EVALUATION OF A WORKING MEMORY TRAINING PROGRAM IN ADOLESCENTS WITH SEVERE ATTENTION DEFICIT HYPERACTIVITY DISORDER AND LEARNING DISABILITIES

by

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A thesis submitted in conformity with the requirements for the degree of Master of Arts
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Abstract

Working memory ability (WM), which is essential for many academic skills, has been found to predict inattentive behaviour and is a common deficit in ADHD and LD. Recent studies have suggested that WM can be improved by intensive and adaptive computerized training. The purpose of this study is to investigate the effects of a WM training program on WM, attention, behaviour and academics in adolescents with severe LD/ADHD. A total of 60 12 to 17 year olds with ADHD/LD were randomized to one of two computerized intervention programs: working memory training or math training, and evaluated before and at three weeks after completion. Adolescents in the WM training group showed greater improvements on some measures of WM than those in the math training group, but no training effects were observed on any other measures. Findings are discussed in the context of theoretical and practical implications of WM training.
Acknowledgements

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Chapter 1

Introduction

Overview and Organization of the Thesis

This thesis explores the literature in the area of working memory (WM) with respect to Attention Deficit Hyperactivity Disorder (ADHD) and Learning Disabilities (LD), two neurodevelopmental disorders in which working memory is compromised. The study within this dissertation, prepared for publication, investigates the effects of working memory training on working memory, attention, behaviour and academic achievement in a population of adolescents with severe ADHD/LD. This is the first randomized controlled trial (RCT) to investigate WM training in this population, in a school setting, using a wide range of outcome measures.

The first chapter of this dissertation reviews the literature on working memory, working memory training, and working memory and ADHD and LD. The second chapter summarizes objectives and hypotheses and details methodological issues that are beyond the scope of the publication. Chapter three is the main study manuscript, prepared for publication (note: in order to make the publication self-contained, some overlap of information was unavoidable) and chapter four is a general discussion that expands upon the discussion in the publication manuscript.

Working Memory

Many frameworks for describing the function of working memory exist; however, it is generally described as a multi-component cognitive system that allows us to hold internal representations of information online for a few seconds in the face of delay or distraction and manipulate the information to produce an output (Baddeley, 2010; Miyake & Shah, 1999). WM
is essential for many academic skills, including reading and listening comprehension, problem-solving, mathematical reasoning and written expression (Gathercole, Alloway, Willis & Adams, 2006; Swanson & O’Connor, 2009) and is correlated with general intelligence (Engle, Tuholski, Laughlin, & Conway, 1999). It is a common deficit found in many psychiatric and neurodevelopment disorders, including attention deficit hyperactivity disorder (ADHD), learning disabilities (LD), intellectual disabilities, