WORKING MEMORY TRAINING IN COLLEGE STUDENTS WITH ATTENTION-DEFICIT HYPERACTIVITY DISORDER/ LEARNING DISABILITIES

by

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Abstract

Working memory (WM) refers to the information processing system that is responsible for the maintenance plus manipulation of information. WM is necessary for the performance of complex tasks, such as reasoning and comprehension. Until relatively recently, WM capacity was thought to be a fixed trait of the individual. However, research findings on the effects of WM training programs have demonstrated otherwise. Therefore, this dissertation examined the impact of WM training in college students with Attention-Deficit/Hyperactivity Disorder (ADHD) and Learning Disabilities (LD), two neuro-developmental disorders in which WM is impaired.

The main objectives of this dissertation were to investigate training gains on the WM training program itself, transfer effects, and 2-month maintenance effects. College students with ADHD/LD, all of whom were registered with student disability services, were randomized to either the WM training program or a wait-list control group. Those who received WM training showed significantly greater improvements in the criterion WM measures (WAIS-IV Digit Span, CANTAB Spatial Span) and self-reported fewer ADHD symptoms and daily cognitive failures, compared to the control group. Analysis of participants who completed the follow-up assessment indicated that the gains in WM were maintained for at least 2 months after training.

The dissertation is presented in four chapters. The introduction provides a broad overview of the research on WM, ADHD/LD, and WM training. The second chapter expands upon the methods used in the current study. The third chapter consists of a manuscript that will
be submitted for publication. The fourth and final chapter summarizes the findings of the current study and discusses its implications for future research and clinical practice.
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Glossary of Abbreviations

APA- American Psychiatric Association

ANCOVA- Analysis of Covariance

ADHD- Attention Deficit Hyperactivity Disorder

ASRS- Adult ADHD Self-Report Scale

CANTAB- Cambridge Neuropsychological Testing Automated Battery

CFQ- Cognitive Failures Questionnaire

CLT- Cognitive Load Theory

DSM-IV-TR- Diagnostic and Statistical Manual, fourth edition, text revised

GPA- Grade Point Average

ICD-10- International Classification of Diseases, tenth edition

LD- Learning Disabilities

MTA- Multimodal Treatment of Children with ADHD study

PASAT- Paced Auditory Serial Addition Test

RCT- Randomized Controlled Trial

RD- Reading Disability

RTI- Response to intervention

STM- Short-Term Memory

WAIS-IV- Wechsler Adult Intelligence Scale, fourth edition

WM- Working Memory
CHAPTER ONE
Rationale and Overview of Dissertation Research
1.1 Introduction

Until relatively recently, WM capacity was considered a fixed trait of the individual. However, a growing body of research has demonstrated that WM may be improved through intensive and adaptive computerized training (Klingberg, 2010). This exciting possibility has led to the creation of WM training programs aimed at improving WM in children, adolescents, and adults. While the effects of these training programs have been examined in various populations, young adults enrolled in post-secondary programs are an understudied population in this field of research. Therefore, this study expanded upon previous research by examining the impact of WM training in college students with previously diagnosed ADHD and Learning Disabilities. The goal was to determine whether WM training would enhance WM capacity and, by so doing, improve functioning in other areas.

The first chapter of this dissertation reviews the literature on WM, beginning with an overview of the theoretical models of WM. What follows is a discussion of the implications of WM impairments in learning/attention disorders and the research on WM training. The second chapter summarizes objectives, hypotheses, and methodological issues that are beyond the scope of a published journal article. The third chapter consists of a manuscript describing the main study, which has been submitted for publication. Since this manuscript was prepared as a stand-alone document, inevitably this will result in some overlap of information amongst the chapters. The concluding chapter discusses the implications of the findings on WM theory and clinical practice, with an emphasis on recommendations for future research in this area.

Recently, several published studies have provided evidence that WM functioning can be improved, that improvements generalize to transfer tasks (i.e., fluid intelligence, reasoning, comprehension), and that transfer effects are sustained over time (Holmes, Gathercole, & Dunning,
2009; Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002; Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009; Westerberg et al., 2007). Similarly, the limited body of research on young adults suggests that WM training leads to improved WM and that these improvements generalize to other non-trained task domains (Chein & Morrison, 2010; Dahlin, Nyberg, Bäckman, & Neely, 2008; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Klingberg et al., 2002). While these findings are indeed promising, the research in this field is in its early stages. Moreover, recently published studies including a meta-analysis have raised questions as to the transferability of WM training effects.

ADHD and LD often co-occur and poor WM, the ability to maintain and manipulate information over a short period of time, is a deficit shared by both groups. College students with ADHD/LD are a high achieving subset of the ADHD/LD population who successfully completed high school and were accepted to post-secondary programs. However, the data suggest that they continue to struggle in many areas of functioning in both the academic and personal realms as well as in WM (DuPaul, Weyandt, O'Dell, & Varejao, 2009; Heiligenstein, Guenther, Levy, Savino, & Fulwiler, 1999). Given the lack of WM training studies in college students, it remains unclear whether college students with ADHD/LD might benefit from WM training. It is also questionable whether these students would be able to comply with the time commitment of the WM training program, given the demands of their school schedules.

1.2 Working Memory

1.2.1 Working Memory: Definition and Theoretical Frameworks

Short-term memory (STM) and WM are two constructs that refer to the storage and the storage plus manipulation of information, respectively. STM is defined as the ability to hold information
for a brief period of time, over a matter of seconds. In contrast, WM is a “mental workspace” that holds an internal representation of information online for a few seconds, so that the information can be manipulated to produce a response (Baddeley, 2010; Miyake & Shah, 1999). While STM consists of a simple storage component, i.e. just the maintenance of information, the WM system involves both the storage and processing of information, i.e. maintenance plus manipulation. In view of the fact that WM involves storing information, it has been argued that STM is a subcomponent of WM (Cowan et al., 2005; Cowan, 2008). Although there may be overlap between these two constructs, research findings support the notion that WM, rather than STM, is important for complex cognitive tasks, such as learning, problem solving, mathematical reasoning, and language comprehension (Gathercole, Alloway, Willis, & Adams, 2006) and is correlated with measures of fluid intelligence (Daneman & Carpenter, 1980; Engle, Tuholski, Laughlin, & Conway, 1999; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Conway, Kane, & Engle, 2003; Cowan, 2008). It is this mental workspace that facilitates the manipulation and application of information that is necessary for learning and reasoning. It is beyond the scope of the present study to provide evidence for or against the distinctiveness of these two constructs and it is likely that there is an overlap, where common processes are involved in both. For the sake of the current research study, the term WM will be used and measured through complex span tasks with the understanding that part of the process of storing and manipulating information involves STM.

The Multi-Component Theory of WM. Baddeley (1986) was one of the first to describe the underlying mechanisms involved in WM. According to Baddeley, WM comprises three intersecting systems. The central executive is a limited capacity system that manages and regulates stored information in the two ‘slave systems’ (i.e., phonological loop and visuo-spatial sketchpad) and incorporates information retrieved from long-term memory. In addition, the central executive
guides attention to relevant information, and suppresses irrelevant information and undesired actions. The *phonological loop* stores and processes auditory-verbal information. The *visuo-spatial sketchpad* processes and stores spatial information. More recently, this model has been supplemented by a fourth component, the *episodic buffer*. This buffer system is capable of holding and combining ‘episodes’ or ‘chunks’ of sensory information which can include visual, auditory, olfactory and/or gustatory elements. It allows the various components to interact with each other as well as with information from long-term memory, and has a limited capacity of about four chunks/episodes (Baddeley, 2010). This multi-component model of WM was selected as the theoretical framework for this thesis, as it has been extensively studied and has received considerable empirical support. Moreover, this is the model upon which WM training programs, such as Cogmed, were developed. Accordingly, in the section on the Cogmed WM training program, the relationship between Baddeley’s model and Cogmed will be described in greater detail. Alternative models of WM have also been proposed. These models are summarized below to highlight the major differences between Baddeley’s WM model and those that were subsequently developed.

In contrast to Baddeley’s model, which described the interface between the two storage systems of WM, one for auditory-verbal information and the other for visuo-spatial, Shah and Miyake (1996) theorized that these two storage systems were more distinct. According to them, this distinction is important when trying to understand the underlying processes involved in spatial reasoning versus language processing. They believed that each domain is independently responsible for manipulating and keeping information on-line. This would suggest that, for example, training auditory verbal WM would not be expected to transfer to visual spatial WM and vice versa.
The importance of controlled attention and the ability to ignore competing information has been examined as it relates to WM capacity (Engle et al., 1999; Engle & Kane, 2004). Research aimed at understanding the link between WM and ‘cognitive attention’ has found that individuals with high WM capacity are less likely to be distracted and “mind-wander” when attention is required (Colflesh & Conway, 2007; Kane et al., 2007). In addition, WM has also been linked to inattentive behaviour, characteristic of individuals with ADHD. This link may help to explain why many individuals with ADHD are impaired in WM. Several meta-analyses have been conducted to examine WM deficits in ADHD (Hervey, Epstein, & Curry, 2004; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Hervey et al. (2004) found that on the basis of the results of six studies, WM in adults with ADHD appears to be ‘mildly impaired.’ Two of these were meta-analyses that found modest effect sizes for impairments in auditory-verbal WM (Martinussen et al., 2005; Willcutt et al., 2005). With regards to visual-spatial WM, Martinussen et al. (2005) reported large effect sizes for studies of visual spatial storage and manipulation in children with ADHD. Willcutt et al. (2005) also reported large effect sizes for visual spatial WM. Moreover, previous research has provided evidence of the correlation between off-task, inattentive behaviour and impaired WM in children with ADHD (Rapport, Bolden, Kofler, Sarver, Raiker, & Alderson, 2009). While correlation does not mean the same thing as causation, it is possible that improving WM would lead to improvements in the behavioural symptoms of inattention.

1.2.2 WM and Academic Achievement

The link between WM and learning explains at least in part why WM capacity appears to predict a wide range of academic abilities, including reading comprehension, language acquisition, and math reasoning skills (Alloway, Gathercole, Kirkwood, & Elliot, 2009; Baddeley, 2003;
Swanson & Jerman, 2007; Swanson, Zheng, & Jerman, 2009). Several studies have found a relationship between performance on domain-specific WM measures and academic subjects. Deficits in verbal WM storage lead to language acquisition weaknesses and attainment in English (Baddeley, Gathercole, & Papagno, 1998; Gathercole & Alloway, 2006; St. Clair-Thompson & Gathercole, 2006; Swanson & Howell, 2001) and deficits in spatial storage lead to low achievement in math and science (Gathercole, Pickering, Ambridge, & Wearing, 2004; Jarvis & Gathercole, 2003; St. Clair-Thompson & Gathercole, 2006). Thus, the relationship between WM, learning and academics appears to be well supported. Therefore, it would follow that if WM capacity can be strengthened, it might lead to concurrent improvement in the ability to learn and retain new information. In turn, these improvements may also transfer to specific areas of academic achievement.

The academic domains of reading and math are of relevance to the present study and were two aspects of academics examined given their strong link to WM. Once basic word reading skills have been established, WM becomes increasingly important as reading demands shift to multisyllabic decoding, comprehension and fluency. Verbal WM has been linked to reading comprehension in both skilled readers and those with reading difficulties (Sesma, Mahone, Levine, Eason, & Cutting, 2009; Swanson & Alexander, 1997). In an attempt to further explore the link between WM and reading comprehension, McVay and Kane (2012) found that mind wandering was a significant mediator in the relationship between WM and reading comprehension. Therefore, it would follow that WM training might improve mind wandering, including distractibility, which would in turn result in improved reading comprehension.

WM has also been associated with math calculation and reasoning skills (Passolunghi & Siegel, 2004). Specifically, both calculation and word problems involve a series of steps that
require the selection of a strategy, implementation and monitoring for a successful solution. These skills become increasingly important as students advance through the higher grades (Compton, Fuchs, Fuchs, Lambert, & Hamlett, 2012). Accordingly, in this study, reading and math comprehension measures were selected as outcome measures because of their strong link to WM.

1.2.3 Measurement of WM

WM capacity is usually assessed using complex memory span tasks that involve the ability to process and store increasing amounts of information. While simple span tasks have been used as a measure of STM, complex span tasks are more demanding of cognitive processes (Unsworth & Engle, 2007). Verbal and visuospatial WM reflect independent domains of functioning requiring distinct tasks; therefore, in the present study, WM capacity in both domains was measured separately.

Typically, in assessing verbal WM, backwards digit recall has been used because it imposes a substantial processing load (complex span), in contrast to forward digit span where the processing load is minimal and does not require the extra aspect of manipulation (Gathercole & Alloway, 2006). In addition, the Paced Auditory Serial Addition Task (PASAT) also measures verbal WM, with the increased challenge of performing mental arithmetic under time constraints (Tombaugh, 2006). Spatial span backwards has been used to assess visual-spatial WM (Aben, Stapert, & Blokland, 2012).

While these aforementioned tasks have been empirically validated, measuring WM is complex. Given the overlap of STM, attention, and the efficient processing of information, it is difficult to design tasks that tap into WM capacity alone. For example, the PASAT imposes a substantial WM load along with numeracy ability and sustained attention. This has implications for the present
study, both in terms of the selection of measures and interpretation of findings. For example, complex span tasks, of varying complexity, were selected as measures of auditory-verbal and visual spatial WM. However, as previously mentioned, it is difficult to measure “pure WM” and findings should be interpreted with this in mind.

1.3 Attention-Deficit/Hyperactivity Disorder (ADHD)

1.3.1. The Defining Features of ADHD

ADHD is one of the most common neurobehavioural disorders in childhood, with worldwide prevalence rates estimated at about 5% (as reviewed by Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007). A recent epidemiological study of adults living in the United States estimated a prevalence of 4.4% for adult ADHD (Kessler et al., 2005). ADHD is characterized by persistent, pervasive and impairing symptoms of inattention, hyperactivity and/or impulsivity. To meet diagnostic criteria for ADHD according to the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision (DSM-IV-TR; American Psychiatric Association, 2000), individuals must experience a minimum of six symptoms of hyperactivity/impulsivity or six symptoms of inattention that have persisted for at least six months. Symptoms of hyperactivity/impulsivity include: fidgeting, frequently leaving one’s seat, running about or climbing excessively, difficulty engaging in activities quietly, often “on the go” or acting as if driven by a motor, frequently blurting out answers, having difficulty waiting one’s turn, and often interrupting others. Symptoms of inattention include: failing to pay attention to detail, difficulty sustaining attention when spoken to directly, inability to follow through on instructions, difficulty organizing tasks, reluctance to engage in activities where sustained mental effort is required, frequently losing things, often easily distracted, and forgetful in daily activities. In addition,
identified symptoms must: a) be present before seven years of age, b) cause impairment in two or more settings (i.e. school and/or work and home) and c) produce clinically significant impairment in social, academic or occupational functioning.

ADHD is conceptualized as falling into one of three subtypes: Inattentive, Hyperactive/Impulsive and Combined. There is ongoing discussion whether the diagnosis should be categorical (based on meeting a set number of symptoms) or dimensional (viewing ADHD on a continuum; Willcutt et al., 2012). In a recent meta-analysis of the literature, Willcutt et al. (2012) concluded that current subtype classifications are temporally unstable and recommend that ADHD be classified as a single disorder with dimensional modifiers that reflect the number and severity of inattentive and hyperactive-impulsive symptoms at the time of assessment. Hierarchical models with a general ADHD factor as well as additional symptom factors of inattention and hyperactivity/impulsivity appear to provide an “optimal fit” for data derived from community and clinical samples (Normand, Flora, Toplak, & Tannock, 2012).

In order to address these aforementioned concerns about the validity of the current subtypes of ADHD, the DSM-5 that is scheduled for release in 2013 has proposed changing these subtypes to specifiers that classify the manifestation of symptoms at the time of assessment. This reflects the understanding that the course of ADHD and symptom presentation can change throughout the lifespan. Additional changes proposed in the DSM-5 include: the presence of ADHD symptoms may be present before the age of 12 as opposed to age 7, the symptom threshold has been reduced for adults aged 17 and older, and the language used to describe symptoms has been adapted to be more appropriate for adults (Tannock, 2012).
ADHD symptoms, especially hyperactivity, decline with age, but adolescents and adults with the disorder continue to manifest many of the same attention and executive function (EF) difficulties as children with the disorder, leading to academic, social and occupational difficulties (Biederman & Faraone, 2006). In adolescence and young adulthood, individuals with ADHD continue to have poorer outcomes as measured by the amount of schooling completed (Mannuzza, Klein, Bessler, Malloy, & Hynes, 1997) and GPA scores, according to their retrospective self-reports (Barkley, Fischer, Smallish, & Fletcher, 2006; Biederman et al., 2006; Biederman & Faraone, 2006). Adults with self-reported ADHD symptoms are significantly less likely to have graduated from high school, obtain a college degree, and be currently employed. In addition, compared to adults without ADHD, they are significantly less satisfied with their family, social and professional lives (Biederman et al., 2006). These ADHD related impairments also result in substantial financial losses in the workplace. Kessler et al. (2005) concluded that ADHD is associated with $19.5 billion (US) lost in human capital per year.

More boys than girls are diagnosed with ADHD; the ratio is approximately 4:1 in community samples (Cantwell, 1996). With age, the ratio appears to decrease; Ramtekkar, Reiersen, Todorov, & Todd (2010) found the prevalence ratio for males versus females to be 2.56:1 in adolescence. Similarly, symptoms of hyperactivity/impulsivity decline more abruptly with age compared to symptoms of inattention. While girls do not manifest the same degree of disruptive, hyperactive-impulsive behaviours, they have greater social problems, a higher incidence of internalizing disorders, and poorer self-esteem (Voeller, 2004).

Moreover, ADHD appears to have a strong genetic component. According to twin studies, the heritability of ADHD is approximately 60% to 76%, suggesting that genetics account for a large percentage of inter-individual variance (Burt, 2009). Brain imaging studies of individuals
with ADHD have consistently implicated the frontal brain regions, including the dorsolateral prefrontal cortex. Structural imaging studies suggest that individuals with ADHD have smaller volumes in the frontal cortex, cerebellum, and subcortical brain structures (Frodl & Skokauskas, 2012; Seidman, Valera, & Makris, 2005). One functional magnetic resonance imaging (fMRI) study in children with ADHD reported reduced specific brain activation during a WM task compared to typically developing children, who showed localized activation of the bilateral prefrontal cortex (Fassbender et al., 2011).

Traditionally, the major treatment approaches employed with ADHD included: psychopharmacology, parent management training, classroom behaviour management, social skills training, and/or a combination of these into a multimodal therapy program. The most influential study in this area was conducted by the MTA Cooperative Group in 1999. This clinical trial assessed the efficacy of various treatment options for children with ADHD and reported that medication management and the combined condition (medication and behaviour modification) were most effective in reducing ADHD symptoms. However, the addition of behaviour modification did not appear to confer an additional benefit above and beyond medication alone.

The effects of stimulant medication, particularly methylphenidate, on components of WM in individuals with ADHD have also been examined in the literature. Findings suggest that it improves the ability to store and manipulate visual spatial information (Bedard, Jain, Hogg-Johnson, & Tannock, 2007; Murray et al., 2011). This improvement in cognitive functioning is due to increases in brain activity in the prefrontal and parietal areas (Mehta et al., 2000). However, the major limitation of medication is that when it is not being taken these improvements disappear. That is, medication does not induce permanent improvements in WM. In contrast, WM training might produce sustained, longer-lasting improvements in WM.
1.3.2 ADHD and Academic Achievement

The relationship between ADHD and poor academic performance has been well documented over recent decades (August & Garfinkle, 1989; Currie & Stabile, 2006; Schachar, Tannock, Marriott, & Logan, 1995). Children with ADHD receive lower grades (Frazier, Youngstrom, Glutting, & Watkins, 2007), perform worse on standardized tests (Frazier et al., 2007), are more likely to repeat grades and eventually drop out of school (Barkley et al., 2006; MTA Cooperative Group, 2009). These trends are stable and persist into adolescence and adulthood (Biederman et al., 2006). A meta-analysis conducted on college students with ADHD found that inattentive symptoms of ADHD continue to be associated with poor academic achievement in young adulthood (Frazier et al., 2007).

In an attempt to explain the relationship between ADHD and academic achievement, Fergusson and colleagues reported that there is an independent negative relationship between attention problems in childhood and academic achievement in adolescence (Fergusson, Lyskey, & Horwood, 1997). Rapport, Scanlan and Denney (1999) expanded upon the previous work of Fergusson by proposing a Dual Developmental Pathway Model, in which classroom behaviour and cognitive variables (memory, vigilance) mediate the impact of attention problems on academic achievement. The work of Langberg et al. (2011) provided further support that the relationship between ADHD and academic achievement is indirect and mediated by classroom performance and homework materials management. However, they made the distinction between school grades (i.e. GPA) and achievement (standardized test measures), suggesting that these two constructs rely on different capacities and skill sets. In their model, parent-rated homework materials management, teacher-rated classroom performance, and parent education predicted school grades, whereas intelligence, inattention, classroom performance, special education services and family
income best predicted standardized test scores. In the present study, standardized test measures were used to examine academic achievement. The model proposed by Langberg et al. (2011) would suggest that improving attention skills through training WM would lead to improved standardized test scores.

1.3.3 ADHD in College Students

Less is known about college/university students with ADHD; however, this population has been the focus of recent research as increasing numbers of high school students with ADHD are enrolling in post-secondary education (Green & Rabiner, 2012). It has been estimated that ADHD affects 2% to 8% of college students (DuPaul et al., 2009; Weyandt, Linterman, & Rice, 1995). While these students have experienced academic success enabling them to attend post-secondary schooling, they appear to struggle as preliminary data suggests that college students with ADHD have lower grade point averages (GPAs), are more likely to be put on academic probation, and report significantly more academic problems than controls (DuPaul et al., 2009; Heiligenstein et al., 1999). Other studies, although not assessing GPAs, have found that high school students with ADHD are less likely to attend and graduate from college than students without ADHD (Murphy, Barkley, & Bush, 2002). Available evidence also suggests that these college students are less confident in their ability to succeed and achieve their academic goals (Blase et al., 2009). Furthermore, they appear to be at greater risk for psychosocial problems, including depression, emotional instability, and increased alcohol and drug use (Blase et al., 2009; Murphy et al., 2002; Rooney, Chronis-Tuscano, & Yoon, 2012). With regard to treatment, misuse of stimulant medication is a common problem in college students with ADHD. Many of these students do not take their medication as prescribed. They also frequently take it at higher doses, in combination with other substances, and/or misuse it to get high (Rabiner et al., 2009). Given the challenges that
these students face, including management of medication, any nonpharmacological intervention directed at improving cognitive functioning would be of benefit.

1.4 Learning Disabilities (LDs)

1.4.1 The Defining Features of LDs

A “Learning Disability” refers to a number of disorders that affect the acquisition, retention, understanding, or use of verbal and/or non-verbal information. These disorders are believed to result from impairments in one or more psychological processes related to learning, in combination with average to above average abilities essential for thinking and reasoning (Learning Disabilities Association of Canada, 2006). It is widely understood that an LD is a biologically based dysfunction in cognitive processing that negatively impacts an individual’s ability to learn, although social and economic factors have also been implicated (Büttner & Hasselhorn, 2011; Lyon, Fletcher, & Barnes, 2003).

Many children, adolescents, and adults struggle with LDs, as well as other comorbid diagnoses. Prevalence rates vary, but approximately 4-7% of children in the United States have been diagnosed with an LD (Geary, 2003; Mercer & Pullen, 2005). LDs are often linked to ADHD and comorbidity ranges from 40% to 80% across various studies (Pastor & Reuben, 2008). In addition, during the past decade there has been a sharp increase in the number of students with LDs pursuing post-secondary education. Estimates suggest 1% to 5% of college students have been diagnosed with LD (Horn & Nevill, 2006; Houck, Asselin, Troutman, & Arrington, 1992). These rising numbers point to the need to examine effective accommodations/interventions for students with an LD diagnosis.

Within the LD field, there is an ongoing debate surrounding both classification and
identification. Both the International Statistical Classification of Diseases and Health Related Problems (ICD-10; World Health Organization, 1992) and the DSM-IV-TR define an LD as “unexpected” academic underperformance in the absence of intellectual disability. LDs are typically diagnosed if there is a discrepancy between an individual’s intellectual ability (which must be in the normal range or above) and their achievement in a certain area (i.e. reading, writing, and math).

Some students underperform academically, but are not diagnosed with an LD if their IQ-achievement discrepancy is less than 1.5 to 2 standard deviations. However, research suggests that academic difficulties exist on a continuum with a continuous distribution (Büttner & Hasselhorn, 2011). Recent research has refuted the assumption that those individuals with and without an IQ-achievement discrepancy would differ in important ways (Büttner & Hasselhorn, 2011; Elliott & Gibbs, 2008; Stanovich, 2005). Furthermore, the IQ-achievement discrepancy approach does not point to effective intervention strategies.

An alternative approach suggests that responsiveness to intervention (RTI) should be used to identify an LD (Gresham, 2002). Using this process, at-risk children are screened and assigned to well-established intervention groups. Only those children who fail to show skill improvement after a fixed period of time are referred to special education services and are the students considered most likely to develop LDs. Although the RTI approach is becoming more widely accepted and highly regarded in the field, there are a number of issues with this approach that should be considered. Firstly, the cut-off point for defining a child as learning disabled remains unclear. In addition, this method is valid only if the interventions were delivered appropriately, which cannot always be guaranteed (Büttner & Hasselhorn, 2011). Moreover, the utility of this approach is questionable, if not altogether impossible to implement with adults because basic
academic skills are not taught in the post-secondary curriculum and validated interventions for teaching college level skills are lacking. As such, it would not be possible to use the RTI method to diagnose college students with an LD.

Despite the lack of validity of the discrepancy approach, it is the current standard of diagnosis used by student disabilities services at the post-secondary level. To receive services under the LD category, students must demonstrate at least average intellectual abilities, with difficulties in at least one area of processing, along with markedly low levels of academic achievement. In the present study, the diagnostic classification provided by student disabilities services served as the starting point for recruitment. Additional procedures were used to quantify current academic skills and ADHD symptoms, as described in Chapter Two.

Typically, many more males than females are diagnosed with an LD. The ratios range from 3:1 to 15:1 (Finucci & Childs, 1981). In terms of the gender differences in cognitive and academic profiles in individuals diagnosed with an LD, females diagnosed with an LD have lower IQs than their male counterparts and more severe academic deficits in math. However, they perform better on tasks of spelling and written language than males with LD (Vogel, 1990). Furthermore, the prevalence of reading difficulties is consistently higher in males than females (Hawke, Olson, Willcut, Wadsworth, & DeFries, 2009).

It is now well established that LDs persist into adulthood. Many adults with LDs continue to experience deficits in reading, writing, and arithmetic, leading to struggles in their chosen field of work. Coupled with their LDs, these adults must learn to navigate several different spheres including family life, employment, daily living routines and community (Gerber, 2012).

Treatment approaches for LDs are varied and partially depend on the nature of the individuals’ LD. Interventions for reading disabilities have the most empirical support, specifically
remediating word reading skills. Treatments typically target the basic reading skill and phonological deficits and it is well understood that the earlier the intervention takes place, the better (Shaywitz et al., 1999). The current knowledge of what works best for written language, reading and mathematics disabilities is understood less well. The etiological factors, core cognitive deficits and trajectory of skill deficits associated with these LDs have not been well defined in the literature. Despite this, it is widely accepted that, regardless of the LD, these students require explicit instruction, opportunities for review of previously mastered concepts, scaffolding, self-monitoring strategies and self-advocacy skills (Lyon, Fletcher, Fuchs, & Chhabra, 2006). Transfer of these skills to untrained domains remains one of the major challenges.

1.4.2 LDs and Academic Achievement

Poor academic achievement is a defining feature of LDs; however, the severity of LDs exists on a continuum and, therefore, so too do the academic difficulties that these students face. Moreover, the longer individuals with LD at any level of severity go without identification and intervention, the more difficult their academic challenges become. One study on adolescents with LDs found that they had lower grades in all reported subjects and invested less effort in their studies than their non-LD peers (Linnenbrink & Pintrich, 2003). Furthermore, research findings support the notion that these students with LDs have a perception of lower academic self-efficacy and perceived scholastic competence (Lackaye & Margalit, 2006).

1.4.3 LDs in College Students

The prevalence of college students with LDs ranges from 1 to 5% (Horn & Nevill, 2006; Houck et al., 1992). Despite the increasing amount of services available to these students, they still enroll at lower rates than their non-learning disabled peers. Sparks and Lovett (2009) conducted a meta-analysis of the research on college students with LDs and found that, while their academic
skills were lower than their non-disabled peers, they were still within the average range, with the exception of written language skills which were below average. In addition, the cognitive ability levels of college students with LD were only moderately weaker. These authors cautioned that there is a limited number of published studies in this area and the identification criteria used across studies varies, resulting in quite a heterogeneous LD population.

This finding, that college students classified with an LD tend to have average achievement despite scoring somewhat below their classmates, suggests that these students have different profiles than students in elementary and secondary school with LDs. However, given the heterogeneity of this population, it is unclear whether college students with LDs will exhibit the same cognitive and academic profiles as younger students with LDs.

1.5 ADHD and LD

1.5.1 The Co-occurrence of ADHD and LD

Learning disabilities frequently co-occur with a diagnosis of ADHD. Data derived from an epidemiological study found the prevalence of ADHD and LD combined to be 3.7% in the general population, with a higher occurrence in boys than girls (Pastor & Reuben, 2008). Based on the research findings, it is clear that students with ADHD are at a higher risk of having an LD and vice versa.

Several theories have been proposed to explain these high comorbidity rates. One hypothesis is that ADHD and reading disabilities (RDs) share a common genetic underpinning (Sexton, Gelhorn, Bell, & Classi, 2011). Based on the result that these disorders have common genetic factors, it is not surprising that individuals with ADHD and RDs manifest common neuropsychological deficits, such as working memory and processing speed difficulties. Moreover, individuals with these comorbid conditions face a ‘double vulnerability’ because they experience
the deficits of both conditions. It has been shown that they experience greater academic impairment and demonstrate more stable deficits than children with either disorder alone (Willcutt et al., 2007). In adulthood, these individuals experience poor psychosocial and occupational outcomes (Sexton et al., 2011). To date, no studies have evaluated interventions for students with comorbid ADHD and LD and the present study is the first to do so.

1.5.2 Issues Pertaining to ADHD/LD in College Students

The possible impact of comorbid ADHD and LD may be especially relevant to college students. Together, students with ADHD and/or LD constitute over half the population of college students with disabilities (Brinckerhoff et al., 2002). However, despite their growing numbers, this population remains under-investigated in the literature and deserves further attention. This subpopulation is especially unique in that they have successfully completed secondary school, yet the research findings suggest they struggle at the post-secondary level.

Several issues emerge when professionals are faced with diagnosing and treating these students. Firstly, the current criteria for diagnosing ADHD are more appropriate for children than adults, and thus might not capture the core symptoms manifest by these young adults. Secondly, college students might be inclined to feign ADHD or LD by over-reporting symptoms to procure academic accommodations or stimulant medication, although this problem is less common in Canada than the United States (Harrison & Edwards, 2010). Lastly, as previously mentioned, medication treatment may be less helpful in this group, since a substantial proportion do not take it as prescribed (Green & Rabiner, 2012).

1.5.3 Working Memory in ADHD/LD
There appears to be an overlap in terms of the underlying processing deficits common to both ADHD and LD. Executive functions (EF) are one area of difficulty shared by both disorders. Specifically, WM, a central component of the EFs, is an important mechanism implicated in these two disorders. WM functioning has consistently been found to be impaired in groups of individuals with LD and ADHD (Gathercole, Brown, & Pickering, 2003; McGrath et al., 2011; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011).

Although working memory impairments have been found in children, adolescents and adults with ADHD, they are not manifest by all individuals with ADHD (Biederman et al., 2004; Loo et al., 2007; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). Studies conducted at the individual level reveal that only about 50% of individuals with ADHD have WM impairments (Lambek et al., 2011). Estimates appear to vary widely based on the definition of impairment and the measures used.

While WM deficits are associated with LDs, the pattern of WM impairment differs based on the subtype of LD. Research has shown reading disabilities (RD) are strongly associated with deficits in WM (Gathercole et al., 2006; Swanson, 2006). Those with both an RD and ADHD have greater deficits in working memory, along with an impairment in rapid naming, which is unique to this comorbid group (Bental & Tirosh, 2007; Rucklidge & Tannock, 2002). In children with reading problems, WM predicted reading comprehension ability (Swanson, 1999). Processing speed and WM have been shown to be significant predictors of oral reading fluency (Jacobson et al., 2011). It appears that later reading skills (i.e. multisyllabic decoding and reading comprehension) rely more heavily on the use of WM. One study found that WM ability distinguished good and poor reading decoders aged 8 to 12 (Conners, Atwell, Rosenquist, & Sligh, 2001).
Research findings also support a relationship between dyslexia and components of WM (i.e. the phonological loop and central executive; de Jong, 2006). Jeffries and Everatt (2004) found that children with dyslexia showed evidence of central executive dysfunction; in addition, Smith-Spark, Fisk, Fawcett, & Nicolson (2003) indicated that the adults with dyslexia in their study also had central executive difficulties; specifically, they struggled on a complex spatial WM task. Recent evidence from neuroimaging studies provides further support for WM deficits in children and adults with developmental dyslexia (Beneventi, Tønnessen, Ersland, & Hugdahl, 2010; Berninger, Raskind, Richards, Abbott, & Stock, 2008).

WM is also associated with the development of math skills, especially calculation and arithmetic word problems (Passolunghi & Siegel, 2004; Wilson & Swanson, 2001). It is assumed that mathematical calculation problems involving a series of steps require WM to hold and manipulate the information.

As reviewed above, WM is an underlying processing deficit shared by both ADHD and LD. To date, no studies have investigated WM deficits in college students with ADHD/LD. Given that this is a high achieving subgroup of young adults, it would be difficult to predict their pattern and severity of WM impairments. One study of college students with ADHD found that these students had WM impairments relative to normal controls, although this group did not have a comorbid diagnosis of an LD (Gropper & Tannock, 2009). This is an important gap in the literature that has yet to be addressed.

1.6 Working Memory Training

Previously, WM was regarded as a fixed trait of the individual. Recent research has challenged this notion by providing evidence that cognitive functions, such as WM, can be
improved through training. Initially, it was assumed that the only way to improve WM was through repeated rehearsal and chunking strategies. However, any improvements that were made were largely ‘material specific,’ as there was no evidence of transfer effects to non-trained cognitive tasks or everyday functioning (Butterfield, Wambold, & Belmont, 1973; Ericsson, Chase, & Faloon, 1980). A limited amount of research has looked at the extent to which reinforcement and incentives can impact WM performance in children with ADHD (Dovis, Van der Oord, Wiers, & Prins 2011; Shiels et al., 2008; Strand et al., 2012). These studies demonstrated that incentives and rewards were able to improve the performance of children with ADHD on WM tasks. The combination of stimulant medication and incentives led to better outcomes than either condition alone (Strand et al., 2012). However, outcome scores were still below normal levels. The problem with these interventions is that when they are not being implemented, WM skills will return to baseline levels. Furthermore, the effectiveness of medication depends on compliance as well as the timeframe in which the drug remains active.

