WORKING MEMORY AND ACADEMIC ACHIEVEMENT IN CHILDREN WITH ATTENTION-DEFICIT HYPERACTIVITY DISORDER

by

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Abstract

This study used pre-existing data to examine whether children with ADHD, with and without working memory (WM) deficits, differ in their academic achievement and clinical profiles. 73 children (26% female), aged 6-12 years, with a confirmed diagnosis of ADHD had completed standardized achievement tests of reading, mathematics, and written language. Six WM measures and three parent and teacher questionnaires probing behaviour and executive functioning were administered. Of the sample, only 26% met the criteria for a WM deficit. Children with WM impairments were found to perform significantly worse than those without WM impairment on all achievement clusters, with no clinical profile differences. Poor WM is not universal in ADHD, but its presence is associated with lower academic achievement scores. Clinicians and educators should consider that underlying impairments in WM may be the contributing factors to academic difficulties in children with ADHD. Interventions targeting WM skills need to be implemented.
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List of Abbreviations

ADHD = Attention-Deficit/ Hyperactivity Disorder
DSM = Diagnostic and Statistical Manual of Mental Disorders
EF = Executive Function
WM = Working Memory
  ADHD = ADHD without Working Memory Deficits
  ADHD + WMD = ADHD plus Working Memory Deficits
W-J III Achievement = Woodcock-Johnson III Tests of Achievement
CELF-4 = Clinical Evaluation of Language Fundamentals – Fourth Edition
WRAML = Wide Range Assessment of Memory and Learning
WISC-IV = Wechsler Intelligence Scale for Children – Fourth Edition
SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behaviours Rating Scale
  IN = Inattention
  H/I = Hyperactive/Impulsivity
BRIEF = Behaviour Rating Inventory of Executive Function
BRI = Behavioral Regulation Index
  MI = Metacognition Index
SDQ = Strengths and Difficulties Questionnaire
ES = Emotional Symptoms
CP = Conduct Problems
HY = Hyperactivity-Inattention
PP = Peer Problems
PB = Prosocial Behaviour
ANOVA = Analysis of Variance
SS = Standard Score
CHAPTER I

Overview, Literature Review, and Rationale of Thesis Research
1.1 Overview

The link between Attention-Deficit/ Hyperactivity Disorder (ADHD), and academic underachievement is well-documented (Frazier, Youngstrom, Glutting, & Watkins, 2007), but contributing factors are unclear. The goal of this dissertation was to determine whether working memory (WM) impairment might be a contributing factor. To do so, I used an existing clinical database and classified children with confirmed diagnosis of ADHD as having good or poor working memory. I then compared these two groups in terms of their academic abilities using standardized tests of academic achievement. Also, I examined their clinical profile to determine whether any differences in academic achievement might be attributable at least in part to differences in their clinical profile (e.g., severity of disorder or comorbidity).

The core of this thesis is a manuscript reporting the results of this databased study which is to be submitted for publication: this manuscript constitutes Chapter II. Chapter I provides more detailed theoretical background and rationale for the study, as well as other more detailed description of the study design and measures. Chapter III presents a more comprehensive discussion of the study findings including the implications for the fields of education, clinical psychology, and medicine (pediatrics and psychiatry in particular), as well as the theoretical implications. Also chapter III considers useful interventions for children with ADHD plus working memory deficits, who are struggling academically. Therefore there will be some redundancy and overlap in terms of information presented in chapters I and II, as well as in chapters II and III.
1.2 ADHD: Clinical Perspective

1.2.1 Definition and Prevalence

Attention-Deficit/ Hyperactivity Disorder (ADHD) is one of the most common childhood onset neuropsychiatric disorders, with prevalence rates ranging from approximately 4-10% of the population globally (Skounti, Philalithis, & Galanakis, 2007; Polanczyk and Jensen, 2008). According to the Diagnostic and Statistical Manual of Mental Disorders- Fourth Edition, Text Revised (DSM-IV-TR; American Psychiatric Association, 2000), in order to be diagnosed with ADHD, children must have either six or more symptoms of inattention or hyperactivity-impulsivity, with persistence for a minimum of six months to a degree that is inconsistent with developmental level. These symptoms must also present themselves before 7 years of age; occur in two or more settings (such as home and school); and must be associated with impairment in academic and/or social functioning. Children can be diagnosed as predominantly inattentive, predominantly hyperactive-impulsive, or a combination of the two types. Although ADHD has been categorized according to these three subtypes, Rowland et al. (2008) found that ADHD subtype distribution is sensitive to how the information regarding symptoms is combined, as procedures used to collect the data from parents and teachers influence the subtype distribution. Hence, it is more important to refer to the symptoms of ADHD versus classification types. For the purpose of this study, inattention and hyperactive-impulsive symptoms will be examined.

Worldwide, boys are more likely to be rated as having ADHD than girls, with male to female ratios ranging from 2:1 to 9:1 depending on the subtype and population (clinic verse epidemiological) (American Psychiatric Association, 2004; Gomez, Harvey,
Impaired neurocognitive functioning has been found in both boys and girls with ADHD (Rucklidge, 2006), with no evidence supporting cognitive or neuropsychological gender differences (Arcia & Conners, 1998). Impairments in academic, behavioural, social and emotional areas of functioning have been found in both genders, with few gender differences (DuPaul et al., 2006). Boys and girls with ADHD are often rated as behaving similarly at home, but not at school, with teachers reporting greater behavior problems for boys (Derks, Hudziak, & Boomsma, 2007). Girls are more likely to be diagnosed as the predominantly inattentive subtype, with more emotional problems, whereas boys tend to be diagnosed as predominantly hyperactive, with greater externalizing problems (Biederman et al., 2002; Holling, Kurth, Rothenberger, Becker, & Schlack, 2008; Radonovich, 2002). Girls are less likely to be referred for ADHD; however, when diagnosed with the disorder, girls tend to have as severe, or even greater impairments, than for ADHD boys when compared to non ADHD gender matched children (DuPaul et al., 2006).

1.2.2 Academic Achievement

A recent meta-analysis on the academic outcomes of children, adolescents, college students, and adults with clinical diagnoses of ADHD indicates that ADHD is associated with significantly lower overall levels of achievement relative to controls (Frazier et al., 2007). These impairments have been found across reading, writing and mathematical domains (Currie & Stabile, 2006; Hinshaw, 1992; Re, Pedron, & Corneldi, 2007; Resta & Eliot, 1994; Rodriguez et al., 2007), even in the absence of comorbid learning disabilities, other types of psychopathology, level of parental education, and
lower family income (Lahey et al., 1998; Pastura, Mattos, & Araajo, 2009). Children with ADHD are more likely to be placed in special education classes, repeat grades and receive academic tutoring compared to non-ADHD children (Faraone et al., 1993), with the probability of grade repetition increasing by up to 6% for children with severe symptoms (Currie & Stabile, 2006). Specifically, children who are diagnosed with the inattentive ADHD subtype tend to perform more poorly on academic measures, such as reading, math and spelling scores over time, when compared to other ADHD subtypes and controls (Massetti et al., 2008).

When examining symptoms, children from community samples with symptoms of inattention, hyperactivity and impulsiveness, with or without formal diagnoses of ADHD, display poorer academic results (Loe & Feldman, 2007). Inattentive symptoms in non ADHD and ADHD clinic-referred samples have also been shown to have adverse effects on academic achievement (Barriga et al., 2002; Terrell, 2008).

1.3 ADHD: Theoretical Perspective

Several varying models have been forwarded in an attempt to account for ADHD. These include: Delay Aversion, Behavioral Inhibition/ Activation, Inhibition, Cognitive-Energetic and neurobiological based theories (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003). However, there is a lack of consensus as to which, if any of these models provides a comprehensive account of ADHD. There is a large body of literature linking the Executive Function (EF) theory to ADHD. A meta-analysis was conducted on 83 studies that administered EF measures to both ADHD and non-ADHD groups. Groups with ADHD exhibited
significant weaknesses in EF (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). As many underlying EF constructs affect academic functioning, the EF model will serve as the foundation of this thesis.

1.3.1 Executive Function Theory

One current theory posits that poor EF is seen as the underlying deficit in ADHD (Barkley, 1997; Pennington & Ozonoff, 1996). EFs refer to a multidimensional, cognitive, self-directed construct that includes: “(a) self-directed actions; (b) the organization of behavioral contingencies across time; (c) the use of self-directed speech, rules, or plans; (d) deferred gratification; and (e) goal-directed, future oriented, purposive or intentional actions” (Barkley, 1997, p.68). This umbrella term comprises planning, attention, reasoning, inhibition, interference control, set-shifting and working memory (Pennington & Ozonoff, 1996), all of which are important factors in academic and everyday functioning.

ADHD has been linked to deficits in EF (Doyle, 2006; Oosterlaan, Scheres, & Sergeant, 2005; Willcutt et al., 2005). Children with ADHD and concurrent EF impairments have been found to exhibit poorer academic outcomes than those with ADHD and good EF (Biederman, Monuteaux et al., 2004). Evidence suggests that it is the working memory (WM) component of EF in particular that is a strong predictor of both current and future academic outcomes (Gathercole, Pickering, Ambridge, & Wearing, 2004). Hence, only the working memory (WM) component of EFs be will explored to see if underlying WM impairments may be the contributing factor to academic difficulties in children with ADHD.
1.3.2 Working Memory

WM is a limited capacity system that is used for the temporary storage and manipulation of information over a very short period of time (Baddeley & Hitch, 1974). Several theoretical WM models exist (see Miyake and Shah [1999] for a review). However, this paper will focus on Baddeley’s (1986) highly influential model, which delineates types of processing (storage versus manipulation of information) and modality of information (auditory-verbal versus visual-spatial). According to this model, the central executive, or command controller of all WM functions such as planning and monitoring information, is connected to two auxiliary slave systems: the phonological loop, responsible for the storage of auditory memory (such as speech), and the visuo-spatial sketchpad, accountable for visual and spatial information. An episodic buffer links with the central executive providing a transitory pathway between these two subsidiary systems and long term memory (Baddeley, 2000).

