouillet, Thevenot, & Fayol, 2010). Two mechanisms
have been proposed with this regard. The first is a deficit in the ability to form phonetic-
based representations in long-term memory. This may explain in part why the comorbidity
of math disability and reading disability is common. Disruption in the ability to represent
or retrieve information from these systems appears to be present in difficulties with
forming math problem/answer associations (Geary, 1993). The second proposed
mechanism is a deficit in the ability to inhibit irrelevant associations during the process of
retrieving facts from long-term memory (Barrouillet & Fayol, 1998; Geary, 2000;
Butterworth, 2005). Since working memory and inhibitory control are two cognitive areas
often affected in ADHD (Alderson, Kasper, Hudec, Patros, 2013; Alderson, Rapport, &
Kofler, 2007) this may explain to a certain extent the higher rate of math difficulty in
children with ADHD. The next chapter of literature review will discuss these possible
associations in more detail.

Combinations of difficulties in domain-specific abilities are present in indifferent types of
mathematics disability. However, the domain-specific cognitive abilities might be
influenced by domain-general factors like processing speed and working memory. Yet,
the interaction between these two domains of cognitive factors affecting mathematics
acquisition and learning are not fully understood.
Domain-General Cognitive Factors

A high level perspective suggests that mathematics difficulties in individuals with ADHD are rooted in the general domain of cognitive abilities, and include problems with retrieval of numerical information from semantic memory, allocation of attention, inhibition of retrieval of irrelevant associations, and attention to details (Lindsay, Tomazic, Levine, & Accardo, 1999; Jacobson, Dodge, Burden, Klorman, & Jacobson, 2011). Two arrays of cognitive factors will be reviewed under the category of domain-general. One factor is inhibitory control as the cognitive factor which is more specific, although not limited to ADHD. Another element is a group of general factors known to be affected in ADHD as well as mathematics and reading disability. The latter group includes working memory, processing speed, visuo-spatial processing, and naming speed.

Inhibitory Control

Inhibitory control is the ability to withhold or suddenly interrupt an ongoing action or thought (Barkley 1997). It has been viewed as an important building block for current models of psychopathology and neuropathology in ADHD (Barkley 1997; Schachar et al., 2000; Aron, Fletcher, Bullmore, Sahakian, & Robbins 2003). Inhibitory control is assessed by an individual’s performance on cognitive and behavioral tasks that require withholding response, delaying response, cessation of ongoing responses and resisting distraction or disruption from competing events (Barkley, 1997).

There are several cognitive tests for inhibitory control, with the Stop Signal Task (SST) being commonly used. The SST simulates a situation that requires the rapid and accurate
execution of a simple motor action and the occasional and unpredictable cessation of this action. Efficient inhibitory control depends on the latency of two independent processes: the response to the action signal (Go Reaction Time), and the response to the stop signal (Stop Signal Reaction Time - SSRT). SSRT is a common measure of inhibitory control (Please refer to Chapter IV- Methods for more details about SSRT).

Our knowledge about inhibitory control is mostly from studies on ADHD individuals. Inhibitory control is a well-evidenced and extensively discussed area of cognitive deficits in ADHD (Barkley 1997; Schachar & Logan 1990). There are consistent meta-analytic reports of deficient Go Reaction Time and SSRT in ADHD with medium effect sizes (Lijffijt, Kenemans, Verbaten, & van Engeland 2005; Alderson et al. 2007; Lipszyc & Schachar, 2010). Deficient inhibitory control has a cascade effect on other aspects of executive functioning such as working memory, self-regulation, planning and set shifting. The difficulty that patients with ADHD have in engaging different executive-control strategies needed in behavior construction and thoughtful action is a result of deficient inhibitory control (Schachar et al., 2000). Deficiency in inhibitory control is the potential core deficit in ADHD (Quay 1997; Schachar et al., 2000); this hypothesis is supported by family studies demonstrating that deficient inhibitory control can be considered as an endophenotype in ADHD (Crosbie, Perusse, Barr, & Schachar, 2008; Goos, Crosbie, Payne, & Schachar, 2009; Crosbie et al. 2013).

ADHD is the most prominent known disorder with deficits in this cognitive ability; however, recent investigations have shown that a deficit in inhibitory control is not unique to ADHD, and can be part of the cognitive profile of other disorders as well (Penades et al., 2007).
A meta-analysis of the literature on inhibitory control revealed small to medium effect sizes for SSRT in reading disability (Lipszyc & Schachar, 2010). Children with both ADHD and reading disability show more prominent inhibitory control deficiency than children with either of the disorders alone (Willcut 2005). Considering the low to moderate level of inhibitory control impairment in reading disability, it is possible that the co-morbidity of ADHD and reading disorder is associated with more severe types of ADHD (Lipszyc & Schachar, 2010).

The literature search for this study did not find any studies investigating inhibitory control in mathematics disability or the co-morbidity of ADHD with mathematics disability. Considering the core role of inhibitory control in cognitive deficits in ADHD, as well as high prevalence of co-morbidity of mathematics disability and ADHD, investigating the role of inhibitory control in this co-morbidity would be of high importance.

**Processing Speed**

Cognitive processing speed is the ability to perform relatively automatic cognitive tasks quickly or under the pressure of timed conditions. Although it is an important and widely examined cognitive ability, the definition is notably general and there is no gold standard definition. As a result, it is difficult to determine whether the processing speed tests used in different studies measure the same underlying cognitive process. For example, many studies refer to reaction time or naming speed tasks to measure processing speed, although these functions involve distinct processes, such as phonological abilities. Speeded tasks might measure the speed at which individuals perceive and process
incoming information, or they may measure output speed. It should be noted that some speeded tasks may require an integration of rapid perceptual, cognitive, and output processing (Kail & Salthouse 1994). There appears to be a dynamic interaction between working memory and processing speed, with working memory being probably mediated by processing speed (Carpenter 1990). Therefore regardless of the test being used it might be difficult to measure each of these cognitive abilities exclusively (Carpenter 1990).

Processing speed is a cognitive ability that is impaired in children with ADHD (Woods, Lovejoy, & Ball, 2002; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). In fact, several studies have found that processing speed measures are among the best predictors of inattentive symptoms in ADHD and more specifically, are found to be impaired in individuals with the ADHD inattentive subtype (Chhabildas, Pennington, & Willcutt, 2001; Rucklidge & Tannock, 2002; Weiler, Bernstein, Bellinger, & Waber, 2000).

In mathematics, processing speed may correspond to the speed with which numbers are counted or quantities are perceived. Faster processing frees cognitive resources; therefore, larger amounts of information can be simultaneously represented in working memory and become available for problem solving. Processing speed strongly predicts mathematics performance and the predictive power is larger than that of working memory (Bull & Johnston 1997). The relationship between working memory and processing speed is debated. It is poorly understood whether working memory capacity is influenced by the speed of cognitive processing and decision making (Ackerman, Beier, & Boyle, 2005), or whether the working memory capacity determines the speed of information processing
(Engle, Tuholski, Laughlin, & Conway, 1999). However, it is well evidenced that mathematics ability can be strongly predicted by processing speed, independent of working memory (Geary, 2010(a)) and regardless of the direction of the association between processing speed and working memory. It is also evidenced that the association between processing speed and arithmetic is independent of language ability (Hecht, Torgesen, Wagner, & Rashotte, 2001).

Theoretically, processing speed may affect reading on two levels. First, a high speed of processing results in a faster automatic response to learned information. In reading, this information includes alphabetic combinations, sound blends and written words. The second effect is through the interaction of processing speed with working memory (Geary, 2007). Similar to that which has been observed in processing speed and mathematics, faster processing speed frees cognitive resources to provide working memory with the higher capacity required for phonological processes. However, reading studies have mostly used naming speed tasks rather than processing speed tests, evidence from which will be presented later in this chapter.

Both ADHD and reading disability are associated with slow speed of information processing. The deficit in processing speed seems to be greater in comorbidity of reading disability with ADHD than in ADHD without reading disability (De Jong, Licht, Sergeant, & Oosterlaan, 2012; Shanahan et al., 2006). The increase in severity of processing speed deficit with the co-morbidity of ADHD and reading disability is controversial. Shanahan in a comparative study demonstrated similar performance on processing speed tasks between reading disabled children and those having reading disability co-morbid with
ADHD (Shanahan et al., 2006). On the other hand there is evidence that the co-morbidity of reading disorder and ADHD is associated with a more severe deficit in processing speed. This is similar to the additive effect on working memory deficit within the comorbidity of reading disability and ADHD (Katz, Brown, Roth, & Beers, 2011).

The literature search for this study failed to find any evidence about processing speed in the co-morbidity of mathematics disability with ADHD.

*Working Memory*

Working memory is the ability to retain representation of objects in mind while simultaneously engaging in other mental processes. It involves retention of task-relevant information for the duration of a task (Pennington & Ozonoff, 1996). According to more recent definitions, working memory consists of verbal working memory and visuo-spatial working memory (Cowan, 1999). Verbal working memory retains language-based information and plays an important role in phonological awareness and processes fundamental to language abilities. Visuo-spatial working memory is responsible for retaining visual and spatial information and patterns in consciousness (Baddeley, 1986; Cowan, 1999; Baddeley, 2012).

Working memory impairment is considered an important cognitive factor associated with ADHD (Barkley 1997; Castellanos & Tannock, 2002). A review by Willcutt of published studies concerning the effect of ADHD on working memory showed a significant yet medium effect (d=0.54) for verbal working memory and d= 0.72 for visuo-spatial working memory) (Willcut et al., 2005). Similarly, Martinussen, in another review of studies,
reported a medium effect size of $d=0.43$ for verbal working memory in children with ADHD and large effect size of $d=1.26$ for visuo-spatial working memory (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005). These data suggest that verbal working memory is affected in ADHD, albeit, the effect is moderate, and the verbal working memory deficit is neither large nor specific to ADHD (McInnes, Humphries, Hogg-Johnson, & Tannock, 2003). The effect of visuo-spatial working memory in ADHD is considerable (Alderson et al. 2013), however since this study uses a measure of verbal working memory as the proxy for working memory, this dissertation stays away from entering more details about visuo-spatial working memory.

The relationship between working memory capacity and performance on mathematics achievement tests has been demonstrated in several studies (McLean & Hitch, 1999; Swanson & Sachse-Lee, 2001; Troovich & LeFevre 2003; LeFevre, Shanahan, & DeStefano, 2004; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; LeFevre et al., 2013). Impairment in working memory can cause problems in the development of mathematics skills, from early childhood into school age. It may negatively impact the development of mathematics ability (Jordan, Hanich & Kaplan 2003). *Enumeration*, the sequencing of elements in a collection of objects, represents the most elementary type of numerical knowledge and is acquired at an early age. So is *counting*, a sophisticated form of enumeration in which a unique number name is paired with each object in a collection. *Number facts* is an advanced skill, acquired during the school age period, of performing arithmetical operations such as adding and subtracting. It relies on the primary skills of enumeration and counting (Geary, 1993). Different components of working memory may
play different roles in aforementioned abilities. Verbal working memory appears to be important in processes that involve the articulation of numbers, such as counting (Krajewski & Schneider, 2009) and solving mathematical word problems (Swanson & Sachse-Lee, 2001). It is a key component in the maintaining of operands or intermediate results and in doing number fact retrievals (Hecht et al., 2001; Rasmussen & Bisanz 2005). On the other hand, visuo-spatial working memory is assumed to provide the required mental space in visual representation of a problem and its solutions (Hitch 1978; Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999).

Impairment in working memory also negatively impacts the acquisition of reading skills and affects the persistence of reading disability (Swanson, 2000, Swanson, Ashbaker, & Lee, 1996). Reading acquisition relies on explicit awareness of distinct language sounds, that is, phonemic awareness, and the ability to decode unfamiliar written words into these basic sounds (Geary 2007). Decoding requires an explicit representation of the sound (e.g., ba, da, ka) in phonemic working memory and the association of this sound, as well as blends of sounds, with corresponding visual patterns, specifically letters (e.g., b, d, k) and letter combinations (Torgesen, Wagner & Rashotte, 1994). Initially, problems in phonological processes result in decoding problems. Subsequently, deficient phonological processes contribute to ongoing problems in spelling (Lefly & Pennington, 1991) and fluency (Berninger, 1999). In both phases the difficulty in phonological processes happens within a deficient working memory structure. The impairment of working memory appears to be of greater severity with the co-morbidity ADHD and reading disability than in pure reading disability or pure ADHD (Bental 2007, Katz 2011).
While children with mathematics difficulty have deficits in working memory, those with both mathematics and reading problems perform worse in working memory tasks (Bull & Johnston, 1997; Geary, 2004). Some studies have suggested that problems with visuo-spatial working memory are likely to characterize children with specific mathematics disability, whereas children with both mathematics and reading disability have more pervasive language and verbal working memories difficulties (Siegel & Ryan, 1989). However, the relationship between mathematics ability and working memory seems to be complex since specific aspects of working memory may relate particularly to mathematics and more specifically, arithmetic skills. For example, in typically developing children numerical computation is related to verbal working memory while visuo-spatial working memory has a greater impact on numerical estimation (Khemani & Barnes, 2005).

*Visuo-spatial Processing*

Visuo-spatial processing is the ability to analyze and synthesize abstract visual stimuli and nonverbal concept formation. Tests that measure visuo-spatial processing generally entail three distinguishable factors: spatial visualization, spatial relations and perceptual speed (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001).

Visuo-spatial processing is one of the cognitive factors affected in ADHD (Biederman et al., 2009). In a study comparing a group of children with ADHD and typical developing controls, ADHD affected children had significantly poorer performance in different tests of visuo-spatial processing including picture arrangement, Block Design and object assembly (Zambrano-Sanchez, Martinez-Cortes, Rio-Carlos, Martinez-Wbaldo Mdel, &
Poblano, 2010). This deficit in visuo-spatial processing is persistent in affected individuals, regardless of clinical remittance from the ADHD by adolescence (Biederman et al., 2009).

There appears to be a close relationship between spatial and numerical processing, which might influence mathematics ability (Delazer, Benke, Trieb, Schocke, & Ischebeck, 2006). Reading ability seems to be less affected by visuo-spatial processing. Brunswick investigated visuo-spatial processing in adults with dyslexia and found no difference between individuals with dyslexia and typically developing controls (Brunswick, Neil Martin, & Rippon, 2012). The information about the effect of the co-morbidity of ADHD and learning disorders on visuo-spatial processing seems to be absent in the literature.

**Automaticity**

Automaticity, or naming speed, is often considered as a feature of phonological processing and as an indicator of the speed with which phonological codes are retrieved from long-term memory (Wagner et al., 1997; Verhagen, Aarnoutse, & van Leeuwe, 2008). It is measured by the speed at which symbols such as letters, numbers, objects or colours can be named.

Deficits in naming speed are interpreted as difficulties in the rapid recognition and retrieval of visually presented stimuli (Wolf & Bowers, 2000). Rapid Automatized Naming (RAN) is a common test used to measure naming speed and is considered a reliable tool for detecting the risk of learning problems in general and the risk of reading disability specifically (Waber, Wolff, Forbes, & Weiler, 2000).
Several studies have addressed the role of automaticity in reading. Deficits in automaticity are caused by the disruption of a precise timing mechanism that normally influences temporal integration of the phonological and visual counterparts of printed letters, digits, colors or objects. These deficits may impair a child’s ability to detect and represent orthographic patterns, store distinct and unitized representations of specific word spellings, and read the words (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Children with reading disabilities are often impaired in the rapid naming of letters, digits and to a lesser extent, objects (Wolf, Bowers, & Biddle, 2000). Automaticity is the core process which at an early age can predict later reading skills (Kirby, Parrila, & Pfeiffer, 2003).

In contrast to reading, there are few, and inconsistent, reports on the impact of rapid naming on mathematical ability. Geary and colleagues contrasted automaticity in three groups of children: typical developers, children with mathematics learning disability and those with mathematics low-achievement. They used the mean response time of letter and number RAN subtests as a variable for automaticity. The differences between all three groups were significant, with typical achievers showing the highest speed and the mathematics disabled group the lowest (Geary, 2007). Although some have indicated that RAN number can predict later mathematics performance (Temple & Sherwood 2002), a study by Mozzacco and Thompson (2005) did not show a differentiating effect of RAN response time for number reading on mathematics disability. A similar conclusion was reached by Landrel in testing 1,064 students who had been divided into one of four groups: dyscalculic, dyslexic, both, and a typically developing control. They studied the effect of disability on number reading speed as a subtest of RAN. The results showed
that lower performance on RAN had a significant effect on reading ability only. There was no significant effect for mathematics ability or the interaction of dyscalculia or dyslexia – the number automaticity of the children with mathematics disability was within the range of the typically developing control group (Landrel, Fussenegger, Moll, & Willburger, 2009). It should be noted that while there is inconsistent information with the RAN number subtest, there is also lack of evidence about the relationship of mathematics disability and other components of RAN.

The role of automaticity in the co-morbidity of ADHD with learning disabilities is not well studied. Automaticity might be an impaired area of cognitive functioning in ADHD. Martinussen and colleagues investigated the contribution of automaticity and phonemic awareness to teacher inattention ratings and word-level reading proficiency in 79 first grade children and reported that automaticity, but not phonemic awareness, was significantly associated with teacher inattention ratings controlling for word reading proficiency (Martinussen, Grimbos, & Ferrari, 2014). Bexkens has hypothesized that in addition to the involvement of phonological processes and processing speed, RAN is a function of inhibition processes (Bexkens, van den Wildenberg, & Tijms, 2014); however the role of that in the cognitive deficit behind ADHD is yet to be understood. Also, the literature search for this study did not find any study with a primary focus on automaticity in the co-morbidity of ADHD with mathematics difficulty. Knowledge in this area is attained by examining studies which have investigated the co-morbidity of ADHD and reading disability. Despite some recent reports of the association between automaticity and some ADHD behavioral or cognitive characteristics
(Martinussen et al., 2014; Bexkens et al., 2014) studies with a focus on clinically diagnosed ADHD failed to detect problems with automaticity in individuals who have ADHD. There are reports of slower RAN scores in reading disability and in its co-morbidity with ADHD, but not in the ADHD-only phenotype (Felton, Wood, Brown, Campbell, & Harter, 1987; Rabeger & Wimmer, 2003).

Summary and Implications for Current Research

This chapter reviewed the research literature pertaining to cognitive factors with solid evidence supporting their role in ADHD, mathematics disability, reading disability and in the combination of these learning disabilities with ADHD. Since the main focus of the current study is mathematics performance in ADHD, the author looked at all domain-general cognitive factors reported to be deficient in mathematics disability. The domain-general cognitive factors reported to influence mathematics ability are working memory, processing speed and visuo-spatial processing (Geary 2007; Geary 2010; Delazer et al., 2006). In addition, the role of these factors in ADHD and reading disability were reviewed. The literature on inhibitory control (Barkley 1997, Schachar 2000, Fletcher 2003) and naming speed (Kirby, Parrila, & Pfeiffer 2003, Landrel et al., 2009) was searched and reviewed as well, given their important respective roles in ADHD and reading disorders, respectively. The summary of the evidence from literature is presented in Table.2.

The literature review showed that little is known about the effect of inhibitory control on the co-morbidity of mathematics disability and ADHD. It has been indicated that many
behavioral and cognitive challenges of children with ADHD are rooted in deficient inhibitory control (Schachar et al., 2002), yet we do not know whether this cognitive factor makes the ADHD individual prone to learning disabilities. Some research studies have reported higher deficiency in inhibitory control in reading disability (Lipszyc & Schachar, 2010), yet the association of this with reading and mathematics concerns within the context of ADHD is not well understood.

Working memory, processing speed and visuo-spatial processing were reported to be affected in ADHD and reading disability similar to mathematics disability. The extent of deficiency of these cognitive factors varies in these disorders. Spatial working memory is affected in ADHD with a quite large effect size, while verbal working memory seems to be the component of working memory being mostly affected in reading disability. Although the role of working memory in mathematics learning has been described to some extent, much less study has been done in this area compared to reading. Processing speed seems to be the best predictor of mathematics ability, independent of working memory. Visuo-spatial processing is strongly affected in ADHD; the few investigations on its influence in reading and mathematics show some role in mathematics with little known effect in reading.

ADHD and reading disability possibly have additive effects in the severity of working memory and inhibitory control deficits; nothing is known about similar additive effect of mathematics disability and ADHD co-morbidity. In addition, despite the well documented processing speed deficits in mathematics disabilities without co-morbidities on one hand,
and in non-comorbid ADHD on the other hand, information about processing speed deficits in the ADHD plus mathematics comorbidity is in need of exploration.

This thesis builds on the work of several areas of research inquiry pertaining to mathematics disability, reading disability, ADHD, and their co-morbidities (e.g. Schachar et al., 2000; Willcut et al., 2005; Geary, 2007; Landrel et al., 2009). It explores how deficits in working memory, processing speed, visuo-spatial processing, inhibitory control and naming speed may contribute to the mathematics learning problems in a proportion of individuals with ADHD. In addition, this dissertation builds on existing research by examining factors distinguishing reading from mathematics ability in children with ADHD. In doing so, this work explores a largely unexamined area of research, extending the limited literature on the cognitive characteristics of individuals with ADHD and comorbid mathematics low achievement.
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Table 2: Summary of the evidence from literature.
CHAPTER III- OBJECTIVES, HYPOTHESIS AND DEFINITIONS

Objectives

Expanding upon previous research related to learning problems in children with ADHD, this thesis examines the cognitive characteristics that might influence the vulnerability of these children to learning difficulties. In particular this thesis investigates cognitive factors influencing mathematics performance in children with ADHD. This study also aims to investigate factors distinguishing mathematics from reading performance in ADHD. In doing so this study tests the relation between mathematics performance and different domain-general cognitive factors including inhibitory control, working memory, processing speed, visuo-spatial processing and automaticity. In a complementary step the same cognitive factors will be tested for their relation with reading ability. By contrasting the factors influencing reading ability to those affecting mathematics the study aims to understand the cognitive elements that are distinguishing for mathematics and might be of use in remediating difficulty in learning mathematics.

To achieve the objectives of this thesis the following questions are answered.

Study questions:

1- Is mathematics performance in children with ADHD associated with a more specific cognitive endo-phenotype of the disorder?
2- Is mathematics performance in children with ADHD associated with cognitive factors known to influence mathematics ability in the general population?

3- Are there any cognitive factors that distinguish mathematics from reading performance in children with ADHD?

Hypotheses

Having reviewed the findings from other studies the following hypotheses were developed:

1. Mathematics ability in children with ADHD is influenced by a known cognitive endophenotype of ADHD, therefore mathematics performance will be correlated with inhibitory control.

2. Mathematics ability in children with ADHD is influenced by domain-general cognitive factors known to be impaired in mathematics disability, therefore mathematics performance will be correlated with working memory (Digit Span-Backward), processing speed and visuo-spatial processing.

3. Mathematics ability is differentiated from reading ability by cognitive factor/s uniquely associated with it. Among the tested factors processing speed will be the unique cognitive factor associated with mathematics performance but not with reading ability.

Definitions

Current Definitions of ADHD
The Diagnostic and Statistical Manual of Mental Disorders - Fourth Edition (DSM-IV) (American Psychiatric Association, 1994) was used for diagnostic purposes of this study. Hence, the DSM-IV definition of ADHD is provided here in detail. DSM-IV listed diagnostic criteria for Attention-Deficit/Hyperactivity Disorder are presented in Table.3.

The diagnosis of ADHD is not free of controversy; a common objection is whether children who may be very active, high-spirited, and perhaps at times disruptive deserve a mental health disorder label. Opinions about where to draw the line to discriminate normal variation from deviation of developmental trajectory or disorder can be difficult. Valid diagnostic criteria ought to take into consideration important characteristics such as functional impairment, heritability, exposure to neurobiological or psychosocial risk factors, risk for adverse outcomes and treatment response (Robins, & Guze, 1970) and, in the case of ADHD and other neurodevelopmental conditions cognitive markers such as executive function deficits. Formal diagnostic criteria for ADHD have been evaluated for each of these domains and consistently discriminate children with inattention, hyperactivity and impulsiveness characteristics from those without (Fitzgerald, Belgrove, & Gill 2007). The DSM-IV criteria for ADHD rely on identification of the core symptoms of inattention, hyperactivity and impulsiveness to a degree that is impairing and developmentally excessive for sex and age. In addition the symptoms should be accompanied by significant distress or functional impairment in social, academic, or occupational activities, onset prior to age seven years, identification of symptoms in multiple settings (at home, school or clinic) and long duration, persisting for at least six months.
Table 3. DSM-IV Diagnostic Criteria for ADHD

The Diagnostic and Statistical Manual of Mental Disorders - Fourth Edition diagnostic criteria for Attention Deficit Hyperactivity Disorder:

A. Having six (or more) of the following symptoms either at inattention or Hyperactivity-Impulsivity domains. The symptoms must have persisted for at least 6 months, to a degree that is maladaptive and inconsistent with developmental level:

Inattention
(a) often fails to give close attention to details or makes careless mistakes in schoolwork, work, or other activities
(b) often has difficulty sustaining attention in tasks or play activities
(c) often does not seem to listen when spoken to directly
(d) often does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace (not due to oppositional behavior or failure to understand instructions)
(e) often has difficulty organizing tasks and activities
(f) often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (such as schoolwork or homework)
(g) often loses things necessary for tasks or activities (e.g., toys, school assignments, pencils, books, or tools)
(h) is often easily distracted by extraneous stimuli
(i) is often forgetful in daily activities

Hyperactivity
(a) often fidgets with hands or feet or squirms in seat
(b) often leaves seat in classroom or in other situations in which remaining seated is expected
(c) often runs about or climbs excessively in situations in which it is inappropriate (in adolescents or adults, may be limited to subjective feelings of restlessness)
(d) often has difficulty paying or engaging in leisure activities quietly
(e) is often “on the go” or often acts as if “driven by a motor”
(f) often talks excessively

Impulsivity

(g) often blurts out answers before questions have been completed
(h) often has difficulty awaiting turn
(i) often interrupts or intrudes on others (e.g., butts into conversations or games)

B. Some hyperactive-impulsive or inattentive symptoms that caused impairment were present before age 7 years.

C. Some impairment from the symptoms is present in two or more settings (e.g., at school and at home).

D. There must be clear evidence of clinically significant impairment in social, academic, or occupational functioning.

E. The symptoms do not occur exclusively during the course of a Pervasive Developmental Disorder, Schizophrenia, or other Psychotic Disorder, and are not better accounted for by another mental disorder (e.g., Mood Disorder, Anxiety Disorder, Dissociative Disorder, or a Personality Disorder).
The DSM-IV also provides an opportunity for further classification into three ADHD diagnostic subcategories: primarily inattentive, primarily hyperactive-impulsive, or combined type.

**ADHD-Inattentive subtype**

This subtype should be used if six or more symptoms of inattention (but fewer than six symptoms of hyperactivity-impulsivity) have persisted for at least six months, to a degree that is maladaptive and inconsistent with developmental level. Hyperactivity may still be a significant clinical feature in many such cases, whereas other cases are more purely inattentive.

**ADHD- Hyperactive-Impulsive subtype**

This subtype should be used if six or more symptoms of hyperactivity-impulsivity (but fewer than six symptoms of inattention) have persisted for at least 6 months, to a degree that is maladaptive and inconsistent with developmental level. Inattention may often still be a significant clinical feature in such cases.

**ADHD- Combined subtype**

This subtype should be used if six or more symptoms of inattention and six or more symptoms of hyperactivity-impulsivity have persisted for at least 6 months, to a degree that is maladaptive and inconsistent with developmental level.
**ADHD - Not Otherwise Specified**

This category is for individuals with prominent symptoms of inattention or hyperactivity-impulsivity that do not meet the DSM-IV diagnostic criteria for Attention-Deficit/Hyperactivity Disorder. Examples include:

1. Individuals whose symptoms and impairment meet the criteria for Attention-Deficit/Hyperactivity Disorder, Predominantly Inattentive Type, but whose age of onset is 7 years or after.
2. Individuals with clinically significant impairment who present with inattention and whose symptom pattern does not meet the full criteria for the disorder but have a behavioral pattern marked by sluggishness, daydreaming, and hypo-activity.

**DSM-5 changes and modification to ADHD definition**

The American Psychiatric Association published the DSM-V in 2013, the first major revision to the diagnostic manual for psychiatric disorders since 1994. In DSM-5, ADHD is now included in the section on Neurodevelopmental Disorders. This change better reflects the way ADHD is currently conceptualized etiologically and phenomenologically as separate from disruptive behavior disorders i.e., Oppositional Defiant Disorder and Conduct Disorder).

The core symptom profile of ADHD in DSM-IV reflected how the disorder presents in school age children; however, the criteria did not capture how it presents in older adolescents and adults. The new diagnostic criteria essentially retains the same symptoms, modified according to the presentations in children as well as in adolescents.
and adults, and is followed by examples of different ways the symptoms may show up, including the manner in which they appear in older adolescents and adults.

Similar to DSM-IV, the new edition indicates that to possibly warrant a diagnosis of ADHD, individuals younger than 17 must display at least 6 out of 9 inattentive and/or hyperactive impulsive symptoms. For individuals 17 and above, only 5 or more symptoms are needed.

In DSM-IV, the age of onset criteria was before 7 years. In DSM-5, this has been revised to 12 years.

In DSM-IV, symptoms were required to cause some impairment in at least 2 settings; thus, not only did symptoms need to be evident in more than one setting, e.g., both school and home, but they also had to undermine the child's functioning in multiple settings.

DSM-5 has changed this to "several inattentive or hyperactive-impulsive symptoms are present in two or more settings"; thus, symptoms must be evident in more than one context, but they don't have to impair an individual's functioning in multiple contexts.

However, it should be noted that DSM-5 came to light after recruitment for the study had taken place. Therefore, this dissertation doesn't go deeper into the diagnostic criteria of ADHD in DSM-5 although the author is aware that they affect current clinical practice.
The concept of a learning disability and its definition

According to the Learning Disabilities Association of Canada, learning disabilities (LD) refer to a number of disorders that may affect the acquisition, organization, retention, understanding, or use of verbal or nonverbal information. These disorders affect learning in individuals who otherwise demonstrate at least average abilities essential for thinking and/or reasoning. As such, learning disabilities are distinct from global intellectual deficiency (Learning Disabilities Association of Canada, 2002). LDs range in severity. They may interfere with the acquisition and use of one or more of the following:

- Oral language (e.g. listening, speaking, understanding);
- Reading (e.g. decoding, phonetic knowledge, word recognition, comprehension);
- Written language (e.g. spelling and written expression); and
- Mathematics (e.g. computation, problem solving).

LDs may also involve difficulties with organizational skills, social perception, social interaction and perspective taking.

LDs are believed to result from impairments in one or more processes related to perceiving, thinking, remembering or learning. These disorders are not due primarily to hearing and/or vision problems, socio-economic factors, cultural or linguistic differences, lack of motivation or ineffective teaching. These factors, however, may further complicate the challenges faced by individuals with LD. They may co-exist with various conditions including attentional, behavioral and emotional disorders, sensory
impairments or other medical conditions (Learning Disabilities Association of Canada, 2002). Difficulties with relationships, overall poorer mental health and higher rates of unemployment are some characteristics associated with LD. However, the presentation of symptoms is different in all individuals, and the unique characteristics that present in each person have to be identified and addressed. The lack of consistency in the presentation of symptoms continues to make LD a difficult diagnosis to make and impedes the formation of a clear and concise definition of the disorder.

In the evaluation of an individual for an LD diagnosis, there is an examination and synthesis of information pertaining to development, medical history, family circumstances, and educational reports, in addition to the administration of standardized psycho-educational assessment tools.

Questions and disagreements surround the issue of exclusionary criteria, relationship to intelligence, hypothesized basic psychological deficits, gender distribution, etiology, determination of a "significant discrepancy," and the nature of frequent association with comorbid problems, including comorbidity with ADHD (Fletcher, 2012).

DSM-IV defined LD as a type of Mental Disorder:

“When individuals demonstrate abilities below the level that would be expected given their age and grade level in school based upon an arbitrary gap, they may be diagnosed with this mental disorder which should be further specified according to the particular academic function affected: Mathematics Disorder; Reading Disorder; Disorder of Written Expression.”
Mathematics, reading and written disorders are defined under separate codes in DSM-IV.

DSM-IV gives the following diagnostic criteria for “Mathematics Disorder”:

A. Mathematical ability, as measured by individually administered standardized tests, is substantially below that expected given the person's chronological age, measured intelligence, and age-appropriate education.

B. The disturbance in Criterion A significantly interferes with academic achievement or activities of daily living that require mathematical ability.

C. If a sensory deficit is present, the difficulties in mathematical ability are in excess of those usually associated with it.

Similarly reading disability was defined as following by the DSM-IV:

A. Reading achievement, as measured by individually administered standardized tests of reading accuracy or comprehension, is substantially below that expected given the person's chronological age, measured intelligence, and age-appropriate education.

B. The disturbance in Criterion A significantly interferes with academic achievement or activities of daily living that require reading skills.
C. If a sensory deficit is present, the reading difficulties are in excess of those usually associated with it.

The diagnostic criteria for written and oral language disabilities were similar in structure to the above criteria for mathematics and reading disability.

DSM-5 published in 2013 has a new approach in defining LD; the term “Specific Learning Disorder” (SLD) is used as an umbrella term for mathematics, reading, and written expression disorders. DSM-5 considers SLD to be a type of neurodevelopmental disorder that impedes the ability to learn or use specific academic skills (e.g., reading, writing, or arithmetic), which are the foundation for other academic learning.

It should be noted that SLD is a clinical diagnosis that is not necessarily synonymous with ‘learning disabilities’ (LDs) as identified within the education system: that is, not all children with learning disabilities/difficulties identified by the school system would meet a DSM-5 clinical diagnosis of SLD. By contrast, those with a DSM-5 diagnosis of SLD would be expected to meet the educational definition.

DSM-5 definition of SLD:

“A neurodevelopmental disorder of biological origin manifested in learning difficulties and problems in acquiring academic skills markedly below age level and manifested in the early school years, lasting for at least six months; not attributed to intellectual disabilities, developmental disorders, or neurological or motor disorders”

Specify if:

1- With impairment in reading
2- With impairment in written expression
3- With impairment in mathematics

The DSM-5 diagnostic criteria for SLD reflect two major changes:

1) An overarching category of SLD with ‘specifiers’ to characterize the specific manifestations of learning difficulties at the time of assessment in three major academic domains, namely reading, writing, mathematics (e.g., SLD with impairment in reading)

2) Elimination of the IQ-achievement discrepancy requirement and its replacement with: duration of symptoms (at least six months despite the provision of extra help or targeted instruction); age at onset of problems and independence from intellectual disabilities, uncorrected auditory or visual acuity problems, other mental or neurological disorders or adverse conditions

Despite the evolving approaches to define LD, the most significant challenge in approaching LDs that has affected the current study is the absence of definition in a universal context, especially with discrepancies between clinical and educational approaches. Also it was noted that different achievement measures and standard deviations and cut points have been used for diagnostic purposes in different studies.

The current study uses two subtests of the Woodcock-Johnston test of Achievement (Woodcock, McGrew, Mathematicser, 2001), Calculation and Word Attack to measure mathematics and reading performance. These are both timed tests in which the
participants have a limited time related to each task. Given the inconsistencies in
definition and clinical diagnosis of LD, this study stays away from the clinical diagnosis
of the reading and mathematics disorder in its participants in order to answer the study
questions. Most of the data analysis looks at the association of cognitive factors within
the scales of Calculation and Word Attack, regardless of the presence of mathematics
or reading LDs. However, where grouping for mathematics or reading achievement is
intended in this study, performance below the 25 percentile on either of the mentioned
subscales is considered as the cut point for learning low-achievement. This
performance threshold has been used in research studies (Geary 2007; Mabbott &
Bisanz, 2008) and is also used for the classification of LDs by some school boards
(Mabbott & Bisanz, 2008). As mentioned above only one subtest under each
mathematics or reading performance is used, therefore, for the purpose of accurate
use of words and definitions, and to be clear in the non-diagnostic nature of this
classification, the term ‘low-achievement” is used instead of ‘disability’ or ‘disorder’ in
this dissertation.
CHAPTER IV- RESEARCH DESIGN AND METHODOLOGY

This chapter presents the research design, sampling procedure, inclusion/exclusion criteria, measures used and analysis methods used. Some advantages and limitations with the methods used in this study are discussed.

Research Design

Sample setting

The current study involves a secondary analysis of an existing large data set, created by professional staff of an outpatient clinic for assessment of learning or behavioral disorders at the Hospital for Sick Children (SickKids). The data set includes all clinical diagnostic, cognitive and behavioral information that could help address the questions of the study. The sample was drawn from 1522 consecutive referrals to the clinic in a cohort study of ADHD and related conditions in the period to 2000 to 2009. The study, “ADHD and development: The role of genetic and cognitive predictors of outcome”, was funded by Canadian Institutes of Health Research [MOP-74699] and received scientific and ethical approval from the SickKids Research Ethics Board.

SickKids is a tertiary care pediatric hospital serving a large metropolitan area. The sample was representative of the Toronto community from which it was drawn; however, as a consequence of an a priori ethical decision, information on ethnicity, religion, and socio-economic status was not collected.
Parents of all subjects gave written consent for their child to participate in the study, and all subjects gave verbal assent. The data set included anonymous information of children and their parents who participated in an initial assessment of ADHD.

**Sampling Procedure and Inclusion/Exclusion Criteria**

In order to ensure that the measurements of cognitive function were made on a medication free condition, all participants were either medication naive or had suspended psychostimulant medication for at least 48 hours prior to evaluation. Hence, individuals taking non-stimulant medication for ADHD were excluded from participation. Children with any chronic medical or neurologic or psychiatric co-morbidities other than LD were excluded from the original study. The presence of co-morbidities had been investigated as part of the comprehensive clinical assessment of the child and was reported in the database.

The following inclusion criteria were applied for the purpose of this study to all cases in the original cohort who had met the above mentioned characteristics:

(a) Age of 6 to 12 years

(b) Receiving the primary diagnosis of ADHD, based on DSM-IV criteria

(c) Full-scale IQ of equal or above 80

(d) Complete data for Stop- Signal Task

The process of sample selection is summarized in Figure.1.
Sample Size

To ensure an adequate sample for the study, the minimum sample size was calculated using formulas designed specifically for regression analysis (Tabachnick & Fiddell, 2001): 

\[ N > \left( \frac{8}{f^2} \right) + (m-1) \]

where \( m \) represents the number of predictor variables and \( f^2 \) represents small (.01), medium (.15) or large (.35) effect sizes (Garson, 2010; Tabachnick & Fiddell, 2001). Considering that the largest regression equation compromising all cognitive behavioral predictors would include 11 variables, the minimum sample required for this study is 59-122 in order to detect a medium to large effect size. Based on the information available about the effect of our executive functions on ADHD or arithmetic disability, the medium effect size can be assumed for the dependent variables of this study (Lipzyc & Schachar, 2010; Butterworth, 2005; Martinussen et al., 2005). The study sampling based on inclusion and exclusion criteria described above resulted in inclusion of 374 eligible cases.

Study Measures

ADHD clinical diagnoses were based on DSM-IV TR criteria, informed by validated semi-structured interviews conducted with the children’s parents (Parent Interview for Child Symptoms- PICS) (Ickowicz, Schachar, Sugarman, Chen, Millete, & Cook, 2006) and their classroom teacher (Teacher Telephone Interview- TTI; Tannock Hum, Masellis, Humphries, & Schachar, 2002). TTIs were performed before interviews with parents and the TTI reports were reviewed on the day of interviewing parents.
Subtests from the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV) (Wechsler, 2003) were used as measures of cognitive factors of interest. Children’s ability in mathematics and reading were assessed with subtests of the Woodcock-Johnson test of achievement- WJ III (Woodcock, McGrew, & Mathematicser, 2001).

**ADHD measures**

*Parent Interview for Child Symptoms (PICS)*

The Parent Interview for Child Symptoms is a semi-structured diagnostic instrument developed specifically for the purpose of diagnosis of disruptive behavior disorders (ADHD, ODD and CD) and screening for diagnoses of other emotional and psychiatric disorders. The PICS differs in several important ways from other diagnostic interviews. It asks the informant to provide a description of child behavior in a variety of different situations. The judgment about the presence and severity of each symptom is made by the interviewer according to a variety of standard clinical criteria. For this reason, a clinician trained in child psychiatry should administer the PICS. Rather than coding the exact response of the informant, as is done typically in structured diagnostic interviews, the PICS aims to probe the informant’s response in sufficient detail to be able to separate child behavior from informant bias, impression or perceptions (Ickowicz et al., 2006).

*Teacher Telephone Interview (TTI)*

The Teacher Telephone Interview for Attention-Deficit/Hyperactivity Disorder and Related Disorders: DSM-IV Version (TTI-IV) is a diagnostic interview for use with teachers. It entails a semi-structured approach. It was developed to systematically assess children’s
disruptive behavior problems and functioning as observed in the school environment. It is used to improve precision in clinical diagnosis in child psychiatry for ADHD and related disorders in children and adolescents. Typically, it takes 30 minutes to administer and score the telephone interview.

The TTI-IV was designed for use in conjunction with the PICS to diagnose ADHD and to distinguish ADHD from ODD and CD.

**Cognitive Measures**

*Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV)*

The Wechsler Intelligence Scale for Children – Fourth Edition is a validated (Benson, Hulac & Bernstein, 2013) individually administered clinical instrument for assessing the cognitive skills (intelligence) of children aged 6 years 0 months through 16 years 11 months. It is comprised of 15 subtests, each measuring a specific facet of intelligence such as verbal comprehension, perceptual reasoning, working memory and processing speed. The theoretical foundation of the WISC-IV is derived from Wechsler's original verbal-non-verbal theory of intelligence (Wechlser, 1939). The WISC-IV reflects attention to the importance of working memory and processing speed as contributors to cognitive functioning. A complete administration of WISC-IV yields standard scores in the following composite areas: Verbal Comprehension Index; Perceptual Reasoning Index; Working Memory Index; Processing Speed Index; Full Scale IQ.

Raw score of the following WISC-IV subtests were used for this study:
Block Design

Block Design is a subtest used to measure perceptual reasoning. It is a test of visuo-spatial processing and measures the child's ability to analyze and synthesize abstract visual stimuli. This test requires the child to view a constructed model or a picture in the stimulus book, and use red-and-white blocks to re-create the design within a specified time limit.

Digit Span-Backward

Digit span is a task with two subtests of ‘Forward’ and ‘Backward’. The Digit Span Forward task requires the child to repeat numbers in the same order as read aloud by the examiner. Digit span forward measures auditory attention span. Digit Span-Backward requires the child to repeat the numbers in the reverse order of that presented by the examiner and is a measure of verbal working memory. The single subtest of Digit Span-Backward was used in the current study for the assessment of verbal working memory.

Coding

Coding is one of the processing speed subtests that assesses visuo-motor processing and is independent from phonological processing. The child copies symbols that are paired with simple geometric shapes or numbers. Using a key, the child draws each symbol in its corresponding shape or box within a specific time limit (Wechsler, 2003). This Coding subtest was used in this study for assessment of processing speed.
Stop Signal Task

The Stop Signal Task is a validated laboratory measure of inhibitory control (Nichols & Waschbusch, 2004). The task requires quick execution of an action, and the occasional inhibition of this behavior. On this computerized task, subjects are asked to respond as fast as they can to go symbols (e.g. X and O) presented on a computer screen by pressing right or left buttons according to instructions. These trials are called ‘go’ or ‘non-stop’ trials in which there is no signal to inhibit response. A portion of the trials will be accompanied by an auditory tone and are called ‘stop’ trials. This auditory tone tells the participant that they are to try and withhold his/her response to the current symbol on the screen. This tone occurs occasionally, is unpredictable, and occurs at various latencies after the appearance of the go symbol. The Stop Signal Reaction Time (SSRT) is an estimation of the time an individual needs to stop their usual ‘going’ behavior (i.e. pressing a key every time they see the symbol) in response to the stop signal. SSRT is a combination of the stop signal and primary “go” response time and is used as a measure of inhibitory control in the current study.

Rapid Automatized Naming (RAN)

Rapid automatized naming is a task that measures how quickly individuals can name objects, pictures, colours, or symbols (letters or digits). Using a serial testing method, participants are shown a row or column of symbols and must name the blocks of letters, numbers, colours or objects sequentially as fast as possible (de Jong & Verielink, 2004). An assumption made regarding serial RAN testing is that it consists of two components: articulation time (the mean time it takes to name the symbol out loud), and pause time
(the mean length of time between naming two adjacent symbols). When referring to pause time, this can include saccadic eye movements, disengagement from previously named symbols and focusing on upcoming symbols (de Jong & Verielink, 2004).

Using the discrete testing method, participants are shown symbols individually, usually on a computer screen. In discrete RAN testing, each individual symbol naming latency is measured. The naming latency consists of the mean time from presentation to articulation of that symbol. The RAN is scored using the mean naming latency of all symbols. Some theorists believe that discrete RAN testing reflects the retrieval of phonological code from memory which can also be referred to as lexical access speed (de Jong & Verielink, 2004). Mean articulation time of each RAN subcomponent was used as a measure of rapid naming in this study.

The cognitive factors, cognitive measures and variables used in this study are summarized in Table.4.

Table.4. Summary of Cognitive Measures

<table>
<thead>
<tr>
<th>Cognitive Factor</th>
<th>Test</th>
<th>Subtest/ Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhibitory Control</td>
<td>Stop Signal Task</td>
<td>SSRT</td>
</tr>
<tr>
<td>Processing Speed</td>
<td>WISC-IV</td>
<td>Coding</td>
</tr>
<tr>
<td>Visuo-Spatial Processing</td>
<td>WISC-IV</td>
<td>Block Design</td>
</tr>
<tr>
<td>Automaticity</td>
<td>RAN</td>
<td>RAN-numbers, letters, objects, colours</td>
</tr>
</tbody>
</table>
Achievement measures

*Woodcock-Johnson III Test of Achievement (WJ-III-ACH)*

The Woodcock-Johnson III is composed of two assessment instruments: Woodcock-Johnson III Test of Cognitive Abilities (WJ-III-COG) and Woodcock-Johnson III Test of Achievement (WJ-III-ACH). Only the achievement instrument was originally used in the ADHD clinic where data for this study was gathered. The WJ-III-ACH is a revised and expanded version of WJ-R of Achievement (WJ-R-ACH) which measures many aspects of academic achievement with a wide variety of relatively brief tests. It contains 22 tests measuring five curricular areas (reading, mathematics, written language, oral language and academic knowledge) and two auxiliary writing evaluation procedures. Data (raw scores) from two subtests, Word Attack and Calculation, were used as proxies for reading and arithmetic ability in this study.

Word Attack measures a child’s skill in applying phonic and structural analysis skills to the pronunciation of unfamiliar printed words. The initial items require the individual to produce the sounds for single letters. The remaining items require the person to read aloud letter combinations that are phonically consistent, or regular, patterns in English orthography but non-words or low-frequency words. The items become more difficult as the complexity of the non-words increases.