Cognitive training programs have provided preliminary evidence that WM shows neuroplasticity, even in adulthood, and can be improved through intensive, systematic training. While several different types of cognitive training programs exist, only those with the most empirical support will be discussed here. Jaeggi and her colleagues have used variations of an adaptive $n$-back task, one of the most popular WM measures in the neuroimaging literature, to improve WM in children and adults. It is based on classic WM span measures (Conway et al., 2005; Daneman & Carpenter, 1980; Shah & Miyake, 1996). Typically administered on the computer, the $n$-back requires test-takers to make a response every time the item currently presented matches a previous item that was presented a specified number of trials ago. The processing load can be matched to the performance of each individual based on his or her response
accuracy and performance time, so that participants are training at their WM capacity limit. In contrast to other WM training regimens, participants are only training on one task, so that transfer effects can be clearly attributed to this particular task. In terms of the intensity of training, typically participants train for approximately 20 sessions lasting 25 minutes each over the course of a month (Jaeggi et al., 2008). In a study on adults, participants demonstrated far transfer of WM training performance to matrix reasoning tasks (Jaeggi et al., 2008). Similarly, children who improved on the training task showed performance increase on an untrained fluid intelligence task (Jaeggi, Buschkuehl, Jonides, & Shah, 2011). These findings support the suggestion that training WM leads to improvements in reasoning with novel information. However, the n-back has recently been criticized due to weak correlations between this task and other WM span measures, providing evidence that they are not all measuring a single WM construct (Kane, Conway, Miura, & Colflesh, 2007; Oberauer, 2005; Roberts & Gibson, 2002). Kane et al. (2007) suggested that complex span tasks require serial recall and retrieval, whereas n-back tasks require recognition and discrimination, and that these two aspects of remembering are minimally related at the individual level, although both are important for fluid reasoning.

Dr. Alloway developed Jungle Memory (2011), an 8-week cognitive training program designed for children aged 8 to 16. This program is administered on the computer and uses an adaptive algorithm so it can adapt to the trainees’ ability levels. It features three adaptive complex span tasks. Preliminary evidence from a sample of children with general learning difficulties suggests that this program not only improves WM, but also leads to better learning outcomes in math and spelling (Alloway, 2012). These results were reportedly replicated in students with dyslexia and high functioning autism, although they have not been published (Jungle Memory,
However, as previously mentioned, this program can only be used with children and, therefore, would not be appropriate for use in the present study.

The WM training program (Cogmed) was initially created by Torkel Klingberg and subsequently developed and marketed by Cogmed Cognitive Systems in Sweden and then by Pearson Education (2011) in North America (www.cogmed.com). Pearson’s claim is that, “Cogmed Working Memory Training is a computer-based solution for attention problems caused by poor working memory.” While originally intended for individuals with ADHD, beneficial training effects have been demonstrated in other child and adult populations (see Klingberg, 2010 for a review). There are some factors that distinguish this program from its competitors. One such factor is the intensity of WM training activities: tasks are repeated for 30-45 minutes a day, 5 days a week for 5 weeks. In addition, training is supported by a Cogmed coach who is responsible for providing motivation, support and feedback throughout the training program. On their website, Cogmed claims to have more published research than any other cognitive training program. In Chapter Two, further details about the Cogmed WM training program are provided.

It is worth noting that none of these aforementioned WM training regimes provides a detailed explicit account of the theoretical WM framework upon which they are based. However, the principles of cognitive load theory (CLT) are highly relevant to the design of these training programs (Sweller, Van Merrienboer, & Paas, 1998). CLT assumes that WM is a limited capacity cognitive system that is unable to process many novel elements simultaneously. The process of learning occurs by combining and organizing novel information that enters through WM, enabling schemas to be created in long-term memory. Once schemas become automated, which requires a great deal of practice, WM capacity can be freed up. CLT has been applied to understanding how information can be efficiently processed in WM. To facilitate learning, it is essential to order tasks
from simple to complex, integrate multiple modalities of information (i.e. auditory verbal and visual spatial), reduce redundancy, fade support and guidance over time, and vary the nature of the tasks being learned (van Merriënboer & Sweller, 2010). An informed appraisal of the design of the Cogmed WM training program indicates that the principles of CLT have been taken into account. For example, each training task incorporates auditory verbal, visual spatial, or both modalities of information. Likewise, tasks start at a relatively easy level and become increasingly difficult as participants gain mastery. For example, as task demands increase participants are required to remember more items and/or changing locations of shapes on the screen. Moreover, each activity is appropriately adjusted to the individual’s performance and skills.

In recent years, a number of studies have been undertaken to examine the effectiveness of the Cogmed WM training program. All published Cogmed studies are presented in Table 1. A meta-analysis of the WM training literature concluded that WM training produces short-term specific improvement in WM skills, but there was limited evidence to support the generalizability of WM training to other skills (Melby-Lervåg & Hulme, 2012). The following studies reported a lack of WM training transfer and/or had methodological limitations. Neither Holmes et al. (2009) or Holmes, Gathercole, Place et al. (2010) found training related improvements on a complex reasoning task, or tests of math calculation and vocabulary. Several studies that did report a decrease in ADHD symptoms following WM training relied on subjective reports. For example, Beck, Hanson, Puffenberger, Benninger, & Benninger (2010) and also Klingberg et al. (2005) relied on parent ratings. However, these parents were heavily involved in the implementation of the WM training and may have been biased in their reporting. Moreover, two studies that reported positive findings did not utilize a control group (Holmes, Gathercole, Place et al., 2010; Mezzacappa & Buckner, 2010). Similarly, the research findings reported in Table 1 indicate that
WM training consistently leads to improvements on WM tasks similar to those trained, but transfer effects to other cognitive and academic tasks has been inconsistent. This would suggest that, in a sample of college students with ADHD/LD, WM training should produce improvements on WM measures, but it is unclear whether these improvements will generalize to attention, cognitive functioning and academic achievement.

There are, however, some studies that have reported beneficial effects on non-trained WM tasks (i.e. complex reasoning, response inhibition and attention), suggesting training related generalizability (Holmes et al., 2009; Klingberg et al., 2002; Klingberg et al., 2005; Thorell et al., 2009; Westerberg et al., 2007). Two of these studies noted sustained treatment effects at 3 and 6-month follow-up (Holmes et al., 2009; Klingberg et al., 2005). There is some evidence to suggest that training effects generalize to behavioural improvements, including a decrease in inattentive and cognitive symptoms (Brehmer, Westerberg, & Bäckman, 2012; Klingberg et al., 2005; Westerberg et al., 2007). In one of the few studies published on adults, Brehmer et al. (2012) found that not only did younger adults show training gains on near and far transfer measures, so did older adults, calling into question the finding that WM performance peaks at 45 years of age. These older adults improved on tasks of auditory verbal WM and sustained attention, and had fewer self-reported memory complaints. These gains were maintained at a 3-month follow-up. Given the link between WM and attention and that individuals with high WM capacity are less likely to be distracted and mind-wander, it is not surprising that improving WM would lead to an improvement in attention skills. Furthermore, one study found improvements in children’s math skills at a 6-month follow-up, while another study showed improvements in reading comprehension at post-test, evidence of the link between WM and academics (Dahlin, 2011; Holmes et al., 2009).
In their review of the WM training literature, Shipstead, Reddick and Engle (2012) concluded that, to date, the current research does not provide conclusive support for the efficacy of WM training. Their primary concern was that most of the studies are methodologically flawed. They emphasized that an ideal design should include multiple measures of ability and valid WM capacity tasks sufficiently different from training tasks, and raters should be blind when subjective measures of change are used. Based on the present literature, there appears to be inconclusive evidence as to whether WM training is effective. Further studies are needed to provide more convincing evidence. Most importantly, these studies should have random assignment, a control group, and an alternative active training procedure when possible. These methodological requirements are necessary in order to demonstrate unambiguous treatment effects (Melby-Lervåg & Hulme, 2012). Taking these factors into account, the present study investigated WM training effects in a group of young adults with a diagnosis of ADHD/LD presently enrolled in post-secondary education. Using an RCT design, the focus of this study was to build on previous research, while addressing many of the methodological concerns raised by previous studies.

1.6.1 Working Memory Training in Attention-Deficit/Hyperactivity Disorder and Learning Disabilities

The most common empirically supported treatments for ADHD and LD include medication, academic and behaviour interventions, and a combination of these approaches into a multimodal therapy program. However, medication is not typically used to treat an LD; it is only effective as long as it is taken regularly, and it does not create long-lasting benefits. Given these shortcomings, efforts are being made to create interventions that lead to long-lasting effects and remediate the underlying neurocognitive deficits associated with these disorders.
Current research directed to WM training in individuals with ADHD has been limited to children and adolescents, and only a limited number of these studies were randomized controlled trials (RCTs; see Table 1). There are two other RCTs to date that have investigated WM training in children and adolescents with co-occurring ADHD/LD (Beck et al., 2010; Gray et al., 2012). Beck et al. (2010) utilized a sample of children and adolescents with co-occurring ADHD/LD. Participants were randomly assigned to experimental and wait-list groups. Following training, parent ratings indicated that participants improved on ADHD inattentive symptoms as well as overall number of ADHD symptoms, initiation, planning/organization and WM. Teacher ratings were non-significant. These findings should be interpreted with caution, as parents provided supervision of WM training, which was conducted in the home; therefore, these parents may have been biased in their reporting. In contrast, Gray et al. (2012) examined the effects of WM training in adolescents with severe LD and comorbid ADHD, using a randomized controlled trial design. Participants completed the training program at school. Results indicated that those who completed WM training improved on a subset of WM measures. Moreover, those students who showed the most improvement were rated as less inattentive/hyperactive at home by their parents.

Previous studies on WM training in young adults have consistently reported that WM shows neuroplasticity and, that by training WM, improvements generalize to non-trained WM tasks. However, with respect to generalizability of WM improvements to other areas of functioning, the findings are less conclusive. Furthermore, the research in the field of WM training has been fraught with methodological concerns. Many of the studies conducted did not utilize a control group or random assignment. To date, there is no existing research examining the effects of WM training in young adults enrolled in post-secondary schooling with a diagnosis of ADHD or LD. Therefore, the aim of the current study was to address this gap in the literature using a
randomized, controlled trial to examine whether Cogmed would be effective in improving WM, academic achievement, and ADHD symptoms in a subgroup of college students with ADHD and/or LDs.
<table>
<thead>
<tr>
<th>Authors</th>
<th>Sample</th>
<th>Question</th>
<th>Design</th>
<th>Measures</th>
<th>Confounds/Weakness</th>
<th>Results</th>
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<tr>
<td>Gray, Chaban, Martinussen, Goldberg, Gotlieb, Kronitz, Hockenberry, Tannock, 2012; <em>Journal of Child Psychology and Psychiatry</em></td>
<td>ADOLESCENTS Severe LD and comorbid ADHD</td>
<td>1. Is it feasible to implement Cogmed in a residential school with hard-to-treat adolescents? 2. Will Cogmed improve WM? 3. Will it improve behavioural symptoms of inattention?</td>
<td>RCT Randomized to adaptive training program or Academy of Math</td>
<td>-Digit Span Forwards and Backwards (WISC-IV) -CANTAB Spatial WM -WM Rating Scale (Alloway, Gathercole, Kirkwood &amp; Elliot, 2009) -D2 Test of Attention -Wide-Range Achievement Test-4-Progress Monitoring Version -The Strengths and Weakness of ADHD-symptoms and Normal-Behaviour Scale (SWAN) -The IOWA Conners’ Scale</td>
<td>- Lack of long-term follow up - Participants not characterized by type of LD</td>
<td>- Cogmed group showed significant improvement on criterion WM measures compared to Academy of Math group - No training effects on near or far transfer measures - Those who showed biggest improvement on WM training tasks were rated as less inattentive/hyperactive at home by parents</td>
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<tr>
<td>Authors</td>
<td>Group Description</td>
<td>Study Aim</td>
<td>Design</td>
<td>Outcome Measures</td>
<td>Findings</td>
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<td>Green, Long, Green, Iosif, Dixon, Miller, Fassbender, Schweitzer, 2012; Neurotherapeutics</td>
<td>SCHOOL-AGED (7-14 years old) ADHD</td>
<td>1. Will WM training increase on-task behaviour?</td>
<td>RCT (double-blind) N=26 12 assigned to Cogmed 14 assigned to placebo control</td>
<td>- The Restricted Academic Setting Task (RAST) - The WM Index score from the WISC-IV - Conners’ Rating Scale</td>
<td>- Greater number of participants on medication in the WM training group - Modest sample size</td>
<td></td>
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<tr>
<td>Söderqvist, Nutley, Ottersen, Grill, and Klingberg, 2012; Frontiers in Human Neuroscience</td>
<td>SCHOOL-AGED (6-12 years old) Diagnosed intellectual disability (IQ&lt;70) Computerized training of non-verbal reasoning and working memory in children with intellectual disability</td>
<td>1. Is WM training feasible? 2. Does WM training lead to improvements on non-trained tasks?</td>
<td>RCT Randomized to adaptive training program or non-adaptive version N=41 22=adaptive training 19=non-adaptive training group</td>
<td>- Word span task - Odd One Out task from the Automated WM Assessment - Block design from WPPSI - Raven’s colored progressive matrices - Auditory Attention and Comprehension of Instruction subtests from NEPSY - Aston Index test for language disabilities - Strengths and Difficulties questionnaire</td>
<td>- Lots of comorbidities</td>
<td></td>
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<tr>
<td>Gibson, Kronenberger, Gondoli, Johnson,</td>
<td>ADOLESCENTS (9-16 years old)</td>
<td>1. Does Cogmed-RM target the</td>
<td>RCT N=61</td>
<td>- Verbal and spatial immediate free recall task</td>
<td>Limited outcome measure – free recall task</td>
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</table>

- Females (compared to males) without comorbid diagnoses and higher baseline performance showed greater progress - No significant effects of training observed at 1-year follow-up

- Cogmed group showed significant reductions on the RAST off-task ADHD-associated behaviour - Cogmed group significant improved on the WMI of the WISC-IV - No differences between groups on the Conners’

Limited outcome measure – free recall task - Secondary memory component of WM capacity did not
<table>
<thead>
<tr>
<th>Morrissey, &amp; Steeger, 2012; <em>Journal of Applied Research in Memory and Cognition</em></th>
<th>Component analysis of simple span vs. complex span adaptive working memory exercises: A randomized, controlled trial.</th>
<th>primary memory (PM) component of WM capacity or the secondary memory (SM) component?</th>
<th>31= simple span training 30= complex span training condition (IFR)</th>
<th>improve even in modified, complex span training condition</th>
</tr>
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<tbody>
<tr>
<td>Gibson, Gondoli, Johnson, Steeger, Dobrzenski, Morrissey, 2011; <em>Child Neuropsychology</em></td>
<td>Component analysis of verbal versus spatial working memory training in adolescents with ADHD: A randomized, controlled trial</td>
<td>1. Is spatial only training more effective than verbal training? 2. Do effects extend past the trained domain? 3. Does training enhance primary (PM) or Secondary (SM) memory?</td>
<td>RCT N=47 23= Spatial WM group 24= Verbal WM group</td>
<td>Limited outcome measure – free recall task  No passive/active control group  Some of the ‘verbal’ condition exercises included a spatial component</td>
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<td>Bergman Nutley, Söderqvist, Bryde, Thorell, Humphreys, PRE-SCHOOL HEALTHY GROUP</td>
<td>1. Is Gf improved through computerized</td>
<td>RCT (double-blind) N=112</td>
<td>- DuPaul ADHD rating scale  - Verbal &amp; spatial immediate free recall tasks (divided into recency and pre-recency scores)  Limited outcome measure – free recall task  No passive/active control group  Some of the ‘verbal’ condition exercises included a spatial component</td>
<td>Non-verbal reasoning group: improvements in Gf (latent variable of Raven’s and block</td>
</tr>
<tr>
<td>Reference</td>
<td>Training and Tasks</td>
<td>24=WM training group</td>
<td>25=Non-verbal reasoning (NVR) training group</td>
<td>27=WM+NVR group</td>
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<td>Klingberg, 2011; <em>Developmental Science</em></td>
<td>Gains in fluid intelligence after training non-verbal reasoning in 4-year old children: A controlled, randomized study</td>
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<td>Johnstone, Roodenrys, Phillips, Watt, &amp; Mantz, 2010; <em>ADHD Atten Def Hyp Disord.</em></td>
<td>A pilot study of combined working memory and inhibition training for children with ADHD</td>
<td>RCT (double blind)</td>
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<tr>
<td>Beck, Hanson, Puffenberger, Benninger, &amp; Benninger, 2010; <em>Journal of Clinical</em></td>
<td>1. What is the impact of WM training on ratings of WM, EF and ADHD (29%)</td>
<td>RCT Waitlist control</td>
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</table>
**Child and Adolescent Psychiatry**

A controlled trial of working memory training for children and adolescents with ADHD

| Computerized training of working memory in children with ADHD-a randomized, controlled trial |

| CHILDREN (Mean age=9) ADHD/attention problems |
| 1. What is the effect of cogmed training on WM in children with ADHD? |
| RCT Non adaptive control Double blind |
| N=44 22=Experimental Group 22=Control Group |

- Digit span - Span board - Stroop task - Raven’s - Head movements - Connors

- No formal ADHD assessment

- Excluded children with ODD

- Ceiling - Raven’s, Stroop

Klingberg, Experiment 1: 1. Can WM RCT - Span board - Some children on meds Improvements on:

- Parent rated WM, plan/organize and initiate index on BRIEF
- Significant differences follow up:
  - Parent Conners’ (inattention, hyperactivity)
  - All subscales of parent BRIEF

**Correlations:** cogmed index score correlated with baseline to post change in parent-rated WM and inattentive symptoms and teacher rated hyperactivity.