The phonological loop has been linked to vocabulary acquisition, reading comprehension, written arithmetical skills, and mathematical word problem solving (Andersson 2007 and 2008; Baddeley, Gathercole, & Papagno, 1998; Holsgrove & Garton, 2006;), while the visual-spatial sketchpad has been linked to the organizational phase of writing, literacy and arithmetic (Gabraith, Ford, Walker, & Ford, 2005; Gathercole & Pickering, 2000). Hence, these components of WM, along with the ability to hold and manipulate information such as instructions, are crucial for the expansion of knowledge, making WM act as the ‘bottleneck’ for learning (Gathercole, 2004). WM deficits have been linked with ADHD both theoretically (Barkley, 1997; Castellanos & Tannock, 2002) and empirically (Martinussen et al., 2005; Willcutt et al., 2005). This
pattern of findings suggests that WM may play an important role in academic abilities, in addition to the general concerns of the impact of ADHD on scholastic potential.

1.3.3 Working Memory and its Association with Inattention

Researchers have linked low WM scores in non-ADHD school samples with atypically high inattentive symptoms and cognitive problems (Gathercole et al., 2008). Similar results linking poorer WM performance and inattention have been found in a community sample of children (Lui & Tannock, 2007). In ADHD populations, WM difficulties have been linked to clinical symptoms of inattention, rather than hyperactive/impulsivity symptoms (Klingberg et al., 2005; Martinussen & Tannock, 2006). Problems in WM and inattention may coincide as children with deficits in WM may not be able to withstand the processing and storage demands needed for learning, which may, in turn cause the child to forget and lose focus in what they are supposed to be attending too (Gathercole et al., 2008; Gathercole & Alloway, 2008; Gathercole, Alloway, Willis, & Adams, 2006). Hence, if a child with ADHD has difficulty in key learning elements, such as WM and attention, their academic attainment may suffer as a result.

1.4 Issues of Consideration for Study Design and Rationale

1.4.1 Rationale

It is well documented that ADHD is linked with academic underachievement (Frazier et al., 2007). Research has linked EF deficits to children with ADHD (Doyle 2006), particularly the WM component (Castellanos & Tannock, 2002; Martinussen et al., 2005). WM deficiencies have been linked to poorer academic outcome in both
clinical and non-clinical samples (Lui & Tannock, 2007; Martinussen & Tannock, 2006). Accordingly, this study will investigate whether WM plays a crucial role as a primary contributor to academic difficulties in children with ADHD. Furthermore, associations between the inattentive symptoms of ADHD and WM deficits have been found (Martinussen & Tannock, 2006). Hence, an examination of clinical profile on both good and poor working memory groups will be conducted in order to determine significant group differences on behavioural functioning. Children with ADHD are already at risk for underachievement in school. If these children have WM difficulties, in additional to ADHD specific symptoms, this puts them at higher jeopardy for academic problems.

1.4.2. Study Design and Measures

This study used data from an existing clinical database pertaining to the topic of investigation, such as psychological, academic achievement, and working memory tests, as well as parent and teacher questionnaires. Specifically, academic achievement and WM scores were analyzed in order to determine whether there were differences in academic achievement scores between WM Groups (ADHD, ADHD + WMD). I also wanted to examine the clinical profile of children with and without WM deficits to determine whether any differences in academic achievement might be attributable, at least in part, to differences in their clinical profile. The questionnaires probing behaviour and executive functioning made this possible. No control group was necessary as standardized scores were used in the analysis of data. This study examined scores of reading, mathematics and written language, as well as six varying WM measures. These measures are described below:
Academic Achievement

The Woodcock-Johnson III Tests of Achievement (WJ-III; Woodcock, McGrew, & Mather, 2001) has been widely used as an individually administered, norm-referenced test (Mather & Woodcock, 2001). As there are two forms of the test, consisting of a Standard and Extended Battery, along with the options of age or grade based norms, the WJ-III provides a range of assessment opportunities for examiners. Test-retest reliabilities range from .76 to .94 for 7 to 11 year olds. Bradley-Johnson, Morgan, and Nutkins (2004) noted that the WJ-III achievement clusters were compared to the Kaufman Test of Educational Achievement (KTEA; Kaufman & Kaufman 1985) and the Wechsler Individual Achievement Test (WIAT; Wechsler, 1992). Correlations for the three subtests and composites ranged from .44 to .82 for reading, .29 to .70 for math, and .31 to .77 for written language.

Hence, as a result of its overall strong psychometric properties, the WJ-III is the most widely used and accepted achievement test used by school boards. This standardized measure was used to examine academic achievement in the current study. Specifically, academic achievement was measured by standard scores on the Broad Reading, Broad Math and Broad Written Language Cluster subtests. Age norms were used to interpret results.

Broad Reading is a composite score that provides an overall measure of reading achievement including decoding, speed and comprehension. It consists of three subtests: In Letter-Word Identification, participants are presented with written words and are asked to read these words fluently and correctly in order to score one point. Basal is reached
when the six lowest administered items are correct (or item 1), and ceiling is reached when the six highest administrated numbers are incorrect (or the last item is reached). In Reading Fluency, the examiner reads a statement and then circles Y (yes) or N (no) according to whether the sentence is true. Sample items are first completed with the participant. Upon understanding of the task, participants are given three minutes to answer as many items as possible, with a score of one point for each correct answer. A maximum of 98 statements are given. Passage Comprehension involves reading a passage silently with the participant identifying a specific word that goes into the presented blank line. Starting points depend on grade and ability level. Basal is reached when the six lowest administered items are correct (or item 1), and ceiling is reached when the six highest administrated numbers are incorrect (or the last item is reached), with a correct answer earning one point. This cluster has a median reliability of .93 in the 5 to 19 range (Mather & Woodcock, 2001).

Broad Math is a composite score based on computational skills, automaticity, reasoning, and problem solving. This cluster includes three subtests: In Calculation, participants answer math questions in their booklets. Basal is reached when the six lowest administered items are correct (or item 1), and ceiling is reached when the six highest administrated numbers are incorrect (or the last item is reached), with a correct answer earning one point. Math Fluency is a timed three minute subtest. Participants are presented with single digit addition, subtraction, and multiplication questions, and receive a score of one for each correct response. In Applied Problems, the examiner presents the participant with a written or pictorial word problem and the examiner reads aloud the corresponding math word problem. Starting point depends on math ability level, and
previously described basal and ceiling rules apply. This cluster has a median reliability of .95 for ages 5 through 19 (Mather & Woodcock, 2001).

The *Broad Written Language* Composite measures the spelling of single words, fluency of writing and quality of expression. Three subtests comprise this composite: In *Spelling* the starting point is selected based on ability level. Children are orally presented with single words and write them down in a response booklet. When the six lowest administered items are correct (or item 1), basal is met, and ceiling is met when the six highest administered items are correct (or item 59). A score of one point is given for each correct response. *Writing Fluency* requires participants to write sentences using three provided words. After sample items are administered, participants are given seven minutes to complete as much of the protocol as possible. A score of one or zero is awarded depending on whether a reasonable sentence was produced using the specified words. No penalization is given for spelling, punctuation and/ or capitalization errors. In *Writing Samples*, participants are administered a block of items, depending on their writing ability level. Instructions are given for each item number and written answers must correspond to the matching pictures. Scoring ranges from 0 through 2 points depending on the type of response received. Although guidelines are provided for scoring, this subtest requires subject judgment on the examiner’s behalf. This cluster has a median reliability of .88 in the 5 to 19 year old range (Mather & Woodcock, 2001).

*Working Memory*

Standardized clinical measures, rather than precise cognitive methods, were used to assess WM as these measures are used in clinical assessments and are readily
interpretable. WM span tasks were selected as they have been found to be both valid and reliable measures of WM capacity (Conway et al., 2005). Six standardized clinical measures of WM, assessing two modalities of information (auditory-verbal and visual-spatial) and different processing demands (storage and manipulation of information), were included in this study. Using four auditory-verbal WM and two visual-spatial WM measures, the likelihood of poor task performance due to chance was reduced. Tasks requiring forward recall are thought to assess storage of information; those that require ‘backwards’ recall (i.e., recall items in reverse order of presentation) are thought to index the ability to manipulate information, since both storage and reordering of information is required.

Auditory-Verbal WM Measures

Participants were administered the *Wechsler Intelligence Scale for Children-Fourth Edition* (WISC-IV; Wechsler, 2003), as a measure of general intellectual functioning. Hence, the WISC-IV encompasses two auditory-verbal WM subtests: *Digit Span* and *Letter Number Sequencing*.

*Digit Span* is comprised of two parts. In the forward condition, participants repeat numbers back to the examiner after they are presented verbally. In the backward condition, participants repeat the numbers back in the reverse order. In both cases, the examiner presents the digits at a rate of one digit per second. Both forward and backward versions are comprised of two trials with the same span length. There are a total of eight trials, with span lengths ranging from two through nine digits for the forward condition and two through eight digits for the backward condition. A score of one point is awarded
for each correct answer. In both conditions, the subtest ends when the participant makes two errors in the same trial. Forward and backward scores are combined to produce an overall score. This score is then converted to an age adjusted scaled score, with a mean of 10 (SD = 3). Internal consistency for this subtest is .86.

*Letter-Number Sequencing* requires participants to listen to a sequence of numbers and letters presented by the examiner at a rate of one digit per second. Participants must repeat the string of letters and numbers back to the examiner with the numbers going in ascending order followed by the letters in alphabetical order. There are three trials per item with the same span lengths. Over ten trials, span lengths increase from two to eight digits. One point is awarded for each correct answer. The task ends when scores of zero have occurred on all three trials of a particular item. The raw score is then converted to an age adjusted scaled score, with a mean of 10 (SD = 3). Internal consistency for this subtest is .87.