Calculation measures the ability to perform mathematical computations. Each item requires the child to perform addition, subtraction, multiplication, and division operations.
There have been difficulties and complexities in defining mathematics learning disability (Mazzocco, 2008). A cut off of 25th percentile on stringent data from achievement tests has been used by some authors to define academic low-achievement (Jordan, et al., 2003; Murphy, Mazzocco, Hanich, & Early, 2007, Mabbott & Bisanz, 2008; Mazzocco, Myers, Lewis, Hanich, & Murphy, 2013); the same threshold was used for the purpose of grouping of the sample in this study for low-achievement. However, it should be noted that only one subtest of WJ-III (Calculation for mathematics and Word Attack for reading), rather than the total score, was used for grouping and low-achievement is not a clinical diagnosis in the current study.

Based on achievement scores of the two sub-tests of ‘Calculation’ and ‘Word Attack’, participants were classified into four groups:

• Group 1: ADHD with Mathematics Low-Achievement and Reading Low-Achievement (ADHD+MLA+RLA) if performance was below 25th percentile on Calculation and Word Attack

• Group 2: ADHD with Mathematics Low-Achievement (ADHD+MLA) if they performed below 25th percentile only on Calculation

• Group 3: ADHD with Reading Low-Achievement (ADHD+RLA) if performance was below 25th percentile only on Word Attack

• Group 4: ADHD without Mathematics Low-Achievement or Reading Low-Achievement (ADHD with no LA) if performance on both Calculation and Word Attack was at the 25th percentile or higher
Data Analysis

Statistical Analysis in Social Science Software (SPSS.16) was used for data analysis. Descriptive statistics were calculated for all variables through appropriate procedures such as frequency and cross tabulation. These statistics provide a thorough picture of the sample’s composition and characteristics such as age distribution, sex ratio, frequency of ADHD subtypes, frequency of mathematics and reading low-achievers, and mean standard score of the cognitive variables.

The main analysis section includes design and development of regression models in order to find out the best cognitive predictors of mathematics (Calculation) and reading (Word Attack) performance in this study sample. The regression analysis began with a series of analytic procedures to determine if the key statistical assumptions had been met for the application of various forms of multiple linear regressions (MLR). First, correlation matrices were produced to study the association between the independent factors, Calculation and Word Attack, and dependent cognitive variables. Possible cognitive predictors entered into correlation matrices were variables of ‘Coding’, ‘Block Design’, ‘Digit Span- backward’, ‘RAN numbers-time’, ‘RAN letters- time’, ‘RAN colours-time’, ‘RAN objects-time’ and SSRT. Standard scores were used for WISC-IV variables; Coding, Block Design and Digit Span- Backward. Normal distributions of the variables were checked using histograms and Shapiro-Wilks tests. Box plots were used to determine the presence of outliers. The linearity of the variables was tested through drawing of scatter
plots. Scatter plots for residuals was used to check homoscedasticity/heteroscedasticity of the variables.

Having tested the assumption for application of regression models, stepwise MLR was used as the main analysis including both forward and backward regression. Different variables were entered to and removed from the model at separate blocks. Predictor variables were selected from correlation matrices where there were significant linear relations present between achievement measures as outcome variables and cognitive factors as independent variables. Regression models were controlled for possible confounders including sex, age and IQ. For each outcome variable, regression models were designed with different orders of entering and removing of the predictor variables, giving the possibility of finding the most powerful blocks of predictors. In each model, the multiple correlation coefficient (R), the coefficient of multiple determination (R²), the adjusted R² and F-test were reported in relation to the significance of relationship and the strength of the statistical prediction.

Analysis of Variance (ANOVA) was used to contrast the four achievement groups of ‘ADHD+MLA’, ‘ADHD+RLA’, ‘ADHD+MLA+RLA’ and ‘ADHD, no LA’ on the different cognitive measures.

The summary of data analysis in relation to testing of each hypothesis of the study is presented in Table 5.
Table 5. Hypotheses and the Statistical Tests Used to Test Them

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Statistical Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>If mathematics ability in ADHD is influenced by cognitive endo-phenotype of ADHD then mathematics performance (Calculation) will be correlated to inhibitory control (SSRT)</td>
<td>Correlation</td>
</tr>
<tr>
<td>If mathematics ability ADHD is influenced by domain-general cognitive factors known to be impaired in mathematics disability, then mathematics performance (Calculation) will be correlated to working memory (Digit Span-BW), processing speed (Coding) and visuo-spatial processing (Block Design)</td>
<td>Correlation</td>
</tr>
<tr>
<td>MLR*</td>
<td></td>
</tr>
<tr>
<td>If mathematics ability is differentiated from reading ability by cognitive factor/s associated with it, then processing speed (Coding) will be distinguishing for mathematics performance (Calculation)</td>
<td>MLR*</td>
</tr>
<tr>
<td>ANOVA**</td>
<td></td>
</tr>
</tbody>
</table>

*Multi-Linear Regression  
** Analysis Of Variance
CHAPTER V - RESULTS

Sample Demographic and characteristics

The total sample size for the current study was 374. The sample was drawn from 1522 consecutive referrals to the ambulatory psychiatry clinic at the Hospital for Sick Children for ADHD assessment. The process for data selection, based on study inclusion criteria and validity screening of the measures is described in the methods chapter.

<table>
<thead>
<tr>
<th>1522</th>
<th>• Total Cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td>983</td>
<td>• ADHD Dx</td>
</tr>
<tr>
<td>824</td>
<td>• 6=&gt;age&gt; 13</td>
</tr>
<tr>
<td>725</td>
<td>• IQ &gt;80</td>
</tr>
<tr>
<td>617</td>
<td>• Completed Achievement Tests</td>
</tr>
<tr>
<td>374</td>
<td>• Completed Stop Signal Test</td>
</tr>
</tbody>
</table>

Figure. 1. The process of selecting the sample. The inclusion criteria of the study including diagnosis of ADHD, age above or equal to 6 and below 13 years and IQ of above 80 applied to the total participants in the cohort (1522) and resulted in inclusion of 725 participants. Complete data from achievement tests and stop signal test were available for 374 cases which included in the data analysis of the study.
There were no significant difference in age between the included and excluded cases in this study. Similarly, the included cases had performed similarly on achievement proxies of mathematic and reading, calculation and word attack. Included cases had higher IQ comparing to the excluded cases (Table.6).

Table.6.Comparision between Included and Excluded Participants

<table>
<thead>
<tr>
<th></th>
<th>Included Mean(SD)</th>
<th>Excluded Mean (SD)</th>
<th>T-score</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>8.85 (1.51)</td>
<td>9.08 (2.64)</td>
<td>1.78</td>
<td>.07</td>
</tr>
<tr>
<td>IQ</td>
<td>101.64 (11.77)</td>
<td>99.59 (15.43)</td>
<td>-2.5</td>
<td>.01</td>
</tr>
<tr>
<td>Calculation</td>
<td>92.28 (12.11)</td>
<td>93.53 (15.33)</td>
<td>1.51</td>
<td>.13</td>
</tr>
<tr>
<td>Word Attack</td>
<td>97.74 (14.29)</td>
<td>97.91 (16.00)</td>
<td>0.18</td>
<td>.86</td>
</tr>
</tbody>
</table>

The sample consisted of 292(78%) males and 82(22%) females. The gender ratio was consistent with reports of gender distribution in children with ADHD (Spencer et. al, 2007; Polanczyk, de Lima, Horta, Biederman, Rohde, 2007; Getahun et. al 2013). The age distribution of the sample was between 6 and 12 with a mean age of 8.5 (SD= 1.72). All participants were attending school in grade levels ranging from grade 1 to 7. Sample characteristics are summarized in Table.7.

All children included in the study met DSM-IV (APA 2000) criteria for ADHD. Specifically, 111(29.7%) children were diagnosed with inattentive subtype, 55 (14.7%) with hyperactive subtype and 208 (55.6%) with combined subtype.
Children were grouped in different achievement groups based on their performance on Word Attack and Calculation subscales of Woodcock Johnson- III test of achievement. 93 (24.9%) of sample had Math Low-Achievement and no Reading Low-Achievement (+MLA/-RLA), 41 (11%) had Reading Low-Achievement and no Mathematics Low Achievement (+RLA/-MLA), 59 (15.8%) had both Math and Reading Low-Achievement (+MLA/+ RLA). 181 (48.4%) children did not show low-achievement in math or reading (No LA). Regardless of having co-morbid reading difficulty, 40.7% of the study sample of children with ADHD had low-achievement in math (see Table.7).

The results from the main analyses are organized according to the objectives of the current study. Specifically, findings from stepwise MLR are discussed in order to describe the relationship between mathematics and reading abilities and cognitive factors.
Table.7. Sample Characteristics

<table>
<thead>
<tr>
<th></th>
<th><strong>Total Sample</strong> (number)</th>
<th>374</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean: 8.5 (SD= 1.7)</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>292</td>
<td>78.0%</td>
</tr>
<tr>
<td>Female</td>
<td>82</td>
<td>22.0%</td>
</tr>
<tr>
<td><strong>Inattentive</strong></td>
<td>111</td>
<td>29.7%</td>
</tr>
<tr>
<td><strong>Hyperactive-Impulsive</strong></td>
<td>55</td>
<td>14.7%</td>
</tr>
<tr>
<td><strong>Combined</strong></td>
<td>208</td>
<td>55.6%</td>
</tr>
<tr>
<td><strong>Learning Achievement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+MLA/-RLA</td>
<td>93</td>
<td>24.9%</td>
</tr>
<tr>
<td>+RLA/-MLA</td>
<td>41</td>
<td>11.0%</td>
</tr>
<tr>
<td>+MLA/+ RLA</td>
<td>59</td>
<td>15.7%</td>
</tr>
<tr>
<td>No LA</td>
<td>181</td>
<td>48.4%</td>
</tr>
</tbody>
</table>

Key Statistical Assumptions for Regression Analysis

*Multicollinearity and independence*

A formal detection-tolerance for multicollinearity was conducted where a tolerance of less than 0.20 indicates a multicollinearity problem (O'Brien, 2007). The tolerance detected for predictor variables, either in mathematics or reading models, was between 0.3-1, suggesting that there was no concern for multicollinearity in the regression analysis (Table.10 and Table.14). There was a large correlation between RAN subtests ($r=0.698-0.861$), and it was a concern that they might test similar constructs. Therefore, to ensure
higher confidence in interpreting the results of the regression model for reading, different univariate and multiple regression models were designed in order to keep the best RAN measures in the final model.

**Normalcy and distribution of outliers**

First, box plots were produced for the variables used in the study to check for outliers. There were some outliers under RAN subtest variables. In order to determine whether the presence of outliers would influence the results, all or not at all, further analyses were performed in two separate steps; with outliers being present and being removed from the MLR models. Since there was no difference in the results with having the outliers in the model they were kept in the final analysis which is reported here.

To determine the normalcy of the distribution, histograms were made for each predictor variable. The histograms showed approximately normal distribution of the variables. Kurtosis statistics for majority of variables were within accepted limits (-1 to +1), ranging from -.536 to .602.

**Linear Correlations**

The strength of relationship between the predictor variables and between the predictor and outcome variables was tested using correlation analyses; separate analyses were conducted for Calculation and Work Attack (Table. 7 and Table.8).

There was a significant, positive correlation between Calculation and Coding, Block Design and Digit Span-backward. No significant relations were evident between Calculation and SSRT or RAN subtests. Further, a significant positive correlation was
observed between Word Attack and Digit Span-Backward and Coding: A significant negative correlation was identified with all RAN measures including Letters, Numbers, Colors and Objects. Similar to Calculation, no significant correlation was found between Word Attack and SSRT. The lack of linear relationship for SSRT suggested that this cognitive variable is unlikely to be related to indices of mathematics and reading in our sample.