No significant teacher ratings

**Also had comorbid disorders**

ADHD symptoms?

| 27= Experimental Group 24= Control Group |
| Teachers blind to condition (training done at home) |

- Analysis: Follow up analysis all t-tests due to missing data (whereas post analysis were repeated measures time*condition)

(Conners’)

- Parent rated WM, plan/organize and initiate index on BRIEF
- Significant differences follow up:
  - Parent Conners’ (inattention, hyperactivity)
  - All subscales of parent BRIEF

Post/follow up improvements on:
- spanboard, digit span, Stroop, Raven’s

Post/follow up parent ratings lower on:
- Inattention
- Hyperactivity/impulsivity

- Lower parent rated ODD symptoms and ADHD index scores at follow up
<table>
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<tr>
<th>Study</th>
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<th>Question</th>
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<tr>
<td>Forssberg, Westerberg, 2002; Journal of Clinical and Experimental Neuropsychology</td>
<td>CHILDREN ADHD (Mean age=11)</td>
<td>Capacity be improved by training?</td>
<td>Non adaptive control Double blind</td>
<td>- Stroop - Matrices - Choice reaction time tasks - Head movements - No measures of changes in everyday life - No follow up</td>
</tr>
</tbody>
</table>
|                                           | Experiment 2: ADULTS HEALTHY (Mean age=25) |                                                                           | Experiment 1: N=14 7= Experimental Group 7= Control Group  
Experiment 2: N=11 4= Experimental Group 7= Control Group |                                                                                                                                                           |
<p>| | | | | |
|                                           |                                        |                                                                           |                                                                                                         |                                                                                                                                                           |
| Brehmer, Westerberg and Bäckman, 2012; Frontiers in Human Neuroscience | YOUNG and OLDER ADULTS (aged 20-30 and 60-70) | 1. Will WM training lead to improved WM in younger and older adults? | RCT 2 conditions: adaptive training or low task difficulty level (active control) program N=100 50 completed adaptive training 50 completed low task difficulty level training | - Digit Span Forward and Backwards (WAIS-IV) - Span Board Forward and Backward - PASAT - Stroop task - Ravens - Cognitive Failures Questionnaire - Training related WM improvements led to improved performance on a task of sustained attention and self-reporting of less cognitive failures for both young and old adults - Improvements sustained after 3-months |
|                                           |                                        | 2. Will improvements in WM generalize?                                   |                                                                                                         |                                                                                                                                                           |
|                                           |                                        | 3. Will improvements be sustained at 3- month follow-up?                 |                                                                                                         |                                                                                                                                                           |
| Lundqvist, ADULTS with an 1. What are RCT | - Questionnaire No active control group |                                                                           |                                                                                                         | Baseline: Most                                                                                                                                                                                                                                                                     |
| Study                                                                 | Participants                                                                 | Design                                                                                     | Measures                                                                                           | Results                                                                                           | Notes                                                                                     |
|----------------------------------------------------------------------|------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Grundstro, Samuelsson, Ronnberg, 2010; Brain Injury                   | acquired brain injury (Mean Age = 43)                                        | Cross-over design 4 week follow up 20 week follow up N=21 10= Experimental Group 11= Control Group | about WM function in daily life - WAIS-IV DS - WAIS-IV block span board - PASAT - Stroop - Listening span - Picture span - Canadian occupational performance measure - EQ-5D (quality of life, health) | Analysis: Didn’t include control group in statistical analyses; Compared test-re-test within each group (pre-post diff in EXP, none in CTL) | commonly reported WM problems: remembering long instructions; solving problems |
| Westerberg, Jacobaeus, Hirvikoski, Clevberger, Ostensson, et al, 2007; Brain Injury | ADULTS Former stroke rehab patients (Mean age = 54)                        | RCT Passive control N=18 9= Experimental Group 9= Control Group                             | - WISC-IV DS - Span Board - Stroop - Raven’s - Claeson-Dahl (word list recall, short term and delayed) - PASAT - RUFF2/7 - CFQ | No active control Assessor not blind for post assessment Ceiling effect on Raven’s          | Significant improvements 4 wk follow up: picture span; PASAT; Listening span; Block span backwards, CWIT Significant improvements 20 wk follow up: PASAT; Listening span; Block span backwards, CWIT; block span forwards; work performance satisfaction Long-term effects: stronger for complex WM tasks |</p>
<table>
<thead>
<tr>
<th>Authors</th>
<th>Sample</th>
<th>Question</th>
<th>Design</th>
<th>Measures</th>
<th>Confounds/Weakness</th>
<th>Results</th>
</tr>
</thead>
</table>
| Dahlin, K. 2011; Reading and Writing | CHILDREN Learning and attention problems (Mean age = 10.5) | 1. To what extend will WM training improve WM of children with learning and attention difficulties?  
2. Will WM training enhance literacy development? | NON-RCT Pre/Post/Follow up  
N=57  
42= Experimental Group  
15=Control Group  
Compared experimental group outcomes with those of Klingberg’s 2005 study (the active CTL group) | - Raven’s colored progressive matrices  
- WISC-III Digit Span  
- WAIS-NI Span board & Stroop  
- Reading comprehension test  
- Phonological non-word reading test  
- Orthographic verification (tests developed for study) | Not randomized  
No active control  
Experimental/control participants from different schools  
Controls weren’t given cognitive measures at T2  
Reading measures not standardized | Experimental group improvement (T2 relative to T1):  
- Span board  
- Digits backwards  
- Raven’s matrices  
Experimental post and follow-up as compared to controls:  
- Reading comprehension  
- Correlations between WM (including Span board) and reading comprehension |
<table>
<thead>
<tr>
<th>Study Source</th>
<th>Population</th>
<th>Research Questions</th>
<th>Study Design</th>
<th>Measures</th>
<th>Data Analysis</th>
<th>Findings</th>
</tr>
</thead>
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<tr>
<td>Kronenberger, Pisoni, Henning, Colson, &amp; Hazzard, 2011; <em>Journal of Speech, Language and Hearing Research</em>&lt;br&gt;Working memory training for children with cochlear implants: A pilot study</td>
<td>CHILD/ADOLESCENT&lt;br&gt;Deaf with cochlear implants (CI)&lt;br&gt;(Mean age = 11)</td>
<td>1. What is the feasibility of WM training for children with CIs?&lt;br&gt;2. Does WM training improve WM/neurocognitive skills and speech &amp; language skills this population?</td>
<td>Single sample&lt;br&gt;N=9&lt;br&gt;Pre/Post/1 month follow-up/6 month follow up&lt;br&gt;Different Digit Span/Spatial Span lists for each visit</td>
<td>- Program feasibility questionnaire&lt;br&gt;- Digit Span&lt;br&gt;- Spatial span&lt;br&gt;- BRIEF&lt;br&gt;- WRAML (sentence memory)</td>
<td>Non randomized&lt;br&gt;No control group&lt;br&gt;WRAML subject to practice effects (only measure for which order wasn’t changed at each trial)</td>
<td>Analysis: used change scores&lt;br&gt;All improved on Cogmed index score&lt;br&gt;Half of parents were satisfied and thought Cogmed helped&lt;br&gt;&lt;br&gt;<em>Post Test Improvement</em>: DSF, SSPF, SSB, BRIEF- WM&lt;br&gt;- Sentence Memory&lt;br&gt;1 Month Follow Up Significant:&lt;br&gt; - Digit Span forward&lt;br&gt;6 Month Follow Up Significant:&lt;br&gt; - Sentence Memory</td>
</tr>
<tr>
<td>Lohaugen, Antonsen, Haberg, Gramstad, Vik, Brubakk, &amp; Skranes, 2011; <em>Journal of Pediatrics</em>&lt;br&gt;Computerized working memory training improves function in adolescents born at extremely low birth weight</td>
<td>ADOLESCENTS&lt;br&gt;Pre-term low birth weight&lt;br&gt;(Mean age = 15)</td>
<td>1. What are the effects of WM training on verbal WM and EF in adolescents who were born at low birth weight?</td>
<td>NON-RCT&lt;br&gt;Pre/Post/6 month follow up&lt;br&gt;N=46&lt;br&gt;16= Low birth weight active Cogmed&lt;br&gt;19= Normal birth weight active Cogmed&lt;br&gt;11= Non-intervention</td>
<td>- Digit Span&lt;br&gt; - Letter Number Sequencing&lt;br&gt; - Visual spatial span (WISC-IV)&lt;br&gt; - Wechsler memory scale-III&lt;br&gt; - Parent ADHD rating scale</td>
<td>Analysis: T-tests for changes from baseline to follow up within groups, no between group analysis&lt;br&gt;No behavioural follow up&lt;br&gt;No active control&lt;br&gt;Limited transfer measures</td>
<td>Post Test:&lt;br&gt; - Both training groups improved on WM tasks and effects were sustained at 6 month follow up&lt;br&gt; - Passive control group no changes</td>
</tr>
<tr>
<td>Mezzacappa, E. &amp; Buckner J., 2010; <em>School Mental</em>&lt;br&gt;Inattention/hyperact</td>
<td>CHILDREN</td>
<td>1) Is it feasible to conduct WM training during school hours</td>
<td>NON-RCT&lt;br&gt;Single group</td>
<td>- ADHD rating scale&lt;br&gt; - WISC DS –</td>
<td>Non randomized&lt;br&gt;Teachers not blind to</td>
<td>Post Test Improvements:&lt;br&gt;-Longest digit</td>
</tr>
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</table>
### Health

Working memory training for children with attention problems or hyperactivity: A school-based pilot study

<table>
<thead>
<tr>
<th>Low SES</th>
<th>with a low SES group of children that have inattentive/hyperactive symptoms? 2) What are the effects of intervention on symptom reduction and working memory performance?</th>
<th>pre/post design</th>
<th>LDB (outcome measure = raw change, sequence length) - WRAML finger windows</th>
<th>condition, no parent reports</th>
<th>backwards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low SES</td>
<td>Mean Age = 9</td>
<td>N=9</td>
<td></td>
<td>Small sample size</td>
<td>- WRAML finger windows</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>No follow up</td>
<td>- Teacher ratings of inattention/hyperactivity</td>
</tr>
</tbody>
</table>

- Holmes, Gathercole, & Dunning, 2009; Developmental Science

Adaptive training leads to sustained enhancement of poor working memory in children

<table>
<thead>
<tr>
<th>CHILDREN</th>
<th>1. Do the benefits of WM training extend to children with low WM who do not have ADHD? 2. What sub-components of WM are trained?</th>
<th>NON-RCT (controlled, not randomized)</th>
<th>Automated Working Memory Assessment (AWMA; Alloway, 2007) - Following instructions task - WORD - WOND - WASI</th>
<th>Control participants in one school experimental in another school</th>
<th>Post test improvement: Experimental participants all WM tasks, instructions task</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHILDREN</td>
<td></td>
<td>Baseline/post/6 months follow up</td>
<td>Non adaptive control N=42 22= Experimental Group 20= Control Group</td>
<td>No 6 month follow up for controls</td>
<td>Follow up improvement: All WM tasks, instructions task, math</td>
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<tr>
<td>LOW WM</td>
<td></td>
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<td>(&lt;15th percentile)</td>
<td>Mean Age=10</td>
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</table>

- Holmes, Gathercole, Place, Dunning, Hilton, & Elliott, 2010; Applied Cognitive Psychology

Working memory deficits can be overcome: Impacts of training and medication on ADHD

<table>
<thead>
<tr>
<th>CHILDREN</th>
<th>1. What is the difference between stimulant medication treatment and WM training on different aspects of WM?</th>
<th>NON-RCT Controlled for re-test effects (new tasks added at post)</th>
<th>AWMA battery</th>
<th>Not randomized/controlled ‘Introduction’ of medication after only 24 hrs off the medication</th>
<th>Post test:</th>
</tr>
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<tbody>
<tr>
<td>ADHD Combined</td>
<td>Mean Age=9</td>
<td>N=25</td>
<td></td>
<td></td>
<td>- Medication improved visual-spatial WM</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Cogmed: gains in all four WM components, especially for visual-spatial from below average to average</td>
</tr>
<tr>
<td>Training and transfer effects of executive functions in preschool children</td>
<td>CHILDREN HEALTHY GROUP (Mean age=4)</td>
<td>1. Will both training programs (visual-spatial WM training, inhibition training) improve trained constructs and transfer to other constructs? 2. Will there be transfer effects after both programs to lab measures of attention?</td>
<td>NON-RCT N=65 18=inhibition training program 17=visual spatial WM training 14=active control (computer games) 16=passive control</td>
<td>- Interference control: day/night Stroop task -Response inhibition: commission errors go/no go -Visual-spatial WM: span-board task (WAIS-R-NI) - Verbal WM: word span task</td>
<td>Training only 15 mins/day Used only 3 of 5 Cogmed tasks (visual-spatial)</td>
</tr>
</tbody>
</table>
CHAPTER TWO

Research Objectives, Hypotheses and Methodology
2.1 Objectives and Hypotheses

The overall objective of this dissertation research was to evaluate the effectiveness of computerized WM training in a population of college students with ADHD/LD using a randomized controlled design. The specific objectives were: 1) to ascertain the feasibility of WM training and compliance level of college students with ADHD/LD; 2) to determine whether WM training will enhance WM; 3) to examine the extent to which Cogmed WM training would lead to improvements on cognitive tasks that do not resemble the training activities as well as daily-life activities, such as self-regulation of attention; 4) to evaluate whether the training effects would transfer to academic performance; 5) to ascertain whether any gains in functioning would persist (for at least 2 months) beyond the end of the training period; and 6) to explore predictors of WM training benefits (or changes or improvements), such as baseline level of WM performance, etc.

Existing literature suggests that auditory-verbal and visual-spatial WM in children and adolescents with ADHD are improved as a result of WM training, and that gains persist for at least 4 months (Beck et al., 2010; Holmes et al., 2009; Klingberg et al., 2005). Thus, it was hypothesized, consistent with Baddeley’s Multi-Component Theory of WM, that at post-treatment and at follow-up, participants would show improvement on both auditory-verbal and visual-spatial WM criterion measures. Previous research has consistently provided support for a relationship between WM and academic achievement (Alloway & Alloway, 2010; Gathercole et al., 2004) and has an impact on reading skills, comprehension and arithmetic (St. Clair-Thompson & Gathercole, 2006). Therefore, it was hypothesized that improvements in WM would be accompanied by improvements in those areas of literacy and numeracy that are...
dependent on WM. Furthermore, WM problems are linked to some of the behavioural symptoms of ADHD/LD (i.e. inattention). Therefore, it was hypothesized that WM training would improve participants’ self-regulation of attention in everyday life.

2.2 Intervention Program

2.2.1 WM training program.

The software-based program developed by Klingberg, and subsequently by Cogmed Cognitive Medical Systems AB, trains visual-spatial and auditory-verbal WM and was selected for use in the present study. Cogmed provided the training licenses free of charge for the present study. There are three different versions of Cogmed for three different age groups. Cogmed JM is the version for pre-schoolers, Cogmed RM is for school-aged children and Cogmed QM is for adults. Thus, QM was selected for the current study on young adults with ADHD/LD. This WM training program is the most empirically validated WM training program available to date. Unlike the n-back tasks, Cogmed includes several training activities (see Table 2.1). Evidence suggests that it leads to increases in WM capacity as well as transfer effects to other cognitive tasks closely related to WM (Klingberg, 2010).

The Cogmed program requires 30-45 minutes of training a day, 5 days a week for 5 weeks, totaling 25 sessions. The training battery includes 12 different WM training exercises involving the manipulation and storage of visuo-spatial information (i.e. reproducing a sequence of moving shapes) and auditory-verbal WM information (remembering strings of digits). Training plans are individualized and modified based on current performance, but the typical plans include 12 different WM training exercises; subjects complete 8 of the 12 tasks every day, 15 trials of each task. In addition, feedback and rewards are provided based on performance of
each trial, and the difficulty level is constantly adjusted as a function of individual performance so that an optimal level of challenge is maintained and participants are always working at their WM capacity. Responses to each trial are logged to a file and participants upload new data files via the Internet to a secure server. Compliance and training performance are verified by a certified Cogmed training coach, typically a psychologist, who supervises the WM training and monitors participants’ data on the server. In this study coaching was provided by Jewish Vocational Services (JVS), a community agency that is completely independent from the research team. It should be noted that, despite the name, JVS Toronto provides services irrespective of religious affiliation. Coaches reviewed the participant’s daily performance on each task and were in touch with the study participants on a weekly basis, via email or telephone calls. This ensured that participants were sticking to an appropriate training schedule. Moreover, the coaches informed students how they were progressing and provided tips if they were struggling (i.e. telling them to train at the same time every day, helping them plan out a schedule).

2.3 Methodology

2.3.1 Study Design

To investigate the effects of any intervention program, the selection of a control group is crucial. Knowing that the use of an active control group is always preferable when designing an RCT, the use of the Cogmed control program was carefully considered, but ultimately rejected and a wait-list control group design was deemed to be the most reasonable choice. The main reason for using a wait-list control design was that the Cogmed control program is the only active control program that would have been appropriate to use with this sample. However, there
is no evidence that training in this control program provides any benefit. Furthermore, the current sample, recruited from various post-secondary institutions’ disability services is a group of “at-risk” students. It is not fair or ethical to ask them to spend large amounts of time, on top of their schoolwork, training on a program that would not benefit them in some way. Lastly, disabilities services would not have approved or promoted this study knowing that some of their students would be required to spend a considerable amount of time each day training on the Cogmed control program for which there are no known benefits. In the current study, the wait list participants were not contacted during the training phase, but were provided with the opportunity to complete the training protocol after completion of their “pre-/post-/follow-up” test visits. It should be noted, however, that their data was not included in this study.