*Recalling Sentences* from the *Clinical Evaluation of Language Fundamentals - Fourth Edition* (CELF-4; Semel, Wiig, & Secord, 2003) presents participants with two trial sentences where they have to repeat the sentences back to the examiner without making any mistakes. The sentences increase in complexity as the task goes on. The examiner writes down each participant’s response verbatim and sentences are marked in correspondence with the number of errors in each response. A minimum of five sentences are completed for each participant, with a maximum of thirty two. The raw score is then converted to an age adjusted scaled score, with a mean of 10 (SD = 3). Internal consistency for this subtest is .91.
Letter Span from the Wechsler Intelligence Scale for Children - Third Edition as a Process Instrument (WISC-III PI; Kaplan, Fein, Kramer, Delis, & Morris, 1999) is a variation of the WISC-III (and WISC-IV) Digit Span subtest. In Letter Span, the examiner reads aloud random sequences of letters at the rate of one per second. Participants have to repeat the letters back to the examiner in the same sequence. Each item consists of two trials of consonants. The trials have the same amount of letters, but there are no repetitions. The first trial is made up of nonrhyming letters, while the second trial consists of rhyming letters. Participants earn one point for each correct trial, and the task ceases when participants are not able to correctly recall both nonrhyming and rhyming trials. The score is then converted to an age adjusted scaled score, with a mean of 10 (SD = 3). Average internal consistency for this subtest is .73.

Visual-Spatial WM Measures

Finger Windows from the Wide Range Assessment of Memory and Learning (WRAML; Adams & Sheslow, 1990) requires participants to memorize visual patterns through a vertically resting card containing nine randomly located holes. The examiner uses a pencil to point to increasingly longer sequences through the holes at a rate of one per second. Sequences start with a string of two holes and increase to nine. Participants have to replicate the exact order, receiving one point if they are correct. The task ceases when three consecutive errors occur. The raw score is then converted to an age adjusted scaled score, with a mean of 10 (SD = 3). Internal consistency is .81.

Spatial Span, another subtest from the WISC-III PI, which visually corresponds to the WISC-III (and WISC-IV) Digit Span subtest is comprised of both forward and backward...
conditions, giving an overall score. In both conditions, the examiner taps a set of ten cubes, labeled one through ten on the examiner’s side, in a particular sequence at a rate of one cube per second. Sequences range from two to eight cubes. Each item has two trials. In the forward condition, the participant must replicate the sequence in exact order. In the backward condition, the order of the sequence must be reversed. Both subtests end when a participant taps the cubes incorrectly on both trials of a particular item. The raw score is then converted to an age adjusted scaled score, with a mean of 10 (SD = 3). Internal consistency for the overall subtest is .78.

Clinical Profiling

Three different clinical profiling measures were given to both parents and teachers. To assess Inattention (IN) and Hyperactivity/Impulsive (H/I) symptoms, the Strengths and Weaknesses of ADHD symptoms and Normal Behavior (SWAN; available through http://www.adhd.net) was administered. This scale directly relates to the IN and H/I symptoms of ADHD based on the DSM-IV, along a continuum (Swanson et al., 2006). The SWAN differs from most behavior rating scales used for assessing developmental psychopathology in that the symptoms of ADHD are reworded using a strength-based rather than a weakness-based formulation as in the DSM-IV. For example, the DSM-IV symptom, “Often avoids, dislikes, or reluctantly engages in tasks requiring sustained mental effort” is reworded as, “Engage in tasks that require sustained mental effort.” Parents and teachers rate participants on nine questions for IN and nine questions for H/I. Each item is rated on a 7-point Likert Scale (Far Below Average =3, Below Average =2, Slightly Below Average =1, Average = 0, Slightly Above Average =
-1, Above Average = -2, and Far Above Average = -3). Thus, the mean of the nine IN scores and nine H/I scores were computed separately for parents and teachers. The higher (more positive) the score, the more severe problems in that domain (IN or H/I). This scale has good psychometric properties (Castelo-Branco et al., 2007; Lui & Tannock, 2007) and yields normally distributed scores (Hay, Bennett, Levy, Sergeant, & Swanson, 2007; Polderman et al., 2007; Young, Martin, & Hay, 2009).

The Behavior Rating Inventory of Executive Function (BRIEF) was selected as a clinical profile measure as it purports to measure EF behaviours in both home and school environments, as oppose to tightly controlled laboratory environments (Gioia, Isquith, Guy, & Kenworthy, 1996). This eighty-six item questionnaire also measures a broad array of eight EF, not just WM. Inhibit, Shift and Emotional Control make up the Behavioral Regulation Index (BRI) and Initiate, Working Memory, Plan/ Organization of Materials, and Monitor comprise the Metacognition Index (MI). Parents and teachers rate each item under three categories (Never = N, Sometimes = S, Often = O). T scores are provided for each category relative to scores of age matched children in the standardization sample. Parent and Teacher BRIEF internal consistency is high, ranging from .90 to .98.

The Strengths and Difficulties Questionnaire (SDQ) was selected as the final clinical measure, as this short behavioural screening measure targets a combination of 25 positive and negative attributes for children between the ages of 4 to 17 (Goodman, 1997). Parents and teachers rate each participant on a 3-point Likert Scale (Not True = 0, Somewhat True = 1, and Definitely True =2). The total items are then equally subdivided into five subscales measuring the following attributes: Emotional Symptoms (ES),
Conduct Problems (CP), Hyperactivity-Inattention (HY), Peer Problems (PP), and Prosocial Behaviour (PB). Scores in each attribute range from having no problems in a given area (0) to clinical levels of functioning (10). The SDQ’s five subscales have been associated with psychiatric disorders, and it is considered a valid and reliable instrument (Goodman, 2001; Roy, Veenstra, & Clench-Aas, 2008), although there could be improvement to conceptual clarity and internal reliability (Roy et al.).

Statistical Analyses

Data analysis was performed using SPSS version 16.0 for Windows: all tests were two-tailed. The choice of data analytic strategies for this study needed to account for missing data in the most powerful manner. To explore the effects of WM Group (ADHD, ADHD+ WMD; see Section 1.4.3 for classification of WMD) on reading and mathematical achievement, reading and math scores were analyzed together using repeated measures analysis of variance (ANOVA). A separate ANOVA was conducted for writing scores because substantially fewer children (n = 21) completed both reading and math components.

Neither the proportion of females in the sample nor their distribution between the ADHD and ADHD+WMD groups was adequate to support a full factorial design involving gender (ADHD: 40 boys, 14 girls; ADHD+WMD: 14 boys, 5 girls). Thus, analyses could only test for differences between males and females with ADHD. ANOVAs were conducted separately for reading, math and written language scores, with Gender as the sole between-subjects factor.
To test for group differences in the clinical profile, repeated measures ANOVAs and one-way ANOVAs were conducted separately for parent and teacher ratings on SWAN, SDQ and BRIEF scores. Repeated measures ANOVAs were conducted for instruments with multiple subscales and individual ANOVAs were conducted for instruments with one scale. Intercorrelational results between parent and teacher clinical ratings indicated generally weak relationships. Hence, repeated measures ANOVAs were conducted separately for parent and teacher ratings on SWAN IN and H/I measures, SDQ subscale measures (ES, CP, HY, PP and PB), and for BRIEF BRI and MI Indexes. ANOVAs were conducted for both parent and teacher BRIEF WM measures. Also, gender differences in the clinical profile of children with ADHD (collapsed across the WM groups) were tested using a series of ANOVAS for both parent and teacher ratings of behaviour on the SWAN, SDQ and BRIEF measures.

1.4.3 Classification of Working Memory

There is no consistent definition for the classification of an EF deficit (EFD). Biederman, Monuteaux et al. (2004) defined an EFD as having impairments on two or more measures, scoring 1.5 standard deviations below the mean for normally distributed data, and used a 7th percentile cut-off for non-normally distributed data. In their study 30% of children with ADHD were subtyped as having an EFD. Nigg, Willcutt, Doyle and Sonugg-Barke (2005) defined an EFD according to the percentage of children who fell below the lowest 10th percentile of scores in a non-clinical sample, reporting 50% of children with ADHD to have EFDs. Loo et al. (2007) performed a principal component analysis, weighing individual standardized test scores according to the degree in which
the test measured the core EFD factor. The scores were individually calculated, and the lowest 10\textsuperscript{th} percentile of scores were used to define EFD. Their study resulted in 52\% of children with ADHD having EFDs. Lambek et al. (2009) analyzed data using these three approaches, adding their own version of an age adjusted score. In their study 51-83\% of the ADHD child sample had EFDs, while 10-49\% of the non-clinical children showed EFDs. Results from this study indicate that the number of children classified as having an EFD will differ depending on how the EFD is defined and measured.

In the absence of any consensus definition of what constitutes an EF deficit, I made the decision to define poor WM as a standard score of 7 or less (i.e., 16\textsuperscript{th} percentile or lower, which is -1 standard deviation below the mean), on at least on three of the six WM measures. A scaled score ranging from 8 to 12 [25\textsuperscript{th} to 75\textsuperscript{th} percentile] is considered to be within the Average range of functioning. Thus children with scaled scores of $\leq 7$ on three or more of the WM measures were classified as ADHD+WMD. Thus, the rationale for this cut-off was three-fold: 1) although our cut-off is broader than previous studies on EFDs (e.g., Biederman et al., 2004; Loo et al., 2007; Nigg et al., 2005), it seemed appropriate given our use of scale scores and that we were categorizing only WM and not several measures of EF; 2), we considered it inappropriate to place individuals with two tests in the below average range, in the adequate WM group (Biederman et al., 2004); and 3) whereas one low score may be due to chance, three or more scores at the 16\textsuperscript{th} percentile or less would likely to be interpreted as an area of vulnerability or difficulty by a clinician.
1.4.4 Objectives and Hypotheses

The primary objective of the present study was to determine whether children with ADHD, with and without WM deficits, differ in their academic achievement. A secondary objective was to determine whether the co-occurrence of WM impairments and ADHD alters the clinical profile of ADHD.