There were medium to large size correlations between RAN Numbers, Ran Letters, Ran Objects and Ran Colors which were considered in further analysis (Table.8 and Table.9).
Table 8. Correlations between Calculation (Mathematics) and Cognitive Factors

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Calculation</th>
<th>Block Design</th>
<th>Digit Span</th>
<th>Coding</th>
<th>RAN Numbers</th>
<th>RAN Letters</th>
<th>RAN Colours</th>
<th>RAN Objects</th>
<th>SSRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>.190</td>
<td>.271</td>
<td>.000</td>
<td>.105</td>
<td>.190</td>
<td>.271</td>
<td>.000</td>
<td>.105</td>
<td>1</td>
</tr>
<tr>
<td>p-value</td>
<td>.000</td>
<td>.105</td>
<td>.000</td>
<td>.043</td>
<td>.000</td>
<td>.043</td>
<td>.000</td>
<td>.043</td>
<td>1</td>
</tr>
<tr>
<td>Block Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>p-value</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit Span</td>
<td>.271</td>
<td>.105</td>
<td>1</td>
<td></td>
<td>.271</td>
<td>.105</td>
<td>1</td>
<td>.271</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
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<td>.000</td>
<td>.125</td>
<td>.000</td>
<td>.043</td>
<td>.000</td>
<td>.125</td>
<td>1</td>
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<tr>
<td>Coding</td>
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<td>.043</td>
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<td>.125</td>
<td>.000</td>
<td>.043</td>
<td>.000</td>
<td>.125</td>
<td>1</td>
</tr>
<tr>
<td>R</td>
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<td>.271</td>
<td>.000</td>
<td>.105</td>
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65
Table 9. Correlations between Word Attack (Reading) and Cognitive Factors

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Main findings

These correlations provided findings to answer the first question of the study. The first objective was to find any association between mathematics, measured by Calculation, and inhibitory control, measured by SSRT. There was no significant linear relation between Calculation and SSRT. Similarly, the correlation study did not show any relation between Word Attack and SSRT. Since the correlations between SSRT and the outcome measures were negated, SSRT was not entered in the regression models which were designed to investigate the best predictors for mathematics (Calculation) and reading (Word Attack).

The second objective of current study was to determine if any, or any combination of the cognitive variables of interest in this study, predict mathematics ability in children with ADHD and the third objective was to find factors that might have unique roles for mathematics and reading. A series of stepwise MLRs were conducted for Calculation and Word Attack, based on the correlation study results. Age and sex and IQ (WISC-IV-full scale IQ) were entered to and removed from the initial models for both Calculation and Word Attack, to test for their covariance effect. Presence of age, sex or IQ did not show any effect on the relation between predictor variables and outcomes.

What Specific Cognitive Factors Best Predict Mathematics?

Based on the correlation study results, the MLR model for Calculation was designed with Coding, Digit Span-Backward and Block Design as predictive factors (Table.10). Additional MLR procedures were performed to determine what, if any, particular cognitive ability best predicts Calculation. According to the correlation analysis, the variable with
The strongest significant linear relation with Calculation was Coding ($r=.305, p<.0001$). The standard scores of Coding were entered in the model in the first block. For the next two separate blocks standard scores of Digit Span-Backward ($r=.271, p<.0001$) and Block Design ($r=.190, p<.0001$) were entered respectively (Table.1). The predictive variables were removed from the model in the same order in a stepwise analysis to further confirm their effect in the model (Table. 12).

The results of stepwise MLR for Calculation showed that Coding (processing speed) Digit Span-Backward (working memory) and Block Design (visuo-spatial processing) were predictors of Calculation score. The strongest influence was observed with Coding (processing speed). Coding accounted for 9.3% of the variability in mathematics scores. 5.2% of variability could be accounted for by Digit Span-Backward and 1.8% could be accounted for by Block Design. The three variables together accounted for 16.3% of variability in Calculation; Coding is the strongest predictor.

**What Cognitive Factors distinguish reading from mathematics?**

The analysis to answer this question started with investigating the best predictors of reading (Word Attack). The primary MLR model included predictive variables of Digit Span-Backward ($r=.283, p<.0001$), RAN numbers ($r=-.257, p<.0001$), RAN letters ($r=-.231, p<.0001$), RAN colours ($r=-.180, p<.0001$), Coding ($r=.151, p<.0001$), and RAN objects ($r=-.118, p<.0001$) (Table .13). The predictive variables were entered into the model in decreasing order of their correlation coefficient values, at separate blocks. The primary model showed no effect with Coding, RAN letters and RAN colours. Although each of these variables had significant linear relationships with reading, their predictive
roles disappeared when combined with other variables. Considering the large correlations existing among RAN subtests, separate MLR models were produced for these variables. RAN variables were entered into the models in different orders. The results of the MLR models for RAN subtests confirmed stronger effects with RAN numbers and objects on Word Attack in all of the different models produced. Considering that there was no significant independent influence with Coding in the model, this variable was kept out from the final model (Table.14). In the final model produced for Reading, Digit Span-Backward, RAN numbers, Coding, RAN objects were entered to the model in the same order (Table.15), followed by stepwise removing of predictors from the model (Table.16).

The final MLR procedures identified that Digit Span-Backward (working memory), RAN (automaticity) number and RAN Objects were the best predictors of Word Attack (reading). Digit Span-Backward was the strongest predictor which accounted for 8% of variability in reading scores; 6.1% of variability in reading could be attributed to RAN numbers and 1.2% to RAN objects. These three variables together described 15.3% of the variability in reading score.

Digit Span-Backward was the only cognitive factor influencing both Calculation and Word Attack in our sample. While Coding had a strong independent effect on Calculation, its influence on Word Attack was mostly through inter-correlation with Digit Span-Backward. RAN-numbers and RAN-objects were the two variables influencing Reading with no predictive role for Mathematics. To sum up, Coding was the distinguishing variable for Calculation as the proxy for mathematics and RAN measures discriminated Word Attack which was the proxy for reading in this study.
To further understand the distinguishing role of cognitive factors in mathematics or reading ability, different achievement groups of +MLA/-RLA, +RLA/-MLA, +MLA/+RLA and ADHD with no LA were contrasted. Analysis Of Variance (ANOVA) was performed to compare cognitive scores of the four groups. Standard scores of WISC-IV subtests, RAN mean time for numbers, letters, colors and objects as well as SSRT were the independent variables (Table.1). The results showed similar scores for Coding in ADHD+MLA/-RLA and ADHD+MLA/+RLA groups. Coding scores in ADHD+MLA/-RLA and ADHD+MLA/+RLA were significantly lower than those in the ADHD+RLA/-MLA and ADHD with No-LA groups (F=12.69, p<.0001). This finding further supported the results of MLR analyses showing an important/unique role of Coding for Mathematics. Digit Span-Backward scores were significantly lower in ADHD+MLA/-RLA ADHD+RLA/-MLA and ADHD+MLA/+RLA groups compared to No-LA (F= 8.68, p<.0001). The ADHD+MLA/+RLA group had significantly slower time of naming in all RAN submeasures. Also, the two groups with reading Low-achievement, ADHD+RLA/-MLA and ADHD+MLA/+RLA performed slower on RAN-numbers (F= 4.41, p<.005) and RAN-letters (F= 4.54, p< .004) than ADHD+MLA and ADHD with No-LA. These findings further supported the MLR results that RAN is related to reading and its performance is more disturbed in reading low-achievement. There were no differences between any of the groups on SSRT.
Table 10. Predictors of Mathematics

<table>
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<tr>
<th>Predictor</th>
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<th>R square Change</th>
<th>F change</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
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<td>.093</td>
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<tr>
<td>Coding, Digit Span BW</td>
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<td>.052</td>
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</tr>
<tr>
<td>Coding, Digit Span BW, Block Design</td>
<td>.163</td>
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</tbody>
</table>

Table 11. Coefficients of Stepwise MLR for Mathematics- (entering)

|                                | Co-efficient | t       | p-value |
|                                |              |         |         |
| Coding                         | .305         | 6.187   | <.001   |
| Coding                         | .272         | 5.602   | <.001   |
| Digit Span-BW                  | .231         | 4.759   | <.001   |
| Coding                         | .257         | 5.305   | <.001   |
| Digit Span-BW                  | .219         | 4.536   | <.001   |
| Block Design                   | .135         | 2.802   | 0.005   |
Table.12. Coefficient of Stepwise MLR for Mathematics- (removing)

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<th>t</th>
<th>p-value</th>
<th>Partial Correlation</th>
<th>Collinearity Statistics</th>
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Table.13. Predictors of Reading (Primary Model)

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Table 14. Predictors of Reading (Final Model)

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Table 15. Coefficients of Stepwise MLR for Reading- (entering)

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Table 16. Coefficients of Stepwise MLR for Reading- (entering)

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<td>RAN numbers</td>
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<td>-5.129</td>
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<td>5.592</td>
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<td>RAN numbers</td>
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<tr>
<td>RAN objects</td>
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<td>.023</td>
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**Table 1.7. Comparison of Cognitive Factors in Achievement Groups**

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<th>Block Design</th>
<th>+MLA/+RLA (1) Mean (SD)</th>
<th>+MLA/-RLA (2) Mean (SD)</th>
<th>+RLA/-RLA (3) Mean (SD)</th>
<th>No LA (4) Mean (SD)</th>
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<td>1&gt;(2,4)</td>
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<td>49.78(10.6)</td>
<td>50.96(15.3)</td>
<td>51.46(13.3)</td>
<td>3.88</td>
<td>.034</td>
<td>1&gt;2</td>
</tr>
<tr>
<td>RAN Object</td>
<td>57.47(17.5)</td>
<td>51.28(9.3)</td>
<td>52.02(10.8)</td>
<td>54.01(13.1)</td>
<td>4.80</td>
<td>.029</td>
<td>1&gt;2</td>
</tr>
<tr>
<td>SSRT</td>
<td>399.92(193.3)</td>
<td>367.97(188.5)</td>
<td>334.12(137.8)</td>
<td>344.61(173.6)</td>
<td>0.62</td>
<td>.148</td>
<td>-</td>
</tr>
</tbody>
</table>

* Between group difference; Bonferroni Post-hoc test
CHAPTER VI- DISCUSSION

The current study shows the association between cognitive factors and learning low-achievement in children with ADHD. The author has attempted to bridge the body of literature on cognitive deficits in ADHD with cognitive difficulties present in learning disability, and examine a range of cognitive factors in the co-morbidity of mathematics and reading low-achievement with ADHD.

To date very few studies have examined the cognitive deficits underlying the comorbidity of ADHD with mathematics learning difficulty, although this is a common co-morbidity with a reported prevalence of 11-26% (Srinivas, Roediger, & Rajaram, 1992; Monuteaux et al. 2005, Capano et al., 2008). The current study supports the high prevalence of this co-morbidity with 40.7% of the sample having MLA. More than half of the children in our sample had learning low-achievement of either mathematics, reading or both types and the proportion of children having MLA was double of those having RLA. The sample of the study well represents the clinical ADHD population. The number of male participants in our sample was 3.5 times that of females, with the proportion of inattentive, hyperactive and combined subtypes in the whole sample being 29.7%, 14.7% and 55.6% respectively. These results are consistent with epidemiology reports on the disorder (Spencer et al., 2007). The fact that the sample is representative of what is observed in larger clinical populations adds to the validity of our findings.
This study specifically explored the association of cognitive factors and mathematics performance in children with ADHD and is believed to be the first to look into this relation. Table.17 summarizes the hypotheses of the study and the reasons they were accepted or rejected.