2.3.2. Participants

Participants were recruited through Student Disability services located in Toronto, Ontario at 3 different major post-secondary institutions. A similar number of students were recruited from each of the 3 schools. To register with student disability services at these institutions, students must provide a professional evaluation completed within the last 3 years and documentation that includes relevant psychoeducational testing, identification of a specific diagnosis, and recommendations for academic accommodations. A total of 62 college students participated (21 males, 41 females) aged 19-52 ($M=27.94, SD=7.1$) years, all of whom were registered with student disability services. Approximately 42% ($N=26$) of the sample were registered with disability services based on a previous confirmed diagnosis of ADHD, 48% ($N=30$) had previously confirmed diagnoses of an LD and 10% ($N=6$) had been diagnosed with both ADHD and LD.
2.3.3 Measures

The measures selected for this study were based on Baddeley’s multicomponent model of WM; therefore, measures of WM include recall and manipulation of information in the auditory-verbal and visual-spatial domains. Based on Westerberg et al.’s (2007) classification of measures, outcome measures were categorized into (1) ‘feasibility measures’ (number of training sessions and compliance with the required training intensity as quantified by the Cogmed Improvement Index score); (2) ‘criterion measures’ (tasks which tap into WM but differ from the trained tasks); (3) ‘near transfer’ measures (indices of other cognitive functions or measures of WM that differed from the trained tasks); and (4) ‘far transfer’ measures (indices of academic achievement and self-report questionnaires).

Feasibility measures. The Cogmed WM training program automatically provides a measure of active engagement and effort for each user, the Cogmed Improvement Index, which is computed from two training indices (Start Index, Max Index). The Start Index is calculated with the results from days 2 and 3, and the Max Index is calculated with the results from the two best days during the training period. The Improvement Index is calculated by subtracting the Start Index from the Max Index. The mean Improvement Index for individuals aged 18 to 65 years is 29 (normal range 15-41).

Criterion measures. The Digit Span subtest from the Wechsler Adult Intelligence Scale- Fourth Edition (WAIS-IV; Wechsler, 2008) was used to assess auditory-verbal WM and the Cambridge Neuropsychological Testing Automated Battery (CANTAB; Fray, Robbins, & Sahakian, 1996) Spatial Span task was used to assess visual-spatial WM. Both of these WM tasks closely resemble but are not identical to Cogmed WM training tasks. WM span tasks have been shown
to be reliable and valid measures of WM capacity (Conway et al., 2005). Internal consistency reliability subtest scores for the WAIS-IV range from 0.84 to 0.94 and test re-test stability ranges from 0.69 to 0.91. The Digit Span subtest requires the participant to listen to increasingly longer lists of digits that are read aloud by the examiner at a rate of one digit per second. On forward trials, the subject must repeat the numbers in the same order that the examiner read them. On the backward trials, the subject must repeat the numbers in the backwards order. On sequencing trials, the subject must repeat the numbers in order from smallest to biggest. Testing commences with a two-digit list and continues to a maximum of an 8-digit list or until the subject misses both trials of any list, whichever occurs first. The Digit Span raw score was converted to an age-adjusted scaled score, with a mean of 10 (SD of 3).

The CANTAB battery has high internal consistency ranging from .73 to .95. Stability coefficients range from .60 to .70 (Luciana, 2003). Test-retest reliability scores range from .64 for the Spatial Span task to .68 on the Spatial WM task (Lowe & Rabbitt, 1998). During the Spatial Span task, subjects are presented with white squares on a screen, which momentarily change colour in a variable sequence. The subject must then touch the boxes in the same order that they changed colour on the screen. Task demands intensify, as the number of boxes is increased from two to nine. However, if the subject makes an error, the next trial remains at the same difficulty level. The task terminates after three errors in a row. Spatial span scores range from 0-9, with the score representing the highest level at which the subject reproduces at least one correct sequence.

**Near transfer measures.** The *Paced Auditory Serial Addition Test* (PASAT; Gronwall, 1977) and the *CANTAB Spatial WM task* were selected as near transfer measures because they measure
related cognitive functions, but differ significantly from the trained WM tasks. The PASAT was used as a secondary measure of auditory verbal WM. It is a reliable and well-validated test of sustained attention and speed of mental computation that requires both WM and attentional control (Tombaugh, 2006). Test-retest reliability scores range from .90 to .96 (McCaffrey, Westervelt, & Haase, 1995). We selected this measure because WM and attention are so closely related. WM is required in order to attend to relevant information and filter out irrelevant information (Engle et al., 1999). Westerberg et al. (2007) reported that their participants showed the greatest transfer effect on the PASAT. Similarly, Brehmer et al. (2012) found that young adults (aged 20 to 30) improved on the PASAT after Cogmed training, and improvements were maintained at a 3-month follow-up. The PASAT consists of sets of numbers stated in serial fashion, presented verbally via computer. The subject is required to add each successive pair of numbers and report the sum to the examiner. For example, when presented with the numbers 3…4…1…6, the correct responses would be 7 (i.e. 3+4), 5 (i.e. 4+1) and 7 (i.e. 1+6). Thus, the task requires continuous updating of working memory as well as inhibition and “forgetting” the sum of the previous calculation. Two different sets are administered: Set A, in which numbers are presented at a rate of 2.4 seconds between each number; and Set B, in which numbers are presented at a rate of 1.6 seconds between each number. The longer the time interval between target stimuli, the greater the challenge for working memory, because working memory will only hold information for a few seconds. Thus, Set A is more taxing of WM. The total number of errors for each set constitutes the score for the test. An age adjusted T-score is generated for each set. Higher T-scores indicate better performance.

The CANTAB Spatial Working Memory task, based on the self-ordered pointing tasks (Petrides & Milner, 1982), was used to assess WM strategy skills. It differs from WM span tasks
because it is not affected by varying levels of dopamine in the dorsolateral prefrontal cortex (Diamond, Briand, Fossella, & Gehlbach, 2004). Participants are required to update information about spatial locations in working memory. They search boxes, using a touch screen monitor, to find a hidden token inside each box on the screen. However, they must not return to the same box where a token has already been found. There are four trials for each of three load conditions (four, six and eight boxes). Performance is measured according to the number of errors made. At the end of the task, subjects receive a strategy score: a low score indicates efficient strategy use, whereas high scores reflect poor strategy use. Both the error score and the strategy score were converted to standardized scores.

**Far Transfer Measures.** The following measures were selected because they examine WM-related functioning in everyday life. The Ruff 2 & 7 Selective Attention Task (Ruff, Niemann, Allen, Farrow, & Wylie, 1992) was chosen as a non-trained task of visual attention. It has been used in previous Cogmed studies and was selected because of the link between WM and controlled attention. The Ruff 2 & 7 measures two aspects of visual attention: sustained attention (ability to maintain consistent performance level over time) and selective attention (ability to select relevant stimuli while ignoring distracters). The Ruff 2 & 7 shows high internal consistency and reliability. Test-retest reliability is very high for speed scores (.94-.98) and adequate to high (.73-.89) for accuracy scores (Messinis et al., 2007). The test consists of a series of 20 trials of a visual search and cancellation task. The participant detects and marks through all occurrences of the two target digits: "2" and "7." In the 10 Automatic Detection trials, the target digits are embedded among alphabetical letters that serve as distracters. In the 10 Controlled Search trials, the target digits are embedded among other numbers that serve as distracters. The automatic detection trials require less cognitive effort, as compared to the controlled search
trials. Correct hits and errors are counted for each trial and serve as the basis for scoring the test. Speed scores reflect the total number of correctly identified targets (hits). Accuracy scores evaluate the number of targets identified in relation to the number of possible targets.

A number of academic measures were included in the assessment battery because of the well-supported link between WM and academic achievement. The Nelson Denny Reading Test was chosen as a standardized test of reading fluency and comprehension. It is commonly used in clinical practice and provides a trustworthy assessment of ability in an important area of academic achievement, reading comprehension. Since it uses a multiple-choice format, it closely resembles academic evaluations at the secondary and post-secondary levels, suggesting high external validity. The reliability values range from .85 to .89 (Brown, Fishco, & Hanna, 1993). Subjects have 20 minutes to read seven different passages and answer multiple-choice questions about each passage. Performance yields a score for reading comprehension, which was converted to a standard score.

The Applied Problems subtest from the Woodcock Johnson-III Tests of Achievement (WJ-III; Woodcock, Mather & McGrew, 2001) was given as a measure of mathematical reasoning ability. Most of the WJ-III subtests show strong reliabilities of .80 or higher; several are .90 or higher. The Applied Problems raw score was converted to a standard score with a mean of 100, SD=15. The Arithmetic subtest from the WAIS-IV was used to measure mental computation abilities. The Arithmetic raw score (number of correct answers) was converted to an age-adjusted scaled score, with a mean of 10 (SD of 3).

The Math and Reading Fluency subtests from the WJ-III were administered at baseline as a marker of LD in this population. Dependent variables were the number of correctly completed
items in 3 minutes. However, it should be noted that LD classification was still based on the
diagnosis with which students were registered at disabilities services.

The Adult ADHD Self-Report Scale (ASRS v1.1) is a reliable and valid scale for
evaluating ADHD in adults and shows a high internal consistency (.63 to .72) and test-retest
reliability of .58 to .77 (Hines, King, & Curry, 2012; Kessler, Adler, & Ames, 2005; Murphy &
Adler, 2004). The ASRS v1.1 is an instrument consisting of eighteen questions based on the
criteria used for diagnosing ADHD in the DSM-IV-TR. Questions focus on how often ADHD
symptoms occur (0=never, 1=rarely, 2=sometimes, 3=often, 4=very often). Scores for each item
were added to calculate a total score. This measure was used for two reasons, the first was to
confirm and quantify current symptoms of ADHD and the second was to determine whether WM
training would be effective in reducing ADHD symptoms. As mentioned above, ADHD
classification was still based on the diagnosis with which students were registered at disabilities
services.

The Cognitive Failures Questionnaire (CFQ) quantifies self-reported failures in
perception, memory, and motor function in everyday life. It was selected as a measure of
cognitive functioning in everyday life. Questions require subjects to rank how often these
mistakes occur (0=never, 1=very rarely, 2=occasionally, 3=quite often, 4=very often). Scores for
each item are added to calculate a total score. This 25-item scale has good reliability, as test-rest
scores are consistent over a period of 16 months (Broadbent, Cooper, FitzGerald, & Parkes,
1982). Furthermore, CFQ scores reliably predict performance on laboratory measures of
attention (Kanai, Yuan Dong, Bahrami, & Rees, 2011; Forster & Lavie, 2007). While Broadbent
et al. (1982) posited that the CFQ measures a general factor of ‘cognitive failure,’ several other
researchers have found that the CFQ consists of several different factors. According to Wallace, Kass, & Stanny (2002), the CFQ yields four internally consistent interpretable factors labeled memory (i.e., do you read something and find you haven’t been thinking about it and must read it again?), distractibility (i.e., do you daydream when you ought to be listening to something?), blunders (errors in task execution; i.e., do you drop things?), and (memory for) names (i.e., do you find you forget people’s names?). The participants in Westerberg et al. (2007) reported a significant decrease in cognitive failures post-intervention, and the present study attempted to replicate these findings.

2.4 Preliminary Analyses

Participant characteristics are presented below, in Tables 2.2 and 2.3. At baseline, 53% of our sample had impaired auditory verbal WM (below the 25th percentile) based on their WAIS-IV Digit Span scores. An examination of their CANTAB Spatial Span scores, which measure visual spatial WM, revealed that 19% scored below the 25th percentile. With respect to the Nelson Denny, which measures reading comprehension, 26% scored below a standard score of 185, which corresponds approximately to the 25th percentile. These data indicated that, overall, our sample of college students with ADHD/LD displayed WM impairments and reading comprehension deficits. However, consistent with previous research conducted by Lambek et al. (2011), only a subset exhibited scores on the reading comprehension and WM tests that were below the 25th percentile (standard score <90). This suggests that although these are university students, a substantial proportion continue to demonstrate academic weaknesses characteristic of individuals with ADHD/LD.
A comparison of the three diagnostic groups indicated that, at baseline, there were few group differences on baseline measures, with the exception of the ASRS, where the ADHD and ADHD/LD groups scored significantly higher than the LD group (p<.001) indicative of greater ADHD symptom impairment. Accordingly, the groups were aggregated, irrespective of the participant’s official disability services diagnoses.

An examination of the experimental and waitlist control groups at baseline revealed that, in general, the groups did not differ significantly at baseline on key outcome measures, suggesting randomization was effective. However, there were some exceptions with the experimental group performing significantly better than the waitlist participants on PASAT Set A and the Woodcock Johnson Math Fluency and Applied Problems subtests. With a relatively small sample size it is inevitable that there will be group differences on some variables, which were not used for stratification. Differences were accounted for by covarying baseline scores on the Intent-to-Treat analyses.

To examine the relationships amongst the various variables at baseline, Pearson’s correlation co-efficients were computed. There was a positive correlation between the WAIS-IV Digit Span and the Ruff 2 & 7 Speed Score (r=.355, p<.01), the WAIS-IV Digit Span and the Woodcock Johnson Applied Problems (r=.427, p<.001), and the WAIS-IV Digit Span and the Nelson Denny Comprehension Score (r=.367, p<.01). Likewise, there was a positive correlation between the CANTAB Spatial Span and the Ruff 2 & 7 Speed Score (r=.268, p<.05) and the CANTAB Spatial Span and the Woodcock Johnson Applied Problems (r=.319, p<.05). Given the findings in the literature, it is not surprising that there was a correlation amongst WM and these academic measures. The relationship amongst these measures also provided additional support
for our hypotheses, that training WM would impact these outcome variables, although there is the possibility that these correlations could be accounted for by a third variable, such as IQ.
### Table 2.1

**Description of WM Tasks in the Cogmed WM Training Program**

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reproducing a light sequence in a visuo-spatial grid</td>
<td>Lamps arranged in a 4X4 grid are displayed. Participants watch several lamps light up and then reproduce the same sequence.</td>
</tr>
<tr>
<td>2. Reproducing a light sequence in a rotated grid</td>
<td>A rotating version of the grid task described above. After the sequence of lamps lights up, the panel rotates 90 degrees clockwise and participants reproduce the sequence in the panel’s new position.</td>
</tr>
<tr>
<td>3. Repeating numbers in reverse order</td>
<td>A keyboard with numbers is displayed and then numbers are read aloud. Participants respond by repeating the digits in reverse order.</td>
</tr>
<tr>
<td>4. Repeating numbers in reverse order with an invisible keyboard</td>
<td>Similar to the task described above, but numbers are not visible on the screen until participants are required to respond.</td>
</tr>
<tr>
<td>5. Identifying letter positions in a sequence</td>
<td>Letters are read aloud, one at a time. Participants have to remember the letters in the order in which they are read. A row of lights becomes visible and a flashing light cues the participant to respond. For example, if light number 3 lights up, then participants report the 3rd letter they heard.</td>
</tr>
<tr>
<td>6. Identifying letter sequences</td>
<td>A sequence of letters is read aloud. Then, the participant is presented with three letters and must select the one that was presented.</td>
</tr>
<tr>
<td>7. Reproducing a light sequence in a rotating circle</td>
<td>A set of lamps is arranged in a rotating circle. Participants watch several lights light up and then reproduce the sequence, even though the lamps are constantly shifting position.</td>
</tr>
<tr>
<td>8. Reproducing a light sequence</td>
<td>A number of moving circles appear on screen and participants must reproduce the order in which they appeared.</td>
</tr>
<tr>
<td>9. Reproducing a sequence of moving shapes</td>
<td>A number of moving shapes light up and participants must reproduce the sequence in which they lit up.</td>
</tr>
<tr>
<td>10. Reproducing a light sequence in a 3D visuo-spatial grid</td>
<td>Lights are arranged in a ‘3D room’ with 20 segments. Participants watch several lights go on and then reproduce the sequence.</td>
</tr>
<tr>
<td>11. Reproducing a light sequence in a 3D visuo-spatial cube</td>
<td>Lights are positioned in a 3D cube with 12 segments. Participants watch several lights go on and then reproduce the sequence.</td>
</tr>
<tr>
<td>12. Reproducing a sequence of numbers on a visual grid</td>
<td>A 4X4 grid with 16 latches is shown. A sequence of latches is opened displaying a set of numbers. Participants sort the numbers by clicking on the latch that contained the numbers in numerical order.</td>
</tr>
</tbody>
</table>
Table 2.2
### Characteristics of the Sample

<table>
<thead>
<tr>
<th></th>
<th>ADHD (N=26)</th>
<th>LD (N=30)</th>
<th>ADHD+LD (N=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>28.1</td>
<td>27.8</td>
<td>30</td>
</tr>
<tr>
<td>Gender</td>
<td>F=17, M=9</td>
<td>F=20 M=10</td>
<td>F=4 M=2</td>
</tr>
<tr>
<td>Year of university</td>
<td>Avg.=3rd year</td>
<td>Avg.=3rd year</td>
<td>Avg.=4th year</td>
</tr>
<tr>
<td>ASRS total score</td>
<td>46.89 (9.65)</td>
<td>36.39 (11.64)</td>
<td>49.20 (10.85)**</td>
</tr>
<tr>
<td>Nelson Denny comprehension standard score</td>
<td>204.80 (29.91)</td>
<td>197.50 (33.53)</td>
<td>210.20 (17.51)</td>
</tr>
<tr>
<td>Cognitive Failures Total Score</td>
<td>58.59 (16.0)</td>
<td>51.53 (13.38)</td>
<td>59.20 (7.69)</td>
</tr>
<tr>
<td>WAIS Digit Span Scaled Score</td>
<td>7.67 (3.18)</td>
<td>7.43 (2.92)</td>
<td>9.40 (3.78)</td>
</tr>
<tr>
<td>CANTAB Spatial Span</td>
<td>6.80 (1.16)</td>
<td>6.41 (1.34)</td>
<td>5.80 (.84)</td>
</tr>
<tr>
<td>Woodcock Johnson Reading Fluency</td>
<td>96.04 (20.96)</td>
<td>87.93 (20.12)</td>
<td>96.80 (20.56)</td>
</tr>
<tr>
<td>Woodcock Johnson Math Fluency</td>
<td>86.67 (17.46)</td>
<td>86.0 (18.19)</td>
<td>90.60 (17.81)</td>
</tr>
<tr>
<td>Woodcock Johnson Applied Problems</td>
<td>94.92 (8.89)</td>
<td>92.61 (11.91)</td>
<td>95.20 (12.42)</td>
</tr>
</tbody>
</table>