It was predicted that children (both boys and girls) with ADHD and poor WM would exhibit significantly lower academic achievement (as measured by standardized tests) than those with good WM. It was also predicted that children with ADHD plus WM deficits would manifest more severe problems with inattention (as indexed by clinical interviews and rating scales).
CHAPTER II

Working Memory and Academic Achievement in Children with ADHD
1.1 Abstract

Objective: To determine whether children with Attention-Deficit/ Hyperactivity Disorder (ADHD), with and without working memory (WM) deficits, differ in their academic achievement and clinical profiles. Methods: Participants were a clinical sample of 73 children (26% female) with confirmed DSM-IV diagnosis of ADHD, aged 6 through 12 years of age. Children completed six standardized measures of WM and standardized achievement tests of reading, mathematics, and written language. Parents and teachers completed three questionnaires that probed the children’s ADHD symptoms, overall behavioural and emotional functioning, as well as executive functioning in everyday life. Results: Only 26% of this clinical sample of children with ADHD met criteria for WM impairment. Those with poor WM performed significantly worse than those with good WM on all achievement clusters, but did not differ in terms of their clinical profiles. Conclusions: Poor WM is not universal in ADHD, but its presence is associated with lower academic achievement scores. Clinicians and educators are advised to consider that children with ADHD who are struggling academically may have underlying impairments in WM. Therefore intervention plans need to include academic skills and working memory as targets, not just the symptoms of ADHD.

Key Words: ADHD, working memory, academic achievement
2.2 Introduction

Attention-Deficit/ Hyperactivity Disorder (ADHD) is one of the most common childhood onset neuropsychiatric disorders characterized by developmentally inappropriate levels of inattention and/or hyperactivity-impulsivity (American Psychiatric Association, 2000). Prevalence rates range from approximately 4% to 10% of the population worldwide (Skounti, Philalithis, & Galanakis, 2007; Polanczyk & Jensen, 2008). Recent meta-analysis of the academic outcomes of children, adolescents, college students, and adults with a clinical diagnosis of ADHD indicates that ADHD is associated with significantly lower overall levels of achievement relative to controls (Frazier, Youngstrom, Glutting, & Watkins, 2007). These impairments have been found across reading, writing and mathematical domains (Re, Pedron, & Corneldi, 2007; Rodriguez et al., 2007). However, as some individuals with ADHD do not manifest any academic impairments, this has motivated researchers to identify factors that contribute to academic problems.

One current theory posits that poor EF is the underlying deficit in ADHD (Barkley, 1997; Pennington & Ozonoff, 1996). EFs refer to a multidimensional, cognitive, self-direct construct that comprises planning, attention, reasoning, inhibition, interference control, set-shifting and working memory (Pennington & Ozonoff, 1996), all of which are important factors in academic functioning. Children with ADHD and concurrent EF impairments have been found to exhibit poorer academic outcomes than those with ADHD who had good EFs (Biederman, Monuteaux et al., 2004). Evidence suggests that it is the working memory (WM) component in particular that is a strong
predictor of both current and future academic outcomes (Gathercole, Pickering, Ambridge, & Wearing, 2004).

WM is a limited capacity system that is used for the temporary storage and manipulation of information over a very short period of time (Baddeley & Hitch, 1974). Several theoretical WM models exist [see Miyake and Shah (1999) for a review]. However, this paper will focus on Baddeley’s (1986) highly influential model, which delineates types of processing (storage versus manipulation of information) and modality of information (auditory-verbal versus visual-spatial). According to this model, the central executive, or command controller of all WM functions such as planning and monitoring information, is connected to two auxiliary slave systems: the phonological loop, responsible for the storage of auditory memory (such as speech), and the visuo-spatial sketchpad, accountable for visual and spatial information. An episodic buffer links with the central executive providing a transitory pathway between these two subsidiary systems and long term memory (Baddeley, 2000).

The phonological loop has been linked to vocabulary acquisition, reading comprehension, written arithmetical skills, and mathematical word problem solving (Andersson 2007 and 2008; Baddeley, Gathercole, & Papagno, 1998; Holsgrove & Garton, 2006), while the visual-spatial sketchpad has been linked to the organizational phase of writing, literacy and arithmetic (Galbraith, Ford, Walker, & Ford, 2005; Gathercole & Pickering, 2000). Hence, these components of WM, along with the ability to hold and manipulate information such as instructions, are crucial for the expansion of knowledge, making WM act as the ‘bottleneck’ for learning (Gathercole, 2004). WM deficits have been linked with ADHD both theoretically (Barkley, 1997; Castellanos &
Tannock, 2002) and empirically (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). This pattern of findings suggests that WM may play an important role in academic abilities, in addition to the general concerns of the impact of ADHD on scholastic ability.

Researchers have linked low WM scores in non-ADHD school samples with atypically high inattentive symptoms and cognitive problems (Gathercole et al., 2008). Similar results linking poorer WM performance and inattention have been found in a community sample of children (Lui & Tannock, 2007). In ADHD populations, WM difficulties have been linked to clinical symptoms of inattention, rather than hyperactive/impulsivity symptoms (Klingberg et al., 2005; Martinussen & Tannock, 2006). Problems in WM and inattention may coincide as children with deficits in WM may not be able to withstand the processing and storage demands needed for classroom learning, which may, in turn cause the child to forget and lose focus in what they are supposed to be attending too (Gathercole et al., 2006; 2008; Gathercole & Alloway, 2008). Hence, if a child with ADHD has difficulty in key learning elements, such as WM and attention, their academic attainment may suffer as a result.

The primary objective of the present study was to determine whether children with ADHD, with and without WM deficits, differ in their academic achievement. A secondary objective was to determine whether the co-occurrence of WM impairments and ADHD alters the clinical profile of ADHD.

We predicted that children (both boys and girls) with ADHD and poor WM would exhibit significantly lower academic achievement (as measured by standardized tests) than those with good WM. We also predicted that children with ADHD plus WM
deficits would manifest more severe problems with inattention (as indexed by clinical interviews and rating scales).

2.3 Method

Participants

Participants were 73 children (54 boys, 19 girls), aged 6.5 to 12 years ($M = 9.09, SD = 1.67$), all with a confirmed *DSM-IV* (American Psychiatric Association, 2000) diagnosis of ADHD. These participants were selected from a larger sample of children ($N = 115$) who had been referred to an outpatient, metropolitan, pediatric hospital by primary care clinicians for assessment of attention, behavior, and learning problems. Eligible participants completed the same systematic diagnostic assessment protocol (described below), had English as their native language, a Full Scale IQ score of at least 80, good physical health, and no evidence of neurological dysfunction, uncorrected sensory impairments and/or a history of psychosis. Participation in the research study was voluntary and all parents and children gave written informed consent. The study was approved by the Institutional Research Ethics Board.

Clinical Diagnostic Assessment

All participants completed the same comprehensive clinical diagnostic assessment, based on *DSM-IV* criteria to evaluate ADHD and comorbid conditions. All met DSM-IV criteria for a clinical research diagnosis of ADHD, using a ‘6/4’ algorithm, which was based on symptom ratings from two validated, semi-structured, clinical diagnostic interviews with parents (Parent Interview for Child Symptoms [PICS]; Ickowicz et al., 2006) and homeroom teacher (Teacher Telephone Interview [TTI]);
Tannock et al., 2000), conducted independently by trained clinicians. The 6/4 rule ensures pervasiveness of symptoms and resulting impairment (Lee et al., 2008). Children were diagnosed with DSM-IV ADHD if all three of the following criteria were met: 1) Children’s score on PICS or TTI indicated the presence of at least 6 (out of 9) inattention symptoms or 6 (out of 9) hyperactivity-impulsivity symptoms, which had persisted for at least six months prior to assessment. 2) Significant impairment from ADHD symptoms was present in at least two settings defined as having at least 4 symptoms of inattention or at least 4 symptoms of hyperactivity/impulsivity both at home (as indexed on the PICS) and at school (as indexed on the TTI). 3) Age of onset of disorder was not later than about 7 years. Parents and teachers also completed three standardized rating scales which asked about the children’s behavior and psychological adjustment at home and at school, respectively (these scales are described below). Each child underwent psychoeducational testing that included the *Wechsler Intelligence Scale for Children-Fourth Edition* (WISC-IV; Wechsler, 2003) and the *Woodcock-Johnson III Tests of Achievement* (WJ-III; Woodcock, McGrew, & Mather, 2001).

Diagnoses (including comorbid conditions) were determined by the clinical team, led by a child and adolescent psychiatrist, based upon the team’s summary and formulation of information from the parent, teacher and informal interview of the child. Diagnosis of ADHD was confirmed in 83 (72%) of the 115 referrals, and thus were eligible to participate. However, not all of these participants completed the measures required for this component project (specifically, three academic achievement test clusters, six WM tests, parent and teacher questionnaires). Hence, the sample for this project consisted of 73 children who had completed at least one academic achievement
cluster along with at least three WM tasks, and whose parents and teachers had completed most of the questionnaires. Table 1 presents medication and comorbidity information for both good and poor WM groups. No significant differences between groups were found on these measures, although a trend emerged demonstrating a proportionally higher amount of Language Impairments in the ADHD+WMD group than in the ADHD only group. Notably, upon referral, only two children in this sample had comorbid Learning Disorders. As reported later (see Table 3), substantially more children with ADHD met a low-achievement definition of a Learning Disorder based upon formal psycho-educational assessment.

Measures

Academic Achievement

Academic Achievement was measured by standard scores on the Broad Reading, Broad Math and Broad Written Language Cluster scores of the WJ-III, which is a widely used individually administered, norm-referenced test. Broad Reading is a composite score that provides an overall measure of reading achievement including decoding, speed and comprehension. It consists of three subtests: Letter-Word Identification, Reading Fluency, and Passage Comprehension. Broad Math is a composite score based on computational skills, automaticity, reasoning and problem solving; subtests include Calculation, Math Fluency, and Applied Problems. The Broad Written Language Composite measures spelling of single words, fluency of writing and quality of expression. Three subtests comprise this composite: Spelling, Writing Fluency, and Writing Samples.
Working Memory Measures

Six standardized clinical measures of working memory, assessing two modalities of information (auditory-verbal and visual-spatial) and different processing demands (storage and manipulation of information), were included in this study. Tasks requiring forward recall are thought to assess storage of information; those that require ‘backwards’ recall (i.e., recall items in reverse order of presentation) are thought to index the ability to manipulate information, since both storage and reordering of information is required. Total raw scores for all six tasks were converted to age-adjusted scaled scores with a mean of 10 and a SD of 3 (U.S. norms). WM tests were administered in the same order to all children, which is shown in Table 1.