The main question of the study was whether children with ADHD are more vulnerable to MLA due to factors influenced by the ADHD condition or independent from it. In this regard, our main finding is the negation of the association between an ADHD known endophenotype, inhibitory control, and mathematics ability. This finding disproves the first hypothesis of the study, *‘If mathematics ability in ADHD is influenced by cognitive endophenotype of ADHD then mathematics performance will be correlated to inhibitory control’.*

Inhibitory control is recognized as one of the fundamental cognitive factors impaired in ADHD (Schachar & Logan, 1990; Pennington & Ozonoff, 1996; Barkley, 1997) and a potential endo-phenotype of the disorder (Crosbie et al., 2008; Goos et al., 2009; Crosbie et al., 2013). This would suggest that some etiologic factors associated with MLA in ADHD are independent from the factors that influence poor inhibitory control. Also, similar to performing mathematics, reading was not associated with inhibitory control in our sample. Considering the lack of association between inhibitory control and mathematics, as well as reading, it could be argued that academic low-achievement in major areas of reading and mathematics is independent of aspecific cognitive deficit in inhibitory control. This study indicates that learning low-achievement seems to be more like co-morbidity to ADHD than an outcome of it.
The study poses a further question of whether the vulnerability of ADHD children to MLA relates to known factors affecting mathematics achievement in the general population. The current review of the studies on non-clinical samples showed two arrays of cognitive factors involved in mathematics, domain-specific factors and domain-general factors. Cognitive factors in the domain-general category that influence mathematical performance are the focus of this study, and include working memory, processing speed, visuo-spatial processing and automaticity. These cognitive factors are not only involved in doing mathematics, but are engaged in several other mental abilities. Testing of the domain-specific cognitive factors in mathematics ability of children with ADHD is beyond the scope of this study.

The study investigated the role of domain-general factors in mathematics ability of children with ADHD. The study findings proved the second hypothesis of the study, ‘If mathematics ability ADHD is influenced by domain-general cognitive factors known to be impaired in mathematics disability, then mathematics performance will be correlated to working memory, processing speed and visuo-spatial processing’. Our results showed significant predictive effects of Coding, Digit Span-Backward and Block Design on Calculation with strongest effects with Coding. These findings show the influence of working memory, processing speed and visuo-spatial processing on mathematics performance in children with ADHD, with the highest association being with processing speed.

The other question of this study was focused on factors that would distinguish mathematics from reading ability in children with ADHD. The study results proved the related hypothesis, ‘If mathematics ability is differentiated from reading ability by
cognitive factor/s associated with it, then processing speed will be distinguishing for mathematics performance’.

Processing speed seems to be a discriminating factor between reading and mathematics. Performance on the Coding test highly influenced mathematics ability in our sample. The comparison of cognitive factors between the four groups of +MLA/-RLA, -MLA/+RLA, +MLA/+RLA and No LA showed processing speed is the only factor that is statistically significantly lower in children with MLA. Table 17 summarises how the results addressed the hypotheses of the study.

Processing speed (Coding) distinguishes the two groups of +MLA/+RLA and +MLA/-RLA from those without MLA. The discriminating role of processing speed for mathematics ability in the ADHD population is an addition to present knowledge in this area. Our findings are consistent with research on non-clinical samples demonstrating that processing speed in pre-school age children is a strong predictor of mathematics skills at later age (Mozzacco & Thompson, 2005). The results also suggest that the predictive power of processing speed for mathematics is larger than that of working memory (Hecht et al 2001, Bull & Johnston 1997, Geary 2010, b). Processing speed as a general ability might influence the efficiency of mathematics specific functions such as subitizing, number line concept and magnitude estimation. Faster speed of processing might free cognitive resources and result in increased efficiencies with number processing and fact retrieval. Further studies are required to describe this relation. We also know that processing speed is the best predictor of inattentive symptoms in children with ADHD (Weiler et al. 2000); yet it is unknown whether it is playing its distinguishing role in
mathematics ability through mediating attention problems or if it has an independent effect.

The study findings also showed that among all tested cognitive factors, reading was most strongly influenced by working memory and automaticity. Working memory had the strongest effect on reading; this finding is in accordance with literature on the involvement of working memory in reading (Siegel & Ryan, 1989; Swanson and Ashbaker, 1996, Berninger & Abbott, 1999; Brooks, Berninger, & Abbott 2011).

The comparison of different achievement groups of the study also indicated that children with ADHD+MLA+RLA have poorer performance on our very working memory test compared to the ADHD no LA group. It is known from studies on non-clinical samples that working memory influences both mathematics and reading at early and advanced stages of acquisition (Torgesen et al., 1994; Berninger et al., 1999; McLean & Hitch, 1999; Swanson & Sachse-Lee, 2001; Trobovich & Lefevre, 2003; LeFevre et al., 2004; Geary et al., 2007, LeFevre et al. 2013).
### Table 18. Results of Testing the Hypotheses

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Testing Result</th>
<th>Study finding</th>
</tr>
</thead>
<tbody>
<tr>
<td>If mathematics ability in ADHD is influenced by cognitive endo-phenotype of ADHD then mathematics performance (Calculation) will be correlated to inhibitory control (SSRT)</td>
<td>Disproved</td>
<td>There is no significant association between calculation and SSRT</td>
</tr>
<tr>
<td>If mathematics ability ADHD is influenced by domain-general cognitive factors known to be impaired in mathematics disability, then mathematics performance (Calculation) will be correlated to working memory (Digit Span-BW), processing speed (Coding) and visuo-spatial processing (Block Design)</td>
<td>Proved</td>
<td>Calculation is significantly correlated with Digit Span-BW, Coding and Block Design</td>
</tr>
<tr>
<td>If mathematics ability is differentiated from reading ability by cognitive factor/s associated with it, then processing speed (Coding) will be distinguishing for mathematics performance (Calculation)</td>
<td>Proved</td>
<td>Coding score is significantly lower in ADHD+MLA+RLA and ADHD+MLA-RLA than ADHD+RLA-MLA and ADHD with no LA</td>
</tr>
</tbody>
</table>
Results also indicate that working memory is the only factor among those tested that is strongly involved in both reading and mathematics. It has been discussed that working memory might be one of the shared cognitive weaknesses between ADHD and reading disability (Rucklidge & Tannock 2002); the combination of the two might have an additive effect as children with both ADHD and reading disability have a larger problem working memory deficit (Bental & Tiros, 2007).

The current study also supports that working memory deficits are higher in those with ADHD+ RLA compared to those with ADHD without RLA. Working memory impairments might predispose children with ADHD to learning difficulties in both reading and mathematics. However, there were no significant differences in working memory between +MLA/+ RLA and either of +MLA/-RLA or −MLA/+RLA in our sample, implying that the deficit in working memory is not necessarily greater in those with mathematics and reading difficulties.

Similar to some studies on non-clinical populations, automaticity in naming seems to be mainly related to reading ability with no defined role for mathematics (Roman, Kirby, Parrila, Wade-Woolley, & Deacon, 2009). Our findings did not show any relation between naming of numbers and mathematics performance. What appears significant in performing mathematics does not seem to be the automaticity in recognizing and verbalizing numbers; it appears to be related to the way their relations are processed.
Summary

The major finding of the study was that learning low-achievement in the two areas of reading and mathematics seems to be independent of ADHD more specific cognitive ability, inhibitory control. Inhibitory control is purported to be a core deficit in the neuropsychopathology of ADHD, but it does not seem to be related to learning abilities in these children in spite of their vulnerability to learning difficulties. Despite the high prevalence of mathematics learning difficulty in this population, it cannot be exclusively attributed to the presence of ADHD.

Processing speed (as indexed by Coding) was related to mathematics, but not reading, ability in ADHD with the strongest predictive effect among three predictors, specifically working memory, visuo-spatial processing and processing speed. Working memory possibly has a more global role, influencing both reading and mathematics achievement; yet its role is not discriminating between mathematics and reading. While working memory plays an important role in both reading and mathematics performance, naming speed appears to be related to reading, but not math ability in children with ADHD.

It is suggested that factors which affect mathematics ability in ADHD individuals are similar to those in the general population. Processing speed seems to have a specific and unique role in learning of mathematics in children with ADHD compared to reading; this distinct role of processing speed has important implications for detection and remediation of mathematics difficulties in this population. However, we cannot conclusively indicate that the role of processing speed at earlier stages of learning mathematics is different from that of advanced stages; if processing speed is only important in acquisition of
mathematics or in maintaining and advancing of it as well. These are important questions that need to be answered in future studies.

Our findings on the cognitive dimensions of the co-morbidity of ADHD with mathematics difficulty may help better understanding of the struggle children with ADHD have in doing mathematics and facilitate discovering the best interventions to help these children.
CHAPTER VII- STRENGTHS, LIMITATIONS AND CONCLUSION

The current study was undertaken to fill a knowledge gap regarding vulnerability of children with ADHD to difficulty in learning mathematics. The focus of this study was the cognitive features of this vulnerability. The study examined a range of cognitive factors to understand the nature of the role they play in mathematics performance in a sample of children with ADHD, recognizing factors differentiating mathematics from reading.

The findings of the study have implications for approaches to remediation of mathematics disability in children with ADHD. The study also poses questions in this area that needs further studies to be answered. Prior to drawing conclusions from the study findings, the strengths and limitations of this dissertation are described below.

Strengths of the study

The present study represents a new area of research in the field of learning difficulty in individuals with ADHD. The study has focused on mathematics, a subject that has a paucity of rigorous study. A strength of this thesis is the provision of a literature review which bridges the gap between works on cognitive profiles of learning disability in non-clinical populations and those with clinical ADHD. The study examined and discussed the effect of these cognitive factors in both mathematics and reading abilities of children with ADHD and recognized the influencing and discriminating factors for MLA and RLA in ADHD for the first time.
Another strength of the study is the size of the cohort, as well as the fact that an interdisciplinary professional team with vast clinical and research experience had gathered data meticulously. Standardized clinical, cognitive, behavioral and academic achievement measures used in the primary study allowed answering of the questions of the current study. The use of the relatively large sample provided sufficient statistical power to perform advanced multivariate statistical analyses in order to examine the relationships between cognitive factors and mathematics and reading performance. Ample statistical power enabled testing different combinations of MLA and RLA with ADHD, which further helped examination of the distinguishing cognitive factors between mathematics and reading ability.

Limitations of the Study

The present study offers new findings related to learning difficulty in children with ADHD, however, there are limitations with this work. The possible limitations of the study could be related to various factors including sampling issues, measurement issues, possible covariates or confounding agents and the directionality between cognitive factors and academic low-achievement (i.e., correlation versus causation).

Possible Sample Related Limitations

There needs to be caution with generalization of the study findings due to the clinical nature of the sampling. The sample was derived from a mental health program for
assessment and treatment of children experiencing learning and behavioral problems, where health care professionals referred participants from the community. These children possibly had greater impairment in association with their academic, cognitive and behavioral problems comparing to what is typically observed in community samples. Therefore, generalization of the results beyond tertiary/quaternary settings ought to be taken cautiously. The current study was limited to a cross sectional design where the association of the cognitive factors and scores on the measures of mathematics and reading were examined. As a result, caution about causative interpretation of the results is definitely required; thus, the study taps on the correlation between studied cognitive factors and reading and mathematics scores, not on the causation.

Another limitation of this study was with sub-sample selection. The availability of valid data on some measures of interest affected the sample. The investigator was limited to participants for whom data were available on the main measures of interest. Inclusion of participants who could perform and finish the tests may have caused selection bias with sampling procedure. Again, this bias warrants caution in generalizing the results of the study. Despite limitations with generalizing, substituting missing data with statistical means of valid data where two groups had significant differences on hypothetical confounders or mediating/moderating variables provided the possibility of solid interpretation of the results.

**Possible Measurement Related Limitations**

The other important limitation is the secondary data nature of the study. The major problem with secondary analysis of data is that the selection of the primary population to
study and data to collect has been predetermined. Although the primary study was a comprehensive investigation of attention problems and included measures that help in answering the questions of this study, it was not primarily focused on academic functioning and impairment. The author used the two sub-components of ‘Calculation’ and ‘Word Attack’ of Woodcock-Johnson III Test of Cognitive Abilities (WJ III COG) as proxies for mathematics and reading and defined low-achievement groups in mathematics and reading according to the scores on these sub-tests. Precise measurement of the reading and mathematics ability and the diagnosis of the disability warrant more comprehensive tests. The author is aware that in an ideal situation with a primary design type of study and use of more comprehensive measures for academic achievement and complete test, instead of single subtest for cognitive factors, the results might have been a bit different.