**p<.001

Table 2.3

A Comparison of Experimental and Wait-List Participants at Baseline
<table>
<thead>
<tr>
<th></th>
<th>Experimental (N=39)</th>
<th>Waitlist Controls (N=23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>27.74 (7.03)</td>
<td>28.48 (7.63)</td>
</tr>
<tr>
<td>Gender</td>
<td>F=23, M=16</td>
<td>F=18, M=5</td>
</tr>
<tr>
<td>Cognitive Failures total score</td>
<td>55.75 (13.08)</td>
<td>56.13 (15.13)</td>
</tr>
<tr>
<td>ASRS total score</td>
<td>42.02 (12.12)</td>
<td>42.29 (11.67)</td>
</tr>
<tr>
<td>Nelson Denny comprehension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>standard score</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CANTAB Spatial Span</td>
<td>6.74 (1.05)</td>
<td>6.14 (1.42)</td>
</tr>
<tr>
<td>PASAT Set A</td>
<td>43.45 (11.20)</td>
<td>31.79 (13.92)**</td>
</tr>
<tr>
<td>Woodcock Johnson</td>
<td>92.94 (17.96)</td>
<td>92.39 (23.91)</td>
</tr>
<tr>
<td>Reading Fluency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woodcock Johnson Math Fluency</td>
<td>91.87 (16.95)</td>
<td>78.74 (16.13)**</td>
</tr>
<tr>
<td>Woodcock Johnson Applied</td>
<td>96.59 (10.40)</td>
<td>90.52 (10.35)**</td>
</tr>
</tbody>
</table>

**p<.001
CHAPTER 3

Manuscript Prepared for Publication

Working Memory Training in College Students with ADHD/LD
Abstract (230 words)

Objective: To determine the effectiveness of working memory (WM) training, as well as the feasibility, generalizability and sustainability of treatment effects in college students with Attention-Deficit/Hyperactivity Disorder (ADHD) and/or Learning Disabilities (LDs). Methods: A total of 62 college students with ADHD/LD (21 males, 41 females) were randomized to either a 5-week intensive WM training program or a wait-list control group. Participants were evaluated before treatment, 3 weeks after completion, and at 2-month follow up. The criterion measures were standardized tests of auditory-verbal (WAIS-IV Digit Span) and Visual-Spatial WM (CANTAB Spatial Span). Near transfer measures included other cognitive tasks; far transfer measures included academic tasks and behavioral rating scales. Results: Intent-to-treat analysis revealed that participants receiving WM training showed significantly greater improvements in the criterion WM measures (WAIS-IV Digit Span, CANTAB Spatial Span) and self-reported fewer ADHD symptoms and daily cognitive failures compared to the control group. No training effects were observed on the academic measures. Analysis of participants who completed the follow-up assessment indicated that the gains in WM were maintained for at least 2 months after training, as were self-reported improvements in cognitive failures. Conclusions: Computerized WM training is a feasible and possibly viable approach for enhancing WM in college students with ADHD/LD, but further program development is warranted to determine the optimal intensity and duration of training and to optimize transfer of training-related changes in everyday life.

Keywords: ADHD, Learning Disabilities, Working Memory, Controlled Trial, College Students
Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most common neurobehavioural disorders in childhood, with worldwide prevalence rates estimated at 5.3% (Polanczyk & Jensen, 2008). Approximately 4% of children in the United States have a comorbid diagnosis of ADHD and a Learning Disability (ADHD/LD) (Pastor & Reuben, 2008). The “multiple deficit model” suggests that there is a common genetic and neuropsychological underpinning to these disorders (Sexton, Gelhorn, Bell, & Classi, 2011). For example, ADHD and LD share similar features, such as core deficits in processing speed and working memory (Jensen, Martin, & Cantwell, 1997; McGrath et al., 2011; Willcutt et al., 2010). Research has shown ADHD/LD symptoms persist into young adulthood, a time when many are attending college and university.

Students with ADHD/LD at the post-secondary education level constitute an emergent subgroup of the ADHD population that has received far less attention in the literature compared to children, adolescents and employed adults. The exact prevalence of ADHD/LD in college populations is unknown; however, it has been estimated that 2-8% of students pursuing post-secondary education have been diagnosed with ADHD (DuPaul, Weyandt, O’Dell, & Varejao, 2009) and 1% to 5% have been diagnosed with an LD (Horn & Nevill, 2006; Houck, Asselin, Troutman, & Arrington, 1992). Students with learning disabilities (LD) and/or ADHD are the largest population of college students with disabilities (Gregg, 2009).

A limited amount of research has been conducted to examine the issues faced by college students with ADHD and LDs. The available research on college students with ADHD suggests that they have lower GPAs compared to controls, report more academic problems and are more
likely to receive academic probation (Frazier, Youngstrom, Glutting, & Watkins, 2007; Heiligenstein, Guenther, Levy, Savino, & Fulwiler, 1999). Socially and emotionally, these students also exhibit lower levels of adjustment, social skills and self-esteem compared to matched controls (Shaw-Zirt, Popali-Lehane, Chaplin, & Bergman, 2005). College students with LDs are more likely to pursue two-year rather than four-year programs and to drop out before they have completed their degrees (Gregg, 2007; Murphy, Barkley, & Bush, 2002).

Working memory (WM), a ‘mental workspace’ that allows information to be held in mind briefly for a few seconds and manipulated during problem-solving, is impaired in those with ADHD (Hervey, Epstein, & Curry, 2004; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Martinussen & Tannock, 2006; Willcutt et al., 2005). In addition, working memory problems are also evident in adults with ADHD, including those in post-secondary education (Gropper & Tannock, 2009). WM is an important cognitive function that is necessary for academic learning and reasoning (Baddeley, Gathercole, & Papagno, 1998; Gathercole, Brown, & Pickering, 2003), particularly in ADHD/LD (Rogers, Hwang, Toplak, Weiss, & Tannock, 2011).

Initially, WM was regarded as a fixed trait; however, recent investigations indicate that WM can be improved by intensive training (Klingberg, 2010). Several studies have investigated the efficacy of this training program and found improvements in WM tasks that were not part of the training program, suggesting improvements in WM capacity (Beck, Hanson, Puffenberger, Benninger, & Benninger, 2010; Holmes, Gathercole, Place et al., 2010; Holmes, Gathercole, & Dunning, 2010; Holmes, Gathercole, & Dunning, 2009; Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002; Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009).
Beneficial effects on WM were sustained for several months after training (Holmes et al., 2009; Klingberg et al., 2005). Three of these studies were controlled trials conducted in children and adolescents with ADHD, with findings that WM training also led to a decrease in inattentive ADHD symptoms, as reported by parents (Beck et al., 2010; Klingberg et al., 2005; Klingberg et al., 2002). Only one study has found that WM training was associated with academic improvements, specifically in mathematical skills, however this was not a randomized controlled trial (Holmes et al., 2009).

To date, there has been one RCT study published on WM training in ADHD and/or LD (Gray et al., 2012). In this sample of adolescents with severe LD and comorbid ADHD, WM training led to improvements on non-trained WM measures and those who showed the greatest improvement were rated as less inattentive/hyperactive by parents. There have yet to be any studies on WM training in a post-secondary population, specifically those students with ADHD and/or LD.

The primary purpose of the present study was to determine the effectiveness of intensive WM training in college students with ADHD and/or LDs using a randomized controlled design. Specific objectives were to determine: i) the feasibility of WM training in this population (i.e., whether college students with ADHD/LD would be able to comply with the required intensity and duration of training); ii) whether WM training would lead to improvements in WM performance on cognitive tasks that did not resemble the training activities, as well as those that did; iii) whether the effects of WM training would generalize to daily-life activities involving WM, such as academic performance and self-regulation of attention; and iv) whether any gains in functioning would persist (i.e., for at least 2 months) beyond the end of the training period.
We hypothesized that WM training would enhance auditory-verbal and visual-spatial WM and that beneficial effects would be maintained beyond the end of the training period. It was also anticipated that WM training would be accompanied by improvements in academic areas that are dependent upon WM (e.g., reading comprehension and math reasoning). In addition, it was expected that WM training would be associated with improved self-regulation of attention in everyday life (albeit perhaps as later-onset effects discernible at follow-up only).

**Method**

**Participants**

Participants were recruited through university and college student disability services located in a major urban centre in Canada. Information sessions were also held on campus at two local universities. To register with student disability services at these universities, the student must provide a professional evaluation completed within the last 3 years and documentation that includes relevant psychoeducational testing, identification of specific diagnosis, and recommendations for academic accommodations. A total of 62 college students participated (21 males, 41 females) aged 19-52 (\(M=28.04, SD=7.2\)) years, all of whom were registered with student disability services with a previously confirmed diagnosed of ADHD (\(n=26\)), LD (\(n=30\)) or both (\(n=6\)). However, examination of test scores revealed that most of the students with a confirmed diagnosis of ADHD or LD also manifested at least sub-threshold levels of the other disorder. For instance, 62% of those with an LD diagnosis reported clinically significant ADHD symptoms on the Adult ADHD Self-Report Scale (ASRS v1.1; Adler et al., 2006; Kessler et al., 2005). Conversely, 54% of the ADHD group scored below the 25\(^{th}\) percentile on the Nelson Denny Reading Comprehension test (Brown, Fishco, & Hanna, 1993) or on the Woodcock Johnson Math Fluency subtest (Woodcock, Mather, & McGrew, 2001). Thus they had higher
levels of ADHD symptoms and learning difficulties than their ‘official’ diagnoses indicate. Accordingly, given the overlap of ADHD and LD symptoms, participants were analyzed together irrespective of their given diagnoses. Amongst the sample, 26% (n=16) were being treated with stimulant medication, as prescribed by a community physician. Medication status and dose remained the same throughout the assessment and training periods.

Inclusion criteria were: 1) current enrollment in a post-secondary program at the college or university level, 2) a previous diagnosis of ADHD and/or LD, 3) registration with respective college disability services that requires documented evidence of a confirmed current diagnosis of ADHD or LD or both, and 4) access to a personal computer with internet connection (students were loaned a laptop if necessary). Exclusion criteria were: 1) uncorrected sensory impairment, 2) major neurological dysfunction and psychosis, 3) current use of sedating or mood altering medication other than stimulants provided for ADHD, and 4) motor or perceptual handicap that would prevent using the computer program.

Students were randomized to experimental and waitlist control groups, using unequal randomization (5:3 assignment, in favor of the WM training program) to enhance recruitment and minimize drop-out rates (Dumville, Hahn, Miles, & Torgerson, 2006). A total of 39 students (63% of sample; 16 males, 23 females) comprised the experimental group. A total of 23 students (37% of sample; 5 males, 18 females) comprised the control group.

**Intervention**

Subjects completed 25 training sessions (about 45 minutes per session) of “Cogmed QM” (the adult version of Cogmed; Pearson Education, 2011) over five weeks. The program was provided on a CD and used on a personal computer. During each session participants completed
a set of auditory verbal and visual-spatial WM tasks, and responded by clicking on displays with the computer mouse. All tasks involved the manipulation and storage of visuo-spatial information (i.e. reproducing a sequence of moving shapes) or auditory WM information (remembering strings of digits), feedback and rewards based on performance of each trial, and progressive adaptation of difficulty level as a function of individual performance so that an optimal level of challenge was maintained and participants were always working at their WM capacity. Training plans were individualized and modified based on current performance, but the typical plans included 12 different WM training exercises; subjects completed 8 tasks every day, 15 trials of each task. The average training time each day was about 45 minutes (excluding breaks). Responses to each trial were logged to a file and participants uploaded new data files via the Internet to a secure server. Compliance and training performance was verified by a certified Cogmed training coach (psychologist from licensed community agency) who supervised the WM training. Coaches were in touch with the study participants on a weekly basis, via email or telephone calls. They monitored participants’ data on the server, advised them about the next week’s training and were completely independent from the research team.

Procedure

The study was approved by the Institutional Research Ethics Board. After a complete description of the study was provided to the subjects, informed written consent was obtained before the study began. Participants were assessed individually in a university lab space at three different time points: prior to training (T1); 3 weeks after completing training (T2); and at two-month follow up (T3). On all three occasions, participants completed the same battery of tests and rating scales. Once every week, the certified training coach called or emailed the participants to inquire about any training difficulties and to give feedback regarding training scheduling and
performance. The Cogmed WM training was completed on the participants’ personal computers, which provided them the flexibility to train where they wanted, at their convenience.

**Outcome Measures**

Outcome measures were categorized as (1) ‘Feasibility measures’ (number of training sessions and compliance with the required training intensity as quantified by the Cogmed Improvement Index score); (2) ‘Criterion measures’ (closely resembled tasks trained in WM program); (3) ‘Near transfer’ measures (indices of other cognitive functions or measures of WM that differed from the trained tasks); and (4) ‘Far transfer’ measures (indices of academic achievement and self-report questionnaires). These measures were selected based on their use in previous studies and the theoretical support (Klingberg et al., 2005; Westerberg et al., 2007).

**Feasibility measures.** The Cogmed Improvement Index score was computed automatically from two training indices (Start Index, Max Index) and provided for every user. The Start Index is calculated with the results from days 2 and 3, and the Max Index is calculated with the results from the two best days during the training period. The Improvement Index is calculated by subtracting the Start Index from the Max Index. The mean Improvement Index for individuals aged 18 to 65 years is 29 (normal range 15-41). Higher Index scores signify good compliance and effort with the training (Cogmed Cognitive Medical Systems, 2009).

**Criterion WM tasks.** The Digit Span subtest from the Wechsler Adult Intelligence Scale- Fourth Edition (WAIS-IV) was used to assess auditory-verbal WM (Wechsler, 2008). This is a composite score consisting of digit span forwards, backwards and sequencing. The Digit Span raw score was converted to an age-adjusted scaled score, with a mean of 10 (SD of 3). The Cambridge Neuropsychological Testing Automated Battery Spatial Span Forward task was
used to assess visual-spatial WM (CANTAB; Fray, Robbins, & Sahakian, 1996). Spatial span scores ranged from 0-9, with the score representing the highest level at which the subject reproduces at least one correct sequence.

**Near transfer measures of WM.** The *Paced Auditory Serial Addition Test* (PASAT) was used as a secondary measure of auditory verbal WM (Gronwall, 1977). It is a well-validated test of sustained attention and speed of mental computation, as well as indexing the updating function of WM. The PASAT consists of sets of numbers stated in serial fashion, presented verbally via computer. The subject was required to add each successive pair of numbers and report the sum to the examiner. For example, when presented with the numbers 3…4…1…6, the correct responses would be 7 (i.e. 3+4), 5 (i.e. 4+1) and 7 (i.e. 1+6). Thus, the task requires continuous updating of working memory as well as inhibition and “forgetting” the sum of the previous calculation. Two different sets were administered: Set A, in which numbers were presented at a rate of 2.4 seconds between each number; and Set B, in which numbers were presented at a rate of 1.6 seconds between each number. The longer the time interval between target stimuli, the greater the challenge for working memory, because working memory will only hold information for one to two seconds. The total number of errors for each set constituted the score for the test. An age adjusted T-score was generated for each set. Higher T-scores indicated better performance.

The CANTAB Spatial Working Memory task was used to differentiate and quantify WM strategy skills. Based on the self-ordered pointing task (Petrides & Milner, 1982), it differs from WM span tasks because it is not affected by varying levels of dopamine in the dorsolateral prefrontal cortex (Diamond, Briand, Fossella, & Gehlbach, 2004). It was administered on a
computer with a touch screen monitor. Subjects are required to update information about spatial locations in working memory: they must search boxes to find the hidden token, but must not return to the same box where a token has already been found. There are four trials for each of three load conditions (four, six and eight boxes). Performance was measured according to the number of errors made. At the end of the task, subjects received a strategy score: a low score indicates efficient strategy use, whereas a high score reflects poor strategy use. Both the error score and the strategy score were converted to standardized Z-scores, which were used in the analyses.

**Far Transfer Measures.** The Ruff 2 & 7 Selective Attention Task (Ruff, Niemann, Allen, Farrow, & Wylie, 1992) was used to measure two aspects of visual attention: sustained attention (ability to maintain consistent performance level over time) and selective attention (ability to select relevant stimuli while ignoring distracters). The test consists of a series of 20 trials of a visual search and cancellation task. The respondent detects and marks through all occurrences of the two target digits: "2" and "7." In the 10 Automatic Detection trials, the target digits are embedded among alphabetical letters that serve as distracters. In the 10 Controlled Search trials, the target digits are embedded among other numbers that serve as distracters. The Controlled Search trials are more demanding of attentional resources. Accordingly, WM training would be expected to improve performance on the Controlled Search tasks. Correct hits and errors are counted for each trial and serve as the basis for scoring the test. Speed scores reflect the total number of correctly identified targets (hits). Accuracy scores evaluate the number of targets identified in relation to the number of possible targets.
Participants were also administered several academic testing measures. The first, the Nelson Denny Reading Test (Brown et al., 1993), is a standardized test of reading fluency and comprehension that predicts college students’ academic outcomes and is linked with working memory (Aldridge, Keith, Sloas, & Mott-Murphree, 2010; Ehrlich, Brebion, & Tardieu, 1994). Subjects had 20 minutes to read seven different passages and answer questions about each passage. Performance yielded a score for reading comprehension, which was converted to a standard score.