Auditory-Verbal WM Tasks: Four measures were used: the Digit Span and Letter-Number Sequencing subtests of the WISC-IV, Recalling Sentences from the Clinical Evaluation of Language Fundamentals - Fourth Edition (CELF-4; Semel, Wiig, & Secord, 2003) and Letter Span from the Wechsler Intelligence Scale for Children - Third Edition as a Process Instrument (WISC-III PI; Kaplan, Fein, Kramer, Delis, & Morris, 1999). Visual-Spatial WM Tasks: Finger Windows from the Wide Range Assessment of Memory and Learning (WRAML; Adams & Sheslow, 1990) and Spatial Span from the WISC III PI were administered.

Clinical Profiling

Parents and teachers completed three rating scales, which were used to examine the clinical profiles of children with and without WM deficits.

The Strengths and Weaknesses of ADHD Symptoms and Normal Behavior (SWAN; Swanson et al., 2006; available through http://www.adhd.net/) is an 18-item
questionnaire, based on DSM-IV-TR, that assesses the inattentive and hyperactivity/impulsive symptoms of ADHD along a continuum. The SWAN differs from most behavior rating scales used for assessing developmental psychopathology in that the symptoms of ADHD are reworded using a strength-based rather than a weakness-based formulation as in the DSM-IV. For instance, the DSM-IV symptom “Often avoids, dislikes, or reluctantly engages in tasks requiring sustained mental effort” is reworded as “Engage in tasks that require sustained mental effort” and “Often fidgets with hands or feet or squirms in seat” is rephrased as “Sit still (control movement of hands/feet or control squirming)”. The informant rates the child’s behavior for each of the 18 items using a seven point scale ranging from “far below average” (score of +3) to “far above average” (score of -3), relative to other children of the same age. Thus, high (positive) scores indicate more severe problems in that symptom domain (IN, H/I). This scale has good psychometric properties (Castelo-Branco et al., 2007; Lui & Tannock, 2007) and yields normally distributed scores (Hay, Bennett, Levy, Sergeant, & Swanson, 2007; Polderman et al., 2007; Young, Martin, & Hay, 2009).

The Behavior Rating Inventory of Executive Function (BRIEF) purports to measure executive function behaviours in both home and school environments (Gioia, Isquith, Guy, & Kenworthy, 1996). This eighty-six item questionnaire measures eight subdomains of executive functioning: Inhibit, Shift, and Emotional Control form the Behavioral Regulation Index (BRI) and Initiate, Working Memory, Plan/ Organization of Materials, and Monitor make up the Metacognition Index (MI). Parents and teachers rate each item under three categories (Never = N, Sometimes = S, and Often = O). T scores
are provided for each category relative to scores of age matched children in the standardization sample.

The *Strengths and Difficulties Questionnaire* (SDQ) constitutes a brief behavioural screening measure that consists of a combination of 25 positive and negative attributes (Goodman, 1997). The SDQ yields five subscales, each comprising five items measuring *Emotional Symptoms* (ES), *Conduct Problems* (CP), *Hyperactivity-Inattention* (HY), *Peer Problems* (PP), and *Prosocial Behaviour* (PB). Parents and teachers rate each item on a 3-point Likert Scale (Not True = 0, Somewhat True = 1, and Definitely True = 2). Scores in each attribute range from having no problems (0) to clinical levels of functioning (10).

**Procedure**

Children completed the assessment in one full-day session, conducted in the metropolitan children’s hospital. Parents were interviewed by the case manager; teachers had been interviewed prior to the assessment day via telephone. Participants received a full clinical psycho-educational assessment along with WM specific research measures from a psychometrist and speech and language pathologist. All tests were administered individually. The team, including a psychiatrist, met at the end of the day, and feedback was given to the parents. A full assessment report was mailed to the family two weeks later.

**Categorical Classification of WM Deficit**

A scaled score ranging from 8 to 12 (25th to 75th percentile) is considered to be within the Average range of functioning. Thus, poor working memory was defined as a standard score of 7 or less (i.e., 16th percentile or lower, which is -1 standard deviation
(SD) below the mean), on at least on three of the six WM measures. Thus children with scaled scores of ≤ 7 on three or more of the WM measures were classified as ADHD+WMD. The rationale for this cut-off was three-fold: 1) although our cut-off is broader than previous studies on EFDs (e.g., Biederman et al., 2004; Loo et al., 2007; Nigg et al., 2005), it seemed appropriate given our use of scale scores and that we were categorizing only WM and not several measures of EF; 2), we considered it inappropriate to place individuals with two tests in the below average range, in the adequate WM group (Biederman et al., 2004); and 3) whereas one low score may be due to chance, three or more scores at the 16th percentile or less would likely to be interpreted as an area of vulnerability or difficulty by a clinician.

**Statistical Analyses**

Data analysis was performed using SPSS version 16.0 for Windows: all tests were two-tailed. The choice of data analytic strategies for this study was complicated by missing data, thus the approaches described were selected to accommodate missing data in the most powerful way. To explore the effect of WM Group (ADHD, ADHD+WMD) on reading and math achievement, reading and math scores were analyzed together using repeated measures analysis of variance (ANOVA). A separate ANOVA was conducted for writing scores because whereas 65 students completed both reading and math cluster assessments, only 44 students completed the written language cluster.

Neither the proportion of females in the sample nor their distribution between the ADHD and ADHD+WMD groups was adequate to support a full factorial design involving gender (ADHD: 40 boys, 14 girls; ADHD+WMD: 14 boys, 5 girls). Thus, analyses could only test for differences between males and females with ADHD.
ANOVA were conducted separately for reading, math and written language scores, with Gender as the sole between-subjects factor.

To test for group differences in the clinical profile, repeated measures ANOVAs and one-way ANOVAs were conducted separately for parent and teacher ratings on SWAN, SDQ and BRIEF scores. Repeated measure ANOVAs were conducted for instruments with multiple subscales and individual ANOVAs were conducted for instruments with one scale. Intercorrelational results between parent and teacher clinical ratings indicated generally weak relationships. Hence, repeated measures ANOVAs were conducted separately for parent and teacher ratings on SWAN IN and H/I measures, SDQ subscale measures (ES, CP, HY, PP and PB), and for BRIEF BRI and MI Indexes. ANOVAs were conducted for both parent and teacher BRIEF WM measures. Also, gender differences in the clinical profile of children with ADHD (collapsed across the WM groups) were tested using a series of ANOVAS for both parent and teacher ratings of behaviour on the SWAN, SDQ and BRIEF measures.

2.4 Results

Working Memory

Table 1 presents the overall means and standard deviations for Group WM subtests in the order of test administration. As predicted from our approach to classification of WMD, children in the ADHD+WMD group scored lower on all of the standardized clinical measures of WM, compared to those with good WM (ADHD). Not only were the scores for the ADHD+WMD group statistically lower than those of the
ADHD group, but the group mean scores on four of the six WM tests were more than 1 SD below the mean.

**Academic Achievement**

Table 2 presents the overall means, standard deviations and the results of ANOVA analyses (critical values and effect sizes [partial $\eta^2$]) for the ADHD and ADHD+WMD groups. Consistent with our hypothesis, children in the ADHD+WMD group had significantly lower academic scores across all three major academic clusters: reading, mathematics and written language. Table 3 presents the percentages of children in both ADHD and ADHD+WMD groups who were impaired in each academic cluster. Results from a definition of impairment of 1 SD (SS of 84 or lower) and 1.5 SD (SS of 78 or lower) indicate that the majority of the sample did not have academic impairments. However, the ADHD+WMD group had significantly higher percentages of academic impairments compared to the ADHD group, particularly in the written language cluster.

As shown in the lower portion of Table 2, the ADHD+WMD group scored significantly lower than the ADHD group on seven of the nine subtests: the two groups did not differ on the spelling or writing samples subtests. The ADHD+WMD had means of clinical impairment on two subscales: math fluency and writing fluency. No other academic impairments were found across subscales of both WM groups.

No significant gender differences were found between the clinical sample of boys and girls with ADHD in all three academic achievement areas ($p$ value > .05 for all measures): Reading $F(1,63) = 2.00$; Mathematics $F(1,63) = 3.87$; and Written Language $F(1,42) = .52$. 
Clinical Profile

Intercorrelations between parent and teacher rating scales on the SWAN (IN and H/I scales), SDQ (ES, CP, HY, PP and PB) and BRIEF (BRI, MI and WM) measures were not strong, ranging from .16 to .47, although some scores were statistically significant indicating these relationships are different from zero in the population. Correlations between parent and teacher ratings were the highest on the SDQ PP, \( r(69) = .47, p < .001 \), SDQ ES, \( r(69) = .40, p < .01 \) and the BRIEF BRI \( r(65) = .39, p < .01 \). As parents and teachers rate differently, their ratings were analyzed separately.

Tables 4 and 5 presents the overall means and standard deviations, along with indication of significance from ANOVA analyses for parent and teacher SWAN, BRIEF and SDQ measures as a function of WM: repeated measures ANOVAs for all SWAN, SDQ and BRIEF BRI and MI measures; one-way ANOVAs for BRIEF WM.

On the parent SWAN there was no significant main effect for Group when the two scores were regarded as a single entity \( F(1,66) = .05, p > .05 \), which indicates that on average scores of IN and H/I were not different for WM Group. On the teacher SWAN there was also no significant difference between the two WM groups \( F(1,70) = .73, p > .05 \). Additional one-way ANOVAs were conducted for both parent and teacher measures of IN. No significant differences amongst WM Groups were found for parents \( F(1,66) = .00, p > .05 \) and teachers \( F(1,70) = 1.25, p > .05 \).