Meeting a minimum full scale IQ score was an inclusion criterion for this study. However, the author is aware that the intelligence test used in this study, WISC-IV, requires knowledge of vocabulary, numbers, and Calculation. As a result, individuals with severe mathematics or reading disability might have had low full scale IQ scores on Wechsler and would have been excluded from this study. Tests of intellectual abilities need to be selected with caution in cognitive and education studies since they can have a serious influence in inclusion of the participants into studies or diagnosis of different learning disabilities in clinical and educational settings (Butterworth & Kovas, 2013). It should also be noted that the study used data from sub-tests of the WISC-IV to measure some cognitive abilities of interest including working memory (Digit Span-Backward),
processing speed (Coding) and visuo-spatial processing (Block Design) and these sub-components contribute to the general measurement of IQ. The author has tried to eliminate this measurement limitation at different steps of inclusion and analysis of data, where possible. A minimum full scale IQ of 80 was an inclusion criterion for this study. The group analysis of variance was controlled for IQ. Also effect of full scale IQ in the regression analysis has been checked and the results showed that IQ was not a covariate for the cognitive factors examined. However, in an optimum setting of the study with primary definition of variables and selection of measures, different types of cognitive tests, separate from the measure of IQ, would be used.

**Limitations Related to Possible Confounders and Multicollinearity**

Domain-specific cognitive abilities related to mathematics such as subitizing, number-line and magnitude perceptions are the possible confounders of the relation between mathematics ability and general domain factors including processing speed, working memory and visuo-spatial processing. Similarly, possible confounders such as phonological awareness exist in the relation between reading and general cognitive factors shown to have influence in reading in this study. These include working memory and naming speed. Due to the nature of the secondary data set and the limitations with the primary measures and the data available, it was not possible to control for the influence of these possible confounders.

The author has been aware of the risk of intercorrelated variables of cognitive abilities in this study. The high dependency of the cognitive factors on each other is a limitation with their measurement which affects cognitive studies in general and is not specific to the
current study (Butterworth & Kovas, 2013). The testing of multicollinearity in data analysis showed that the intercorrelation of the variables was not of a statistically significant degree. Despite this, minimal effect of multicollinearity with the study results is a conceptual limitation that should be considered in discussion of the results.

Even though the study faced limitations, it opened new windows to understanding of the cognitive mechanisms with mathematics difficulty in ADHD. It showed the distinctive role of processing speed and lack of effect with inhibitory control in mathematics performance and the similar influence of working memory in mathematics and reading ability of children with ADHD.
Conclusion

The relationship between ADHD and academic underachievement has been widely studied and reported yet the nature of this relationship has not been specified. Individuals with ADHD experience substantial functional and academic impairment due to difficulties in learning mathematics and reading that affect them throughout their lives (Biederman et al. 1996; Loe & Feldman 2007; Frazier et al. 2007). Despite the comparable prevalence of reading disability and mathematics disability in ADHD (Srinivas et al. 1992, Monuteaux, et al., 2005; Capano, et al. 2008) limited knowledge is available about the comorbidity of ADHD with mathematics disability. The limitation is even more prominent in cognitive features of this comorbidity. It is very surprising that despite the great burden associated with co-morbidity of ADHD with mathematics disability, there is paucity of research on this topic. The majority of available work has focused on behavioral symptoms of ADHD that predispose patients to learning problems; noticeably less studies have been devoted to cognitive profiles. Nevertheless, understanding of the cognitive deficits is of grave importance for remediation and education of these children.

The current study provided a unique approach to the assessment of cognitive deficits influencing mathematics ability in children with ADHD. The study presented a selective review of research related to cognitive deficits in mathematics disability, reading disability, ADHD and combination of these disorders. Multiple identified cognitive factors were tested for their relation to mathematics performance and the results were contrasted to reading ability. This approach resulted in valuable findings adding new perspectives to
knowledge in the area and confirmation of some established findings. The most important finding of the study was the negation of relation between inhibitory control and mathematics, as well as reading ability. This finding implies possible independence of learning low-achievement from ADHD specific cognitive deficits. The study also found out that processing speed, working memory and visuo-spatial processing are the three cognitive factors that influence mathematics ability in this sample of children with ADHD. Processing speed showed stronger relation to mathematics amongst these three cognitive factors. This finding is in harmony with evidence from prior studies showing predictive effect of processing speed in acquisition and advancement of mathematics skills (Bull & Johnston 1997, Hecht et al. 2001). While working memory affects both reading and mathematics performance, processing speed has a more specific association on mathematics. The discriminating role of processing speed for mathematics implies possible benefits from processing speed oriented strategies in helping children with ADHD overcome deficits in achieving mathematics skills.

**Implications and Future Directions**

Despite the advances in what we know about deficits in ADHD and about cognitive problems affecting learning disabilities, it is disconcerting that a considerable proportion of children with ADHD continue to suffer low-achievement in mathematics. Early identification and remediation of mathematics disability is very important in changing the learning trajectory that children with ADHD might follow. It is known that those who start
school behind their peers in mathematics tend to stay behind (Duncan et al., 2007). When students’ needs go unaddressed over the first years of education, the “wait and fail” model creates large performance deficits in children who might have developed well with earlier prevention efforts (Fletcher & Vaughn, 2009; Solis, Miciak, Vaughn, Fletcher, 2014). Therefore, development of specific screening tools and early intervention strategies are crucial for preventing development of mathematics disability in children with ADHD. Neither of these is achievable without a sound understanding of the cognitive roots of this co-morbidity. The current study presented some novel findings that might facilitate future research toward cognitive oriented screening tools and intervention methods.

This study showed the independence of mathematics ability from the inhibitory control endophenotype of ADHD. In other words, mathematics learning difficulty seems to be a co-morbidity to ADHD rather than an inherent problem of it. However this finding needs duplication in future studies seeking. Proper research designs to examine causative relations rather than associative ones are needed to further test the independence of mathematics disability from inhibitory control. Children with co-morbid ADHD and math disability might benefit from dual approaches in remediation of mathematics difficulty including treatment of ADHD symptoms as well as strategies to help them better acquire mathematics skills. Research has focused on a variety of interventions in classrooms attempting to find a way to best instruct children with ADHD and mathematics disability. With respect to ADHD, instructional interventions including behavioral modification and teaching cognitive strategies have been tested (DuPaul & Weyandt, 2005, Martinussen, Tannock, McInnes, Chaban, 2006). Interventions geared to math disabilities have
examined the effects of tutoring, implementation of technological support and focused instruction (Gersten, Jordan & Flojo, 2005). Teachers might need to use a combination of these approaches rather than either to best help students with the comorbidity of ADHD and mathematics disability. Interventional studies with primary objective to test this assumption will be needed in future.

Apart from behavioral and instructional approaches, stimulant medications have been effective in improving academic achievement in students with ADHD (Martinussen & Tannock, 2006). It has been shown that stimulant therapy in ADHD remediates mathematics difficulty to some level (Carlson et al., 1991; Benedetto-Nash and Tannock, 1999; Zentall, et al., 2013). Considering the absence of relation between mathematics ability and inhibitory control, the beneficial effect of stimulants on mathematics seems to happen through cognitive abilities or neurobiological pathways other than those involved in inhibitory control. It has been discussed that this remedial effect could be described by behavioral modifications, in particular, improvement of inattention (Benedetto-Nash and Tannock, 1999). However, at a cognitive level, working memory, processing speed or visuo-spatial processing that were associated with mathematics performance in the current study are possible mediators of remediation of stimulants on mathematics difficulty. Further studies are needed to directly test the effect of stimulant medications on cognitive factors known to be involved in mathematics and reading in children with ADHD. Moreover, the interaction between behavioral and cognitive factors in the development of learning disabilities, in particular mathematics disability, is not yet understood. Future research warrants an approach towards understanding the relation
between behavior problems, cognitive deficits and learning disabilities in ADHD. Of particular interest will be studies that investigate the mediating effect of behavioral problems on the relation between cognitive deficits and mathematics learning in ADHD. One of the best approaches to this topic would be randomized control trials using stimulants and targeting measurement of behavioral and cognitive effects and their interaction and impact on academic achievement.

This study showed that processing speed is related to mathematics learning and is unrelated to reading achievement. On the other hand, working memory emerged as a factor with a more general influence, affecting both mathematics and reading in ADHD individuals. This study was not designed to examine the causative relation, though the discovered associations suggest the potential effect of processing speed targeted interventions in improving mathematics ability in children with ADHD. Working memory focused interventions on the other hand might target broader areas of learning. The specific influence of either of these cognitive factors on different aspects of mathematics would need to be tested as well. This study has only used the ‘calculation’ subtest of an academic achievement test to index mathematics performance, while mathematics more broadly includes other abilities such as problem solving and mathematics reasoning. The author is cautious to generalize the findings of this study to other such aspects of mathematics learning and is aware of the need to conduct other studies to understand cognitive features of other mathematics domains. Similarly, it should be noted that this study only investigated domain-general cognitive factors influencing mathematics ability in ADHD. It is not known whether children with ADHD and mathematics disability show
similar deficits in domain-specific factors to mathematics disabled peers without ADHD. Further advances in the knowledge of the cognitive mechanisms underlying mathematics difficulty in ADHD will require fine assessment of both domain-specific and domain-general factors and the relation between these two.

Considering the broader definition of ADHD in DSM-5, further epidemiologic studies to better understand the comorbidity of ADHD with mathematics disability are warranted. DSM-5 pays specific attention to characterizing the disorder in adolescents and adults. With more accurate diagnosis of ADHD in adolescents comes the need for more attention to their comorbid academic difficulties, including mathematics disability. The current study investigated this co-morbidity in primary school and early middle school age children; yet the pattern of cognitive deficits with mathematics problems at more advanced education levels is not understood. This study had a cross-sectional approach. Of particular importance would be longitudinal studies investigating the cognitive deficits in different trajectories of mathematics ability across different grades. Longitudinal studies would produce valuable information regarding the predictive role of cognitive factors in the development of mathematics disability in early and advanced stages of learning. Early interventions to modify the trajectory of learning will be effective if sound knowledge of predictors at young age is available and informs development of remedial approaches and tools.

The findings of the current study will help create an improved setting for the basis of future studies on cognitive aspects of mathematics disability in ADHD, and their relation to reading difficulties. Despite the limitations with secondary data analysis and cross-
sectional types of studies, the findings of this thesis would be of help in designing future primary longitudinal studies on the subject.

In conclusion, there is a need for richer understanding of the difficulties children with ADHD experience in mathematics learning. In particular, the knowledge of cognitive deficits that predispose these children to mathematics disability needs to be expanded. This thesis presented findings that add to our understanding of the relation between mathematics disability and ADHD and describe some possible cognitive constructs in this comorbidity. Future studies are needed to advance these findings in a way that would be applicable to development of remediating tools and methods. Early interventions would modify the learning trajectory of these children and decrease burdens with academic underachievement.
**Abbreviations**

ADHD: Attention Deficit and Hyperactivity Disorder

ANOVA: Analysis of Variance

CD: Conduct Disorder

LA: Low-Achievement

LD: Learning Disability

MLA: Mathematics Low-Achievement

MLR: Multi-Linear Regression

ODD: Oppositional Defiant Disorder

PICS: Parent Interview for Child Symptoms

RAN: Rapid Automatized Naming

RLA: Reading Low-Achievement

SLD: Specific Learning Disorder

SSRT: Stop Signal Reaction Time

SST: Stop Signal Task

TTI: Teacher Telephone Interview

WISC: Wechsler Intelligence Scale for Children

WJ-III-ACH: Woodcock-Johnson III Test of Achievement

WJ-III-COG: Woodcock-Johnson III Test of Cognitive Abilities
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