Participants were also given the Applied Problems subtest from the Woodcock Johnson-III Tests of Achievement as a measure of mathematical reasoning ability (Woodcock et al., 2001). The Math Fluency and Reading Fluency tasks from the WJ-III were only administered at baseline to determine automaticity of identifying words and recalling math facts. Scores on these subtests provided quantifiable information about the nature of learning difficulties in this population. Dependent variables were the number of correctly completed items in 3 minutes. All subtest raw scores were converted to standard scores with a mean of 100, SD=15.

Each participant was also required to complete two questionnaires to assess current symptom impairment. The Adult ADHD Self-Report Scale (ASRS v1.1) is a reliable and valid scale for evaluating ADHD in adults (Adler et al., 2006; Murphy & Adler, 2004). The ASRS v1.1 is an instrument consisting of eighteen questions based on the criteria used for diagnosing ADHD in the DSM-IV-TR. Questions focus on how often ADHD symptoms occur (0=never, 1=rarely, 2=sometimes, 3=often, 4=very often). Scores for each item were added to calculate a total score. Higher scores indicate greater symptom impairment. Post hoc analyses were
conducted to examine the relative impact of Cogmed WM training on inattention versus hyperactive/impulsive symptoms.

The Cognitive Failures Questionnaire (CFQ) measures self-reported failures in perception, memory, and motor function in everyday life. This 25-item scale has good reliability, as test-rest scores are consistent over a period of 16 months (Broadbent, Cooper, FitzGerald, & Parkes, 1982). Furthermore, CFQ scores reliably predict performance on laboratory measures of attention (Kanai, Yuan Dong, Bahrami, & Rees, 2011; Forster & Lavie, 2007). Questions require subjects to rank how often these mistakes occur (0=never, 1=very rarely, 2=occasionally, 3=quite often, 4=very often). Scores for each item were added to calculate a total score. In addition, the CFQ has been found to yield four separate factor scores, memory (i.e., do you read something and find you haven’t been thinking about it and must read it again?), distractibility (i.e., do you daydream when you ought to be listening to something?), blunders (errors in task execution; i.e., do you drop things?), and (memory for) names (Wallace, Kass, & Stanny, 2002). Therefore, four subscale scores were also computed. Previous research has found that scores on the CFQ are predicted by gray matter volume in the left superior parietal cortex (Kanai, Yuan Dong, Bahrami, & Rees, 2011). It is this region of the brain that is responsible for directing attention to relevant stimuli. Given the link between WM and controlled attention, it would follow that WM training would have a differential impact on the four subscales and would be more likely to improve the distractibility subscale score.

Statistical Analysis

Data were first checked for outliers and the shape of distribution of scores. A Winsorizing technique described in Tabachnick and Fidell (2007) was required to minimize the
effect of one outlier in the variable Ruff 2 & 7 Total Accuracy T-Score and two outliers in the Nelson Denny Reading Rate Standard Score. We used an Intent-to-Treat analysis (ITT), using the Last Observation Carried Forward (LOCF) for missing data, to test for training effects at post-test (conducted 3 weeks after training had been completed). To check for possible effects of gender, ANCOVA ITT analyses were conducted first with gender as a covariate. Males performed better than females on the following measures: CANTAB Spatial Span, WAIS-IV Digit Span and Arithmetic, and PASAT. However, there were no interaction effects with the intervention, so the reported analyses do not include gender as a between–subjects factor. Next, we tested for potential effects of medication and ran ANOVAs with medication status as a covariate. There were no effects of medication, other than on the Cognitive Failures Questionnaire, where those on medication reported fewer cognitive failures, and so reported analyses did not include medication as a factor. Thus, reported ITT analyses used analyses of covariance (ANCOVA) with baseline as a covariate and group (experimental, WL control) as a between-subjects factor. The dependent variables were post-test scores on target indices. Substantial missing data at 2-month follow-up (mainly due to scheduling conflicts with exams or changing academic demands during the semester) precluded an ITT analysis of these data. Thus, analysis of follow-up data was based on an As-Treated approach, using repeated measures analysis of variance (ANOVA), with Group (experimental, waitlist control) as a between subjects factor and time (pre, post, follow-up) as a within-subjects repeated measure. All analyses were conducted using SPSS v.19.

Results

Feasibility Measures
Overall, attrition was low; almost all participants (92%) completed the required 25 training sessions. Most (97.5%) obtained an Improvement Index score within the normal range for age (i.e., a score of 15 to 41, $M=25.72$, $SD=6.54$) suggesting good effort and compliance with WM training.

**Post-Intervention Results**

**Criterion WM measures.** As hypothesized, significant effects of WM training were found for the WAIS-IV Digit Span subtest of medium effect size (see Table 3.1 and Figure 2). Using the Binomial Effect Size Display (BESD) calculation (Rosnow, Rosenthal, & Rubin, 2000), the WM training group experienced a 28% greater improvement compared to controls. Post hoc analyses were conducted for Digit Span Forward, Backward and Sequencing. At post-test, there was a significant group difference on Digit Span Backwards ($p<.05$), with experimental participants performing significantly better $M=10.87$ (0.64) than wait-list controls $M=8.77$ (0.74). There were no group differences on the Digit Span Forwards and Sequencing subscales. For the CANTAB Spatial Span there was also significantly greater improvement from baseline to post-intervention measurement in the treatment group compared to waitlist control of large effect size (see Figure 2). The BESD indicated that there was a 47% difference in outcome between the WM training group and wait-list controls.

**Near transfer WM measures.** Other WM tasks were considered secondary outcome measures. With respect to the PASAT, analyses revealed no significant effects of WM training for either Set A or Set B. Similarly, on the CANTAB Spatial WM task there were no training effects on either the Between Errors Standard Score or the Strategy Score.
Far transfer measures. There were no training effects on the Ruff 2 & 7 Total Accuracy T-Score and the Total Speed T-Score. Nor were there any training effects on the Nelson Denny Comprehension Standard Score. Furthermore, no differences between the two groups were found on the Woodcock-Johnson Applied Problems or on the WAIS-IV Arithmetic subtest. By contrast, the ITT ANCOVA was significant for the ASRS questionnaire, with the WM training group reporting significantly fewer ADHD symptoms post-intervention compared to controls. Post-hoc analyses were conducted to ascertain whether WM training had a differential effect on inattention versus hyperactive/impulsive symptoms, with a finding of no significant group differences. The BESD indicated that the WM training group reported a 28% greater reduction in symptoms compared to controls. For the CFQ, the ANCOVA was also significant, with participants in the WM training group reporting 25% fewer cognitive difficulties in everyday life post-intervention compared to controls (see Table 3.1). Post-hoc analyses did not reveal differential effects of training on the four different subscale scores (memory, distractibility, blunders, memory for names).

Follow-up Outcomes

Follow-up analyses, which were based on an As-Treated approach, included 24 participants who received WM training (62% of participants who completed pre-/post testing) and 21 WL controls (91% of participants who completed pre-/post testing). A one-way ANOVA revealed no significant differences on key measures of WM and self-report questionnaires in participants from the experimental group who completed follow-up testing versus those who did not. Tests of repeated measures ANOVA were performed for Time (pretest, posttest, follow-up) and Group (experimental, waitlist). Data are reported in Table 3.2 and Figure 2.
Criterion WM measures. For the WAIS-IV Digit Span, the ANOVA yielded significant main effects for time and group, which were qualified by a group by time interaction of medium effect size. Post hoc analyses indicated that the WM training group showed greater improvements in Digit Span than controls at both post-test and follow-up ($p < .001$), but no group differences at baseline. This pattern of findings indicated that the gains were related to WM training and that these treatment-related gains in this component of WM were sustained for at least 2 months. This significant finding was followed up with post hoc analyses to ascertain any differential effects of WM training on the Forwards, Backwards and Sequencing subscales. At follow-up, there was a significant group difference on Digit Span Sequencing, with experimental participants $M=9.10$ (2.29) showing significantly greater improvement than wait-list controls $M=6.94$ (3.27). On the CANTAB Spatial Span there was a significant main effect of time but not group. Of key interest was the significant group by time interaction of large effect size. Post hoc analyses revealed significant group differences at both post-test and follow-up, indicating that compared to the wait-list group, those receiving WM training showed greater improvements in WM spatial span at post-test and those gains were maintained for at least two months after completing the training (see Figure 2).

Near and far transfer measures. We found significant main effects for time, but not for group and no group by time interaction for the following measures: CANTAB SWM Strategy Score, CANTAB SWM Between Errors Scores, the Ruff 2 & 7 Total Speed and Total Accuracy Scores, and the Woodcock Johnson Applied Problems subtest. Thus, both groups obtained better scores on these measures across time regardless of whether participants received WM training. Significant main effects for both time and group (but not the group by time interaction) were found for scores on PASAT Set A and B. This pattern of findings indicated that scores of both
groups increased over time and that the group assigned to WM training scored higher overall on these measures than the control group, despite randomization. Note that the primary Intent-To-Treat analysis controlled for the group differences at baseline. On the WAIS-IV Arithmetic subtest there were no time, group, or group by time effects.

Analysis of the 2-month follow-up data for the Cognitive Failures Questionnaire revealed a significant effect of time and a group by time interaction of medium effect size. Post-hoc between-group comparisons showed no significant differences at any time point. However, the experimental group showed significant reduction in scores between baseline and post-test ($p<.05$) and baseline and follow-up ($p<.01$), suggesting training-related gains in everyday cognitive functioning that were maintained for at least 2 months. By contrast, the waitlist control group did not show any significant changes across time in CFQ scores. There were no significant group differences on the four different subscale scores. On the ASRS, there was a main effect of time, not group, and a non-significant trend for the experimental group to show sustained reduction in ADHD symptoms from post-test to follow-up. However, there were no significant group differences on the inattention and hyperactivity/impulsivity subscales.

**Supplemental Analyses**

In order to examine those variables that predicted significant WM training outcomes, a multiple regression analysis was performed. The results of the regression analysis revealed that the WM Improvement Index Score ($\beta=.277, p < .05$) and performance on the WAIS-IV Digit Span at pre-test ($\beta=.679, p<.001$) predicted performance on WAIS-IV Digit Span at post-test. Similarly the WM Improvement Index Score ($\beta=.681, p < .001$) predicted performance on the CANTAB Spatial Span at post-test. With respect to the ASRS, both the WM Improvement Index
Score ($\beta=-.252, p < .01$) and scores on the ASRS at pre-test ($\beta=.907, p<.001$) predicted scores on the ASRS at post-test. For the CFQ, pre-test scores on the CFQ ($\beta=-.342, p < .05$), the WM Improvement Index Score ($\beta=-.247, p < .05$) and the ASRS pre-test scores ($\beta=-.534, p < .001$) all predicted CFQ post-test scores. This suggests that the amount of effort participants put into their training, reflected by the WM Improvement Index Score, affected their performance at post-test on both WM and behavioural self-report measures. Furthermore, for the WAIS-IV Digit Span, the ASRS and the CFQ, baseline scores on these measures were also predictors of outcome.

**Participant Perspectives**

Before beginning the Cogmed WM training, participants created a set of training goals in conjunction with their coaches. After completing the training program, the coaches asked the participants to reflect back to their original goals and think about how the training impacted their daily lives. Based on their accounts, a number of consistent improvements were noted. The majority noticed improvements in their ability to retrieve verbal information (i.e., phone numbers, peoples names, appointments). Furthermore, with respect to academics, this improved recall of verbal information enabled them to learn and retain information from lectures and books, without having to re-read multiple times. In addition, several participants reported that they were able to sustain attention and feel more alert for longer periods of time. When asked about areas where they did not see improvements, some of the participants indicated that they hoped to improve time management and organization skills, but they had not noticed any substantial changes. Overall, the feedback from the participants was positive. However, a causal effect between Cogmed and the improvements noted cannot be assumed.
Discussion

This study provides the first investigation of the effectiveness of an intensive WM training program for college students with ADHD/LD. This group constitutes a unique subset of the ADHD/LD population. On the one hand they are, by definition, a high-achieving subgroup of individuals with ADHD/LD who were successful enough to pursue post-secondary education; on the other hand they continue to manifest cognitive, academic and other functional impairments compared to their peers.

One major objective of this study was to determine the feasibility of carrying out this program with this population. Overall, attrition was low; most participants in the experimental group did complete the requisite number of training sessions and the majority reached the optimal index score of improvement. Another major objective was to determine whether WM training would be effective with this college population of young adults with ADHD/LD. The most robust findings were training-related effects on two WM span measures that resembled but were not identical to the trained tasks: a test of auditory-verbal WM (WAIS-IV Digit Span) and a short-term visual spatial storage measure (CANTAB Spatial Span Forward). Beneficial effects on these aspects of WM were still discernible at 2-month follow-up. These findings are consistent with previous research (Klingberg et al., 2002; Klingberg et al., 2005). Results also indicated that participants in the WM training group self-reported fewer ADHD symptoms and fewer cognitive failures in their everyday lives at post-test. At follow-up, they continued to endorse a decrease in cognitive failures. Since we utilized a WL control group, participants were not blind to training conditions, thus we cannot rule out the possibility of participant bias in their self-reports.
In contrast to predictions, we did not find transfer effects to other measures of WM (e.g., the PASAT) or other aspects of cognitive function (e.g., as indexed by the Ruff 2 & 7). It is possible that more complex tasks, such as these, may not be targeted through training. Similarly, treatment related improvements in WM were not accompanied by gains on academic measures. This could be due to the measures used or that changes may not appear until later, which would have required a longer-term follow-up (Holmes et al., 2009).

**Limitations**

One important limitation of this study is that we used a wait-list control design as opposed to an active control group. Thus, both groups were aware of which treatment condition they were in, which might have biased their ratings on self-report scales. For example, participants in the wait-list group might underreport any positive changes over the study period in case that might preclude the opportunity to then receive the WM training. To rule out informant bias, it would have been beneficial to select an independent objective measure, such as the Restricted Academic Setting Task (RAST), which has yielded evidence of training related improvements in ADHD symptoms during tasks (Green et al., 2012). By contrast, rating scales may be less sensitive because participants rate their own behaviour across broader time frames and contexts.

An additional methodological limitation is that participants in the experimental group received weekly calls from the training coach; however, the wait-list control group did not receive the same level of attention. Thus, we cannot disentangle any non-specific effects of attention from specific effects of WM training. Furthermore, the study may have lacked statistical power to detect some sustained or later-emerging benefits from WM training because a
substantial portion (38%) of the sample did not return for follow-up testing. Due to increasing work demands across the semester and exams, it was difficult to get many of the students to come back 2 months after they completed training.

Clinical Implications

Notwithstanding the aforementioned limitations, our findings provide support for the effectiveness of intensive, computerized WM training for improving WM, at least as measured by neuropsychological tests. Effects were maintained at a 2-month follow-up, suggesting that WM training may have long-term beneficial effects. Previous studies have found training-related reduction in ADHD symptoms, as measured by parent-completed rating scales (Beck et al., 2010; Holmes et al., 2009; Klingberg et al., 2002; Klingberg et al., 2005). In this study, participants self-reported a reduction in core ADHD symptoms post-treatment; however, our use of a wait-list control group and lack of an independent corroborating report does not allow us to disentangle training-related effects from participant bias in self-report.

It is worth noting that despite the significant time requirement of this program, most students were able to comply with the treatment demands. One advantage of the Cogmed intervention is that individuals are in control of their training schedule (i.e. when and where they do the training). This suggests that flexibility around scheduling may be worth incorporating into other intervention approaches.

Overall, these results provide further support for the neuroplasticity of WM, even in adulthood, and suggest that WM training might provide an adjunctive treatment in combination with other treatments, such as stimulant medication. The lack of evidence of transfer effects to complex reasoning and academic skills suggests that modification to the training program along with the addition of other interventions, such as ADHD coaching, might result in more practical
and meaningful transfer of gains in WM to daily functioning. Had we only conducted a pre-post test study, rather than an RCT, we might have incorrectly interpreted the pre-post changes in scores on the measures of near and far transfer as a result of WM training. However, our analyses of the RCT revealed that scores improved in both groups regardless of WM training, indicative of practice effects or measurement unreliability. Thus clinicians are advised to use caution in attributing any gains in scores from the start to end of training to specific effects of WM training.
Table 3.1

Posttreatment Effects on WM, Academic and Symptom Measures for College Students with ADHD/LD Who Received WM Training or a Control Condition

<table>
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<tr>
<th>Measures</th>
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<th></th>
<th>Posttreatment</th>
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<td></td>
<td></td>
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<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
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<td>0.789</td>
<td>0.791</td>
<td>0.791</td>
<td>0.789</td>
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<td>0.789</td>
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<td></td>
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<td>1.08</td>
<td>-0.157</td>
<td>0.954</td>
<td>-0.157</td>
<td>0.954</td>
<td>0.077</td>
<td>0.954</td>
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<td>10.24</td>
<td>3.06</td>
<td>10.24</td>
<td>3.06</td>
<td>10.24</td>
<td>3.06</td>
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<td>CANTAB Spatial WM Between Errors</td>
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<td>.96</td>
<td>.185</td>
<td>.96</td>
<td>.185</td>
<td>.96</td>
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<tr>
<td></td>
<td>Control(^b)</td>
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<td>-.205</td>
<td>1.18</td>
<td>-.205</td>
<td>1.18</td>
<td>-.205</td>
<td>1.18</td>
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<td>.925</td>
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<td>.925</td>
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<td>.049</td>
<td>1.19</td>
<td>.049</td>
<td>1.19</td>
<td>.049</td>
<td>1.19</td>
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<td>12.49</td>
<td>50.27</td>
<td>18.19</td>
<td>50.27</td>
<td>18.19</td>
<td>50.27</td>
<td>18.19</td>
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<td>Mean 4</td>
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<td>p-value</td>
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<td>PASAT Set B T-Score</td>
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<td>15.72</td>
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Nelson Denny Reading Comprehension Standard Score

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<tr>
<td></td>
<td>207.1</td>
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<td></td>
<td>29.72</td>
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<td></td>
<td>213.1</td>
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<td>0.009</td>
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PASAT = Paced Auditory Serial Addition Test (Gronwall, 1977); CANTAB = Cambridge Neuropsychological Testing Automated Battery (Fray, Robbins & Sahakian, 1996); SWM= Spatial Working Memory; SSP= Spatial Span; WAIS-IV= Wechsler Adult Intelligence Scale-Fourth Edition (Wechsler, 2008)

Note: The F values reported are for group (experimental vs. control) by time (baseline vs. posttreatment) interactions.