On parent BRIEF BRI and MI measures, no significant Group main effect was found \( F(1,67) = .45, p > .05 \), which indicates that on average BRI and MI scores were not different for WM Group. When examining the subcomponent BRIEF WM measure, no Group main effect was found \( F(1,67) = .22, p > .05 \). No significant WM main effect was
found overall on the teacher BRIEF BRI and MI measures $F(1,68) = .24, p > .05$. Furthermore, when investigating the teacher reported BRIEF WM measure, results indicated an absence of Group main effect $F(1,70) = 2.47, p > .05$. As T-scores are presented, a score of 65 or higher indicates potential clinical significance. When analyzing the overall parent and teacher reported measures on the BRI and MI scales, 53-83% of the ADHD group were considered to be clinically impaired, while 50-89% of the ADHD+WMD group were defined as clinically impaired (depending on source and target measure). Parents reported WM impairment in 88% of the ADHD group and in 72% of the ADHD+WMD group. Table 6 presents the percentages of children in both ADHD and ADHD+WMD groups who were impaired in both parent and teacher reported BRIEF WM measures. Results indicate there is no relationship between the classification of our objective WM measures and those of the BRIEF WM.

There was no indication of significant Group main effect on overall parent SDQ $F(1,69) = .30, p > .05$ and teacher SDQ $F(1,68) = .542, p > .05$ measures. Hence, on average, scores on the five SDQ scales do not differ between WM Groups.

**Gender**

Table 4 presents the overall means and standard deviations, along with indication of significance from ANOVA analyses for parent and teacher SWAN, BRIEF and SDQ measures as a function of Gender for SWAN and BRIEF measures. Table 5 presents the same analyses for SDQ measures. Parent ratings of behaviour were not significantly different for boys and girls, with the exception of one subscale, whereas several teacher ratings of behaviour were significantly different.
All teacher BRIEF measures produced a moderate to large Gender main effect: BRI $F(1,69) = 18.79, p < .001$, partial $\eta^2 = .214$; MI $F(1,69) = 36.94, p < .001$, partial $\eta^2 = .349$; and WM $F(1,70) = 13.10, p < .01$, partial $\eta^2 = .16$. Hence, average girls’ scores were higher than boys’ scores across all measures. Interestingly, a small Gender main effect was found on the SDQ ES scale for both parent $F(1,69) = 4.08, p < .05$, partial $\eta^2 = .056$ and teacher $F(1,70) = 6.56, p < .05$, partial $\eta^2 = .086$, ratings with girls’ scoring higher than boys’ on emotional symptoms. No other SWAN, BRIEF or SDQ gender differences were found.

2.5 Discussion

The primary goal of the present study was to determine whether children with ADHD, with and without WM deficits, differ in their academic outcome. Secondarily, we sought to determine whether children with and without WM deficits also differed in their clinical profile, particularly in inattention. Consistent with our hypothesis, children with WM deficits scored significantly lower on reading, math and written language academic achievement tests than children with good WM and ADHD. This finding is novel as this is the first report of evidence that children with ADHD and WM deficits have lower academic scores. However, in contrast to our hypothesis, children in the ADHD+WMD did not manifest more severe inattention compared to the ADHD group with good WM. Moreover the two groups did not differ in other aspects of their clinical profile.

Previous research has linked poorer academic outcomes in children with ADHD to concurrent EF impairments (Biederman, Monuteaux et al., 2004). The WM
component of EF has been suggested to be the strong factor behind academic outcomes (Gathercole et al., 2004). Our research supports these findings, indicating ties with stronger academic performance and good WM. Academic impairments have also been found across reading, writing and mathematical domains in children with ADHD (Currie & Stabile, 2006; Hinshaw, 1992; Re, Pedron, & Corneldi, 2007; Resta & Eliot, 1994; Rodriguez et al., 2007) even in the absence of comorbid learning disabilities, other types of psychopathology, level of parental education, and lower family income (Lahey et al., 1998; Pastura, Mattos, & Araajo, 2008). Although the majority of the sample did not have academic impairments, the ADHD+WMD group had significantly higher percentages of academic impairments compared to the ADHD group, particularly in the written language cluster. Notably, the largest Effect Sizes for the WM Group differences generally occurred in subtests placing greater demand on WM (Passage Comprehension, Applied Problems, and Writing Fluency). This pattern suggests that children with ADHD and WM impairments tend to struggle more when WM demands increase. For instance, individual differences in WM capacity are believed to influence the acquisition and fluency of early transcription skills (Berninger, 1999; Graham & Harris, 2000). Also, research has confirmed that WM (as well as overall EF) contributes to overall writing proficiency, as well as planning, translation, revision and many sub-measures of written output such as punctuation and grammar (Altemeier, Jones, Abbott, & Berninger, 2006; Graham & Harris, 2000; Hooper, Swartz, Wakely, de Kruiif, & Montgomery et al., 2002). Moreover, evidence suggests that the controlled attention component of WM is intricately tied to writing in school aged students (Vanderberg & Swanson, 2007).
Our secondary goal was to determine whether children with ADHD, with and without WM deficits, vary in their clinical profiles. Inattentive symptoms of both ADHD and non-clinical populations have been linked to low WM (Gathercole et al., 2008; Lui & Tannock, 2007; Martinussen & Tannock, 2006). Unexpectedly, our study did not reiterate these findings. We found that WM groups were rated similarly across inattention and hyperactivity/impulsivity symptoms on the SWAN rating scale and on the hyperactivity-inattention scale on the SDQ. Notably, only two children in the sample met clinical diagnosis criteria for a Learning Disorder. Moreover, there were minimal comorbid conditions, with only one trend in Language Impairments. Therefore, we can rule out the possibility that poor academic outcomes are attributed to comorbid Learning Disorders or other comorbid conditions. Instead, poorer academic outcomes are related to WM deficiencies in this ADHD sample.

Furthermore, no significant WM differences on the BRIEF were found between both parent and teacher ratings of EF, even when investigating WM on its own. Interestingly, teachers and parents rated the majority of children in both ADHD and ADHD+WMD groups as having significant WM problems. This raises the issue of whether the BRIEF WM measure is an effective gauge of WM, as it was not successful in stratifying WM problems amongst our sample of children with ADHD. Lastly, there were no significant findings across WM groups when inquiring about other childhood problems including emotional symptoms, conduct problems, peer problems, as well as prosocial behaviour.

Sub-goals of this research included looking for gender effects across academic achievement and clinical profiles. As expected, boys and girls in this clinic referred
sample were more alike than different, consistent with previous research (DuPaul et al., 2006). When examining clinical profiles, gender differences were found on teacher reported measures of EF on the BRIEF. Small gender effects were also found on both parent and teacher measures of emotional symptoms. Thus, girls in this clinical sample tend to have greater psychosomatic complaints than boys their age.

We acknowledge several limitations present in the current study. Missing data precluded the comprehensive analysis of the inclusion of all academic measures under one multivariate analysis. Also, certain aspects of the WJ-III may underestimate or overestimate a participant’s abilities. One area is in the Writing Samples subtest, as scoring is highly subjective and up to the examiner. Furthermore, we do not know the extent to which our findings of poor academic achievement in the WM deficit group are attributable in part to Language Impairments. Previous research has in fact shown a link between WM deficits and Language Impairments (Jonsdottir, Bouma, Sergeant, & Scherder, 2005). We do, however, know that the findings cannot be accounted for solely by comorbid LD, since only a proportion of the youngsters in the ADHD+WMD group met the low-achievement definition of LD and some youngsters with intact working memory could be classified as LD. Also, the sample size for females, and particularly for females with ADHD+WMD, was too small to support a full factorial analysis to examine interaction effects, and cannot generalize our findings on gender to those with good WM or WMD. We also cannot ascertain that our clinical WM measures are adequately sensitive to real life demands on WM, and may underestimate WMD in this population. We may have only identified those with extreme WMD; those that cannot perform fairly simple task demanding WM tasks efficiently, even in a controlled lab environment with
minimal distraction. Future studies are encouraged to investigate these interaction effects with larger sample sizes. Lastly, our measures of inattention were not collected simultaneously to our WM tasks. Rapport et al. (2009) have noted that children, especially those with ADHD, exhibit significantly higher rates of activity while performing WM tasks.

**Clinical and Research Implications**

Children with ADHD are already at risk for low academic achievement (DuPaul, McGoey, Eckert, & Vambrakle, 2001; Rapport, Seanlan, & Denney, 1999). Hence, children with ADHD and WM deficits may be at higher risk for performing poorly in school. The classroom places great demands on WM in all subject domains. Some students may struggle more with specific tasks that tend to be inherently complex. Hence, they may find it difficult to comprehend instructions or activities as they are unable to maintain the information in their minds in order to make links between key ideas. They may also be unable to compose a piece of writing that is clear and error free as they may not be able to easily engage in each of the processes required to produce a coherent piece of work. If children with low WM often fail in meeting WM demands of these individual learning episodes, or situations that provide learning, the continual growth of acquiring skills and knowledge is disrupted (Alloway, 2006). Thus, it is essential for teachers to consider that underlying WM deficits might be a contributing factor to poor academic outcomes. Hence, teachers must continue to monitor academic achievement, looking for WM difficulties if achievement scores are low. Signs of WM struggles may include the repetition and/or skipping of words or sentences during writing, missing parts of a task, losing track of place in an assignment, and the
abandonment of a task (Gathercole and Alloway; 2008a); if suspected, accommodations placing fewer demands on WM should be implemented. These accommodations include keeping instructions brief, breaking down tasks into smaller parts, “chunking” information into manageable pieces of information, and using external memory aids such as a number line (Gathercole et al., 2006). Furthermore, evidence-based academic intervention programmes targeting academic weaknesses would be highly beneficial for students who are having difficulties in specific areas. Interventions supporting self regulation, such as the Self-Regulated Strategy Development (SSRT; Harris & Graham, 1996) instruction program for writing may be successful for children with ADHD (Lienemann & Reid, 2008), along with Lovett, Lacernenza, and Borden’s (2000) evidence-based Phonological and Strategy Training (PHAST) reading program. Within these interventions, there are often facilitators and external supports that minimize the WM load. However, some children may benefit from a combination of accommodations and interventions, such as small group instruction.

Our study has implications for clinicians. Our research demonstrated that the BRIEF measure of WM did not differentiate between those with good WM and those with WMD. Hence, clinicians need to be cautious in administering clinical WM measures, especially the BRIEF, and may benefit from determining WMD through the examination of individual academic achievement subtests. In terms of intervention, computerized training is a promising approach to aiding WM. These programs aimed at visuo-spatial components of WM have shown to improve WM in pre-schoolers, children and young adults with WMD, including children with ADHD (Klingberg, Forssberg, & Westerberg, 2002; Klingberg et al., 2005; Thorell, Lindqvist, Bergman, Bohlin, &
Klingberg, 2008). Physicians can also consider prescribing medication targeting WM, as researchers have found that medication, such as methylphenidate produces moderate, but beneficial effects on certain aspects of WM (Bedard & Tannock, 2008).

In summary, results from our study demonstrate that lower academic scores are evident in children with WM deficits. As there were no significant differences between WM groups in terms of their clinical profile, this supports the notion that WM deficits are the contributors to poorer academic scores, rather than particular behaviours or other types of executive functioning. Teachers should be aware that poor WM may underscore some of the academic problems in children with ADHD and may benefit from being provided with tools and strategies in altering instructional practices, along with academic interventions, for those with WM problems. Children with ADHD and WM deficits are at much higher risk for performing poorly in school. Teachers and parents need to be made aware of these difficulties and accommodations need to be implemented in both school and home settings in order to ensure greater success in this population.
Table 1: Demographic Characteristics, Comorbidities and Summary Data for Working Memory Scores According to Good and Poor Working Memory Groups

<table>
<thead>
<tr>
<th>Variables</th>
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<th>df</th>
<th>$X^2$</th>
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<td>19 (74)</td>
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<td></td>
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<td>Medication Status</td>
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<td>.051$^b$</td>
<td></td>
</tr>
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<td>Conduct Disorder</td>
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<td></td>
<td>1.00$^b$</td>
</tr>
<tr>
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<td></td>
<td>1.00$^b$</td>
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<td>.318$^b$</td>
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<td>Tics</td>
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<td>.567$^b$</td>
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<tr>
<td>Learning Disorder$^c$</td>
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<td>1 (5)</td>
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<td>.502$^b$</td>
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<table>
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<tr>
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<th>SD</th>
<th>n (%)</th>
<th>Mean</th>
<th>SD</th>
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<tr>
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<td>1.84</td>
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<td>6.95</td>
<td>1.99</td>
<td>69</td>
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<td>5.57</td>
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<td>58</td>
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<td>2.61</td>
<td>59</td>
<td>2.89**</td>
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</tbody>
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Note: WMD = Working Memory Deficit; WISC-IV represents the Wechsler Intelligence Scale for Children-Fourth Edition; CELF-4 represents the Clinical Evaluation of Language Fundamentals – Fourth Edition; WRAML represents the Wide Range Assessment of Memory and Learning; WISC-III PI represents the Wechsler Intelligence Scale for Children-Third Edition as a Process Instrument; $^a$ Pearson Chi-Square; $^b$ Fisher’s Exact Chi-Square Test was used as more than one cell had an expected count less than 5 and Pearson’s Chi-Square assumptions could not be met; $^c$ Learning Disorder’s diagnosed upon referral; *p < .05; **p < .01; ***p < .001
<table>
<thead>
<tr>
<th>Measures</th>
<th>ADHD</th>
<th>ADHD+WMD</th>
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<th>p</th>
<th>ES</th>
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<td>Mean</td>
<td>SD</td>
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<td>Mean</td>
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<td>W-J III Achievement</td>
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<td>Math</td>
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<td>9.70</td>
<td>90.42</td>
<td>8.44</td>
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<td>16.33</td>
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<td>16.31</td>
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</table>

Note: WMD = Working Memory Deficit; W-J III Achievement represents the Woodcock-Johnson III Tests of Achievement; Reading represents the Broad Reading Composite; Math represents the Broad Math composite; Written Language Represents the Broad Written Language Composite; a represents Standard Error; ES = Effect Size (partial $\eta^2$); *p < .05; **p < .01; ***p < .001
Table 3: Percentage of Impairment on Academic Achievement Clusters for Good and Poor Working Memory Groups

<table>
<thead>
<tr>
<th></th>
<th>Reading</th>
<th></th>
<th>Math</th>
<th></th>
<th>Written Language</th>
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<tbody>
<tr>
<td></td>
<td>ADHD</td>
<td>ADHD+WMD</td>
<td>ADHD</td>
<td>ADHD+WMD</td>
<td>ADHD</td>
</tr>
<tr>
<td>% Impaired at 1 SD</td>
<td>9%</td>
<td>21%</td>
<td>2%</td>
<td>32%**</td>
<td>9%</td>
</tr>
<tr>
<td>(SS ≤ 84)</td>
<td>(n=4)</td>
<td>(n=4)</td>
<td>(n=1)</td>
<td>(n=6)</td>
<td>(n=3)</td>
</tr>
<tr>
<td>% Impaired at 1.5SD</td>
<td>0%</td>
<td>11%</td>
<td>0%</td>
<td>5%</td>
<td>3%</td>
</tr>
<tr>
<td>(SS ≤ 78)</td>
<td>(n=0)</td>
<td>(n=2)</td>
<td>(n=0)</td>
<td>(n=1)</td>
<td>(n=1)</td>
</tr>
</tbody>
</table>

Note: WMD = Working Memory Deficit; W-J III Achievement represents the Woodcock-Johnson III Tests of Achievement; Reading represents the Broad Reading Composite; Math represents the Broad Math composite; Written Language represents the Broad Written Language Composite; SD = Standard Deviation; SS = Standard Score; *p < .05; **p < .01; ***p < .001
Table 4: Comparison of Working Memory Groups and Gender on Parent and Teacher Ratings of the SWAN and BRIEF

<table>
<thead>
<tr>
<th>Measures</th>
<th>ADHD</th>
<th>ADHD+WMD</th>
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<th>Girls</th>
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<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>SD</td>
<td>n</td>
</tr>
<tr>
<td>SWAN Parent</td>
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<td></td>
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<td></td>
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<tr>
<td>IN and H/I</td>
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<td>1.24</td>
<td>.10a</td>
<td>18</td>
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<td>IN</td>
<td>50</td>
<td>1.36</td>
<td>.76</td>
<td>18</td>
</tr>
<tr>
<td>H/I</td>
<td>50</td>
<td>1.12</td>
<td>.89</td>
<td>18</td>
</tr>
<tr>
<td>SWAN Teacher</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN and H/I</td>
<td>53</td>
<td>1.66</td>
<td>.09a</td>
<td>19</td>
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<tr>
<td>IN</td>
<td>53</td>
<td>1.91</td>
<td>.66</td>
<td>19</td>
</tr>
<tr>
<td>H/I</td>
<td>53</td>
<td>1.41</td>
<td>.92</td>
<td>19</td>
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<td>BRIEF- Parent</td>
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<tr>
<td>BRI and MI</td>
<td>51</td>
<td>68.01b</td>
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<td>BRI</td>
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<td>MI</td>
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<td>WM</td>
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<td>74.02b</td>
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Note: WMD = Working Memory Deficit; SWAN represents the Strengths and Weaknesses of ADHD Symptoms and Normal Behaviours Rating Scale; IN = Inattention; H/I = Hyperactivity/ Impulsivity; WM = Working Memory; BRIEF represents the Behavioral Rating Inventory of Executive Function; BRI = Behavioral Regulation Index; MI = Metacognition Index; WM = Working Memory; a represents Standard Error; b represents clinical significance; ES = Effect Size (partial $\eta^2$); *p < .05; **p < .01; ***p < .001
<table>
<thead>
<tr>
<th>Measures</th>
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<td>18</td>
<td>2.44</td>
</tr>
<tr>
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<td></td>
<td>2.97</td>
<td></td>
<td>2.23</td>
</tr>
<tr>
<td>CP</td>
<td>52</td>
<td>2.88</td>
<td>18</td>
<td>4.22</td>
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<td>2.25</td>
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<td>4.48</td>
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<tr>
<td>HY</td>
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<td>8.65</td>
<td>18</td>
<td>8.72</td>
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<td>PP</td>
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<td>18</td>
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<td></td>
<td></td>
<td>2.62</td>
<td></td>
<td>2.83</td>
</tr>
</tbody>
</table>

\(^a\)represents Standard Error; ES = Effect Size (partial \(\eta^2\));

*p < .05; **p < .01; ***p < .001

Note: WMD = Working Memory Deficit; SDQ represents the Strengths and Difficulties Questionnaire; OVERALL represents the overall mean of the five combined subtypes; ES = Emotional Symptoms scale; CP = Conduct Problems scale; HY = Hyperactivity-Inattention scale; PP = Peer Problems scale; PB = Prosocial Behaviour scale; WM = Working Memory.
Table 6: Percentage of Impairment on BRIEF WM scores for Good and Poor Working Memory Groups

<table>
<thead>
<tr>
<th></th>
<th>Parent Reported</th>
<th>Teacher Reported</th>
<th>( \chi^2 )</th>
<th>Parent Reported</th>
<th>Teacher Reported</th>
<th>( \chi^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ADHD</td>
<td>ADHD+WMD</td>
<td></td>
<td>ADHD</td>
<td>ADHD+WMD</td>
<td></td>
</tr>
<tr>
<td>% Unimpaired on BRIEF WM (T-score &lt; 65)</td>
<td>12% (n=6)</td>
<td>28% (n=5)</td>
<td>.140*</td>
<td>24% (n=13)</td>
<td>11% (n=2)</td>
<td>.327*</td>
</tr>
<tr>
<td>% Impaired on BRIEF WM (T-score ≥ 65)</td>
<td>88% (n=45)</td>
<td>72% (n=13)</td>
<td></td>
<td>76% (n=41)</td>
<td>89% (n=16)</td>
<td></td>
</tr>
</tbody>
</table>

Note: BRIEF represents the Behavioral Rating Inventory of Executive Function; WM = Working Memory; *Fisher’s Exact Chi-Square Test was used as more than one cell had an expected count less than 5 and Pearson’s Chi-Square assumptions could not be met; *p < .05; **p < .01; ***p < .001
CHAPTER III

Clinical and Research Implications
Clinical and Research Implications

Discussion of Results

This study investigated whether children with ADHD, with and without WM deficits, differed in their academic achievement and clinical profiles. Only 26% of this sample of children with ADHD met criteria for WM impairment, indicating that not all children with ADHD have WM impairments.