*p<.05, ** p<.01, *** p<.0001

\(^a\)n=39 for the experimental group.

\(^b\)n=23 for the control group.
Table 3.2
Changes from Pretreatment to Follow-Up on WM, Academic and Symptom Measures for College Students with ADHD/LD Who Received WM Training or a Control Condition

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<th>Measures</th>
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<th>Post-Treatment</th>
<th>Follow-Up</th>
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<td>SD</td>
<td>Mean</td>
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<td>Experimental</td>
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<td>.830</td>
<td>.907</td>
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<td>Control</td>
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<td>0.023</td>
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<td>Control</td>
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<td>.032</td>
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<td>Mean 2</td>
<td>Mean 3</td>
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### Nelson Denny Reading Comprehension Standard Score

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PASAT = Paced Auditory Serial Addition Test (Gronwall, 1977); CANTAB = Cambridge Neuropsychological Testing Automated Battery (Fray, Robbins, & Sahakian, 1996); SWM= Spatial Working Memory; SSP= Spatial Span; WAIS-IV= Wechsler Adult Intelligence Scale-Fourth Edition (Wechsler, 2008)

Note: The $F$ and $p$ values reported are for group (experimental vs. control) by time (baseline/posttreatment/follow-up) interactions.

* $p<.05$, ** $p<.01$, *** $p<.0001$

*a* $n=24$ for the experimental group.

*b* $n=21$ for the control group.
List of Figures

Figure 1. Flow diagram of subject recruitment and participation in controlled trial of WM training in college students with ADHD/LD.

Figure 2, Panel A. Mean values for CANTAB spatial span at Baseline (T1), Post-Intervention (T2) and Follow-Up (T3).

Figure 2, Panel B. Mean values for WAIS-IV Digit Span at Baseline (T1), Post-Intervention (T2) and Follow-Up (T3).
Figure 1.

Assessed for eligibility ($n=67$)

- Excluded ($n=5$)
  - Not meeting inclusion criteria ($n=1$)
  - Declined to participate ($n=1$)

Randomized ($n=62$)

- Allocated to experimental group ($n=39$)
  - Received allocated intervention ($n=34$)
  - Did not receive allocated intervention and provided no post-treatment data (only partial training) ($n=5$)

- Lost to follow-up (scheduling, on vacation) ($n=10$)
- Discontinued intervention ($n=5$)
  - Pre-/Post Data Analysed ($n=39$)
  - Follow-up Data Analyzed ($n=24$)

- Allocated to waitlist control group ($n=23$)
  - Received allocated intervention ($n=13$)
  - Did not receive allocated intervention (did not complete Cogmed training) ($n=10$)

- Lost to follow-up ($n=2$)
  - Pre-/Post Data Analysed ($n=23$)
  - Follow-up Data Analyzed ($n=21$)
Figure 2. Panel A

![CANTAB Spatial Span Graph](image)

Figure 2. Panel B

![WAIS-IV Digit Span Graph](image)
CHAPTER FOUR

General Discussion
4.1 Summary of Findings

This study investigated the effects of a computerized WM training program on WM, attention, academic skills, and everyday functioning in college students with ADHD/LD. There were four specific objectives. Each, with its corresponding findings, is summarized below.

The first objective was to investigate the feasibility of WM training and whether college students with ADHD/LD would be able to comply with the required intensity and duration of training. Overall, 92% of participants completed the requisite number of training sessions and the majority reached the optimal index score of improvement. Given the time commitment required by Cogmed and the demands of the college curriculum, it is impressive that almost all participants were able to complete the training protocol.

The second objective was to determine the effectiveness of WM training in college students with ADHD/LD. The most significant finding was training-related effects on two WM span measures that resembled the trained tasks: a test of auditory-verbal WM and a short-term visual spatial storage measure. Beneficial effects on these tasks were maintained at 2-month follow-up. These results provided evidence that WM can be enhanced in this subgroup of young adults using intensive and adaptive computerized training.

The third objective was to examine whether WM training would lead to improvements on cognitive tasks that did not closely resemble training activities. By contrast to predictions, participants did not improve on measures of controlled (“cognitive”) attention. However, they did self-report fewer ADHD symptoms following training, suggesting training-induced improvements on behavioural symptoms of inattention.
The final objective was to explore whether the effects of WM training would generalize to daily-life activities involving WM and academic performance and whether improvements would be sustained. At post-test, participants in the WM training group reported fewer cognitive failures in their everyday lives. At follow-up, they continued to endorse a decrease in cognitive failures. However, in contrast to predictions, improvements in WM did not generalize to academic skills that involve aspects of WM.

4.1.1 Feasibility of WM Training

One objective of this study was to assess the feasibility of carrying out this intervention with college students who have ADHD/LD. Despite the time commitment required to complete training, it is very impressive that 92% of study participants complied with the training protocol. Most likely, the flexibility of the training schedule (i.e., participants training on their own computers on their schedules) is one of the main factors that accounted for this high completion rate. While some individuals found it more beneficial to train first thing in the morning before class, others believed they achieved the most optimal training results late at night. It appeared that sticking to a schedule and training at the same time every day, regardless of the time of day training occurred was most helpful.

4.1.2 Effectiveness of WM training

Consistent with previous research findings, results from the present study provided further support that WM training improves both auditory verbal and visual spatial WM, as measured by neuropsychological tasks. This suggests that WM shows neuroplasticity across a wide age range and can be ‘trained.’ Enhanced WM capacity that consistently results from WM training is an impressive and important outcome that should not be overlooked. Based on the
results of the present study, conclusions cannot be drawn as to the generalizability of WM training effects.

4.1.3 Transfer of Effects to Cognitive Tasks

In contrast to predictions, participants did not improve on measures of controlled (“cognitive”) attention or academic tasks that rely on aspects of WM. One possible explanation for this finding is that longer or more intensive training may be required to produce far transfer effects. Moreover, previous research suggests that these changes may take longer to consolidate, which would have required a longer-term follow-up (Holmes et al., 2009). Furthermore, the WM training study that found improved reading comprehension at follow-up was conducted in a child population and, perhaps, their cognitive abilities are more malleable than those of young adults. In addition, reading comprehension also requires good decoding skills, a well-developed vocabulary, and the ability to call on prior knowledge (Perfetti, 2010). Therefore, WM is just one of the aspects involved and these other areas may continue to constrain reading comprehension performance. Lastly, the current WM training programs may need to be enhanced and/or successful teaching of transfer of newly acquired skills might be necessary to produce more broad reaching effects.

On the other hand, it is quite possible that improving WM capacity does not necessarily generalize to other cognitive and academic skills that rely on WM. While there may be a correlation between these cognitive functions, correlation does not imply causation. The results of the current study, in combination with previous research, seem to negate a causal relationship between these variables.

4.2 Participants’ Perspectives
Before beginning Cogmed, students listed what they perceived to be their WM weaknesses and, with their training coach, they created a set of training goals. Following the completion of the WM training program, the coaches informally asked participants to reflect back to their original goals and provide an account of how the training impacted their daily lives. Based on their narratives, consistent improvements were noted in a number of areas of everyday functioning. Firstly, the majority noticed improvements in their ability to retrieve verbal information. This included recall of everyday conversations, numbers (i.e. telephone numbers and postal codes), appointments, as well as people’s names. For instance, one of the participants volunteered in a pharmacy and, after completing Cogmed, she noticed it was easier for her to recall the 8 digit DIN numbers. Similarly, another participant commented that, at work, it was easier for her to recall product code numbers.

Secondly, with respect to academics, this improved recall of verbal information facilitated the ability to learn and remember material from lectures and books, without having to review it repeatedly. Several participants said they found it difficult to listen to lectures while attempting to take notes. Following Cogmed, it was easier to remember what the professor said in class, even if they did not review the material immediately after. When it came to taking exams, these students felt more confident, as they were able to access this knowledge more readily from memory. One participant noted that she used to be very anxious when it came to test taking. If she could not come up with an answer immediately, she would “freak out.” After completing Cogmed, she noticed she would stop, think, and try to problem solve rather than panic. Moreover, this student also reported getting an A on her most recent exam, whereas her course average going into the exam was a B.
Thirdly, several participants noted that they were able to sustain attention and feel more alert for longer periods of time. A number of students said they used to go into a room and forget why, as well as misplace things (i.e. keys, wallet, and cell phone); after completing Cogmed, this became less of an issue. One participant who wrote a column for a magazine felt he was able to maintain his attention and write for sustained amounts of time, making it easier to meet his deadlines.

Lastly, and perhaps because of all of the aforementioned improvements, these young adults reported that they felt more confident, “on top of things,” motivated, and focused on getting things done.

When asked to comment on areas where they did not see improvements, some of the participants stated that they had hoped to improve their time management skills, but had not noticed any significant change. Similarly, organization skills continued to be an area of struggle. With regard to their academic goals, a few participants commented that it was still difficult to get their ideas down on paper in an organized manner.

Overall, the feedback from the participants was positive. However, a causal effect between Cogmed and the improvements noted cannot be assumed. Nevertheless, building confidence in one’s ability to learn and remember information as well as self-efficacy are significant outcomes that cannot be overlooked. Because this is anecdotal feedback, it would have been beneficial to include “other ratings” to strengthen these claims.

4.3 Study Limitations and Strengths

There are several limitations of the current study that must be addressed. Firstly, we used a wait-list control design as opposed to an active control group. Thus, both groups were aware of
which treatment condition they were in, and as such, positive results might reflect expectancy effects. It would have been ideal to have an active control group, where an alternative training program could be delivered the same way. However, we did not believe it was ethical for our sample to spend large amounts of time training on a low difficulty level program that has no effect. In addition, we were concerned participants training on the low-level program would not be as motivated as those doing the adaptive training and this could potentially influence the results. While it may have been informative to use an intervention that does not target WM as a control group (i.e., organization or mindfulness training), these interventions had not been piloted in college students at the time. In retrospect, it would have been useful to supplement self-report questionnaires with ‘other’ reports (i.e., parent, spouse, partner, roommate).

Secondly, the absence of a longer-term follow up is another limitation. It was very difficult for participants to return for 2-month follow-up testing due to the short duration and variability of the school semester. Holidays, exams, and midterms often coincided with the times participants were due to return for testing. As such, this study may have lacked the statistical power to detect some sustained or later emerging benefits from WM training. Specifically, it may take time for certain skills to transfer and generalize (e.g., reading comprehension). Thus, longitudinal studies may be more successful at understanding the impact of the training on academic functioning. Lastly, due to multiple testing, there was a lack of control over inflated alpha that undoubtedly increased the chance of Type I Error in the analyses.

Notwithstanding the aforementioned limitations, this study is the first randomized, controlled study to investigate WM training in college students with ADHD/LD. College students with ADHD/LDs are a unique and understudied subset in the ADHD/LD literature.
While most research has focused on the challenges that these students face, this was the first study to examine whether WM training can confer the same improvements for college students with ADHD/LD as it has in other populations.

There are two other RCTs to date that have investigated WM training in children and adolescents with co-occurring ADHD/LD (Beck et al., 2010; Gray et al., 2012). Similar to the present study, Beck et al. (2010) utilized a wait-list control design and training was conducted in the home setting. Their most robust finding was a decrease in ADHD symptoms at post-test and 4-month follow-up, according to parent reports. In addition, parents also rated significant changes on the BRIEF subscales of Working Memory, Initiate, and Plan/Organize. However, these parents were not blind to treatment conditions and may have been biased in their ratings. Similar to the present study, the adolescents with severe LD and comorbid LD in the Gray et al. study (2012) showed significant improvements on WM criterion measures, but no training effects were observed on the near or far transfer measures.

There is minimal to no evidence from randomized, controlled studies to indicate changes in inattentive behaviour, academic skills, and cognitive errors following WM training. Previous findings regarding behaviour change with ADHD populations were restricted to ratings by parents, who were involved in supervising the intervention, and therefore, were not free from bias (Beck et al., 2010; Klingberg et al., 2005). With respect to academic achievement or more general cognitive functioning in day-to-day life, there are no RCTs to date that have found that improving WM will generalize to these other skill areas.

4.4 Implications for Clinical Practice
The current study adds to the accumulating empirical evidence that WM training leads to significant improvement on WM tasks that resemble those trained (near transfer) and raises the possibility that WM training may be an effective intervention for ADHD/LD. While our participants self-reported fewer ADHD symptoms and cognitive failures at post-test, these results must be interpreted with caution given possible expectancy effects. Our pattern of findings is consistent with other studies where there was an absence of transfer effects on academic measures (i.e., reading and math reasoning).

This calls into question whether or not clinicians should be recommending Cogmed in their practices. On the one hand, it is one of few interventions for ADHD that does not involve medication and appears to produce sustainable WM improvements. On the other hand, does this program do what it claims to? Often parents of children with ADHD and adults who have ADHD themselves are in search of a treatment that will help with focusing, time management, and organization skills. At present, there is little evidence that Cogmed will lead to improvements in any of these areas.

Currently, the main challenge facing researchers and clinicians is how to best transfer newly acquired WM skills from Cogmed to alternate environments, especially school and work. In order to achieve maximum benefit from WM training programs, it may be necessary to include specific coaching whereby individuals are given strategies on how to transfer newly acquired skills to everyday tasks. Moreover, combining WM training with stimulant medication may also help to enhance its effect. Lastly, it may be useful to take into account the individual’s characteristics (i.e., cognitive ability, education level, and age) when considering which training approach will be most beneficial (Morrison & Chein, 2011). These are all avenues that require further study.
4.5 Theoretical Implications

A prevailing criticism of the current WM training programs is that they are not based on a clear theory of the underlying processes involved, nor is there an explicit rationale provided for the use of specific training tasks. Melby-Lervåg and Hulme (2012) noted that the existing training programs appear to be based on a “physical-energetic model,” the more you train in an area, the greater the improvements will be. Future studies should attempt to clarify the mechanisms responsible for training gains.

A review of the literature, combined with the findings of the current study, raises two fundamental questions: does WM training improve WM and does WM training lead to generalized cognitive enhancement? The pattern of findings within the WM training literature provides strong evidence of near-transfer effects, but weaker support for far-transfer (Melby-Lervåg & Hulme, 2012). This trend may be interpreted in several different ways. On the one hand, it is possible that far-reaching improvements are difficult or impossible to produce with short-term training programs. In addition, it may take more than six months to a year for improvements to consolidate and no studies to date have conducted a follow-up after one year’s time. Furthermore, WM is just one aspect involved in more complex processes (i.e. reading, writing, attention) and other factors (i.e., classroom behaviour and cognitive variables) might continue to constrain performance despite improved WM.

Baddeley’s Multi-Component Model of WM, where there are two short-term storage components plus the central executive, would predict that WM training should improve the functioning of the central executive. Given the interdependence of these three systems, the improved functioning of the central executive should also improve the phonological loop and visuo-spatial sketchpad. The present findings were consistent with this prediction, as WM
training led to improvements on Digit Span Backwards and the CANTAB Spatial Span. Furthermore, Engle and Kane (2004) emphasized the link between cognitive attention and WM. At post-test, participants self-reported fewer symptoms of ADHD and less cognitive failures, providing further support that improving WM leads to improved attention and less “mind wandering.” However, these results should be interpreted with caution because this was an unblinded study.

4.6 Future Directions

The evidence to date regarding the effects of WM training remains inconclusive. Studies have consistently shown that WM training leads to improvement on tasks similar to those trained (near-transfer) and that gains are typically maintained several months later. However, far-transfer of effects to complex reasoning skills, attention, and academic achievement is minimal and further investigation through randomized controlled trials is needed. Possible avenues for future study could include investigating variation in tasks, conditions, and duration and intensity of training. At present, it is unclear how much training is necessary to maximize gains and whether “booster” sessions are required to sustain training benefits. Furthermore, enhancing WM training with specific coaching might help bring to awareness of newly acquired skills and assist with transferring these skills to everyday life.

4.7 Conclusion

Findings from this study indicated that the Cogmed WM training program is a viable intervention for college students with ADHD/LD. One major objective of this study was to determine the feasibility of carrying out this program with this population. Overall, attrition was low; most completed the requisite number of training sessions and the majority reached the optimal index score of improvement. Another major objective was to determine whether WM
training would be effective in this population of young adults with ADHD/LD. Training-related effects were found on two WM span measures, a test of auditory-verbal WM and a short-term visual spatial storage measure. Beneficial effects on these measures were sustained at 2-month follow-up. Results also indicated that participants in the WM training group self-reported fewer ADHD symptoms and fewer cognitive failures in their everyday lives at post-test. At follow-up, they continued to endorse a decrease in cognitive failures. We did not find transfer effects to other measures of WM or other aspects of cognitive function. Similarly, treatment related improvements in WM were not accompanied by gains on academic measures. The lack of evidence of transfer effects suggests that combining WM training with other well-established ADHD/LD treatments might result in more practical and meaningful transfer of gains in WM to daily functioning.
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