This study found that children with ADHD and WM deficits performed, on average, significantly lower on reading, math and written language academic achievement tests than children with good WM and ADHD. When analyzing written language, children with good and poor WM tended to perform equally on sample writing activities. However, children with WM deficits struggled to perform as well as those with good WM on spelling and writing fluency tasks.

It is also important to note that the WJ-III was used as a measurement of academic achievement. Although the WJ-III was able to distinguish the strengths and difficulties of each child, which is extremely beneficial to clinicians, and in turn teachers, it is not known whether these children would have scored any differently on another type of academic achievement test. Certain aspects of the WJ-III may underestimate or overestimate a participant’s abilities. One area is in the Writing Samples subtest, as scoring is extremely subjective and up to the examiner. Mayes, Calhoun and Lane (2005) compared WJ-III Written Language subtests, which measure single words and single sentences, to the WIAT Written Expression subtest, which encompasses a combination of writing skills. The WIAT identified 78% of the sample as having writing problems, whereas the WJ-III only found 35% of children to have writing problems. Other
Woodcock measures, such as the *Woodcock Reading Mastery Test* (Woodcock, 1998) have been found to inflate the scores of participants when norms were updated on identical test items (Pae et al., 2005). Hence, it is unknown if the WJ-III underestimates current classroom demands.

Previous research has linked poorer academic outcomes in children with ADHD to concurrent EF impairments (Biederman, Monuteaux et al., 2004). The WM component of EF has been suggested to be the strong factor behind academic outcomes (Gathercole et al., 2004). Our research supports these findings, indicating ties with stronger academic performance and good WM. Academic impairments have also been found across reading, writing and mathematical domains in children with ADHD (Currie & Stabile, 2006; Hinshaw, 1992; Re, Pedron, & Corneldi, 2007; Resta & Eliot, 1994; Rodriguez et al., 2007) even in the absence of comorbid learning disabilities, other types of psychopathology, level of parental education, and lower family income (Lahey et al., 1998; Pastura, Mattos, & Araajo, 2008). Although the majority of the sample did not have academic impairments, the ADHD+WMD group had significantly higher percentages of academic impairments compared to the ADHD group, particularly in the written language cluster. Writing tasks often involve increasing demands of WM, requiring children to keep the goals of the writing task in mind, while physically writing or typing their thoughts, in addition to correctly spelling and punctuating their work. Notably, the largest Effect Sizes for the WM Group differences generally occurred to subtests placing greater demand on WM (*Passage Comprehension, Applied Problems*, and *Writing Fluency*). This pattern suggests that children with ADHD and WM impairments tend to struggle more when WM demands increase.
As only two children in the sample had a diagnosis of a Learning Disorder upon referral, and there were minimal comorbid conditions, we can attribute poorer academic outcome to WM deficiencies in this ADHD population. However, depending on the definition of a Learning Disorder, it is possible that more children could have been diagnosed with this disorder. The use of a low achievement criterion, as in Table 3, does not constitute a formal clinical diagnosis of a Learning Disorder, although it states that impairments were made in these domain-specific subjects.

Our secondary goal was to determine whether children with ADHD, with and without WM deficits, vary in their clinical profiles. Inattentive symptoms of both ADHD and non-clinical populations have been linked to low WM (Gathercole et al., 2008; Lui & Tannock, 2007; Martinussen & Tannock, 2006). Unexpectedly, our study did not reiterate these findings. We found that WM groups were rated similarly across inattention and hyperactivity/impulsivity symptoms on the SWAN rating scale and on the hyperactivity-inattention scale on the SDQ. Furthermore, no significant WM differences were found between both parent and teacher ratings of EF, even when examining WM on its own. Interestingly, teachers and parents rated the majority of children in both ADHD and ADHD+WMD groups as having significant WM problems. This raises the issue of whether the BRIEF WM measure is an effective gauge of WM, as it was not successful in stratifying WM problems amongst our sample of children with ADHD. Lastly, there were no significant findings across WM groups when considering other childhood problems including emotional symptoms, conduct problems, peer problems, as well as prosocial behaviour.
Sub-goals of this research included the exploration of gender effects across academic achievement and clinical profiles. As expected, boys and girls in this clinic referred sample were more alike than different, consistent with previous research (DuPaul et al., 2006). When examining clinical profiles, gender differences were found on teacher reported measures of EF on the BRIEF. Small gender effects were also found on both parent and teacher measures of emotional symptoms. Thus, girls in this clinical sample tend to have greater psychosomatic complaints than boys their age.

Implications

It has been estimated that one child in every class will likely have ADHD (based on a minimum of 20 students) and teachers need to be equipped with the knowledge of any implications associated with this disorder (DuPaul & Stoner, 2003 Rutherford, DuPaul, & Jitendra, 2008). Children with ADHD are already at risk for low academic achievement (DuPaul, McGoey, Eckert, & Vambrakle, 2001; Rapport, Scanlan, & Denney, 1999). Hence, children with ADHD and WM deficits are at potentially higher risk for performing poorly in school. The classroom places great demands on WM in all subject domains. Some students may struggle more with specific tasks that tend to be inherently complex. Hence, they may find it difficult to comprehend instructions or activities as they are unable to maintain the information in their minds in order to make links between key ideas. They may also be unable to compose a piece of writing that is clear and error free as they may not be able to easily engage in each of the processes required to produce a coherent piece of work. If children with low WM often fail in meeting WM demands of these individual learning episodes, or situations that provide learning, the continual growth of acquiring skills and knowledge is disrupted (Alloway,
Thus, it is essential for teachers to consider that underlying WM deficits might be a contributing factor to poor academic outcomes. Effective measurements of WM that are reliable and valid for teachers to use in the classroom could be introduced to teachers. The Automated Working Memory Assessment (AWMA; Alloway, 2007) is a computer based assessment of working memory, designed to target verbal and visuo-spatial working memory domains for 4 to 22 year olds. As the administration and scoring of the AWMA is automatic, this would be an ideal tool for teachers to use. However, as time limitation is a factor for formal assessment, teachers should continue to monitor and informally evaluate WM difficulties in their students in order to find out which children may be at risk for academic difficulties. Signs of WM struggles include the repetition and/or skipping of words or sentences during writing, missing parts of a task, losing track of place in an assignment, and the abandonment of a task (Gathercole and Alloway; 2008a).

Once WM difficulties have been identified, teachers should be aware of interventions targeting WM deficits. Teachers are encouraged to create accommodations for their students that place fewer demands on WM. Gathercole and Alloway (2008a) have created several principles on WM for teachers to understand and implement: Look for Warning signs of WM failures (e.g. don’t follow instructions, abandon work); Evaluate WM loads (e.g. notice how detailed the instructions are, keep track of multi-level tasks); Reduce WM loads when necessary (e.g. simplify material, reduce unfamiliarity); Regularly monitor the child; Be prepared to repeat important information; Encourage and provide practice in the use of memory aids; and Develop the child’s use of memory strategies (e.g. rehearsal). Other helpful strategies include keeping
instructions to a minimum, breaking tasks and ideas into small pieces of information, ‘chunking’ data into manageable pieces of information, using mnemonics and external memory aids such as a number line or word wall (Gathercole et al., 2006).

Furthermore, evidence-based academic intervention programmes targeting academic weaknesses would be highly beneficial for students who are having difficulties in specific areas. Interventions supporting self regulation, such as the Self-Regulated Strategy Development (SSRT; Harris & Graham, 1996) instruction program for writing may be successful for children with ADHD (Lienemann & Reid, 2008), along with Lovett, Lacernenza, and Borden’s (2000) evidence-based Phonological and Strategy Training (PHAST) reading program. Within these interventions, there are often facilitators and external supports that minimize the WM load. However, some children may benefit from a combination of accommodations and interventions, such as small group instruction.

Our study has implications for clinicians, including psychologists, physicians and psychiatrists. As our research showed, typical measures of WM, such as the BRIEF did not differentiate between those with good WM and those with WM deficits. Hence, clinicians need to determine WM deficits by examining individual subtests on academic achievement tests. In terms of intervention, computerized training is a promising approach to aiding WM. The Cogmed program aimed at visuo-spatial components of WM has shown to improve WM in pre-schoolers, children and young adults with WM deficits, including children with ADHD (Klingberg, Forssberg, & Westerberg, 2002; Klingberg et al., 2005; Thorell, Lindqvist, Bergman, Bohlin, & Klingberg, 2008). Cogmed Working Memory Training (see http://www.cogmed.com) is the formal software
training program catering to the needs of both children and adults with WM deficits. The at-home training is extensive, starting with an initial interview and a start up meeting, followed by 25 sessions of approximately 30-40 minutes. Over five weeks, the program is completed, with weekly coach calls, followed by a wrap-up meeting and a six month check up. Progress is monitored online, and participants have the option of continuing their training for another 100 sessions over one year. Holmes, Gathercole and Dunning (2009) conducted a study on the impact of computerized WM training. They found substantial and sustained gains in WM after training, with significant improvement in mathematics evident six months later. Lastly, physicians can also consider prescribing medication targeting WM, as researchers have found that methylphenidate produces moderate, but beneficial effects on certain aspects of WM (Bedard & Tannock, 2008).

In summary, results from our study demonstrate that lower academic scores are evident in children with WM deficits. As there are no significant differences amongst WM groups on clinical profiling, this supports the notion that WM deficits are the contributors to poorer academic scores, rather than particular behaviours or other types of executive functioning. Teachers should be aware that poor WM may underscore some of the academic problems in children with ADHD and may benefit from being provided with tools and strategies in altering instructional practices, along with academic interventions for those with WM problems. Children with ADHD and WM deficits are at much higher risk for performing poorly in school. Teachers and parents need to be made aware of these difficulties and accommodations need to be implemented in both school and home settings in order to ensure greater success. As ADHD continues into adulthood, along with any cognitive and psychiatric impairments (Biederman, Faraone,
Monuteaux, Bober & Cadogen, 2004), it is essential that these adults be made aware of any WM problems they may have at an early age in order to advocate for themselves in higher education settings.
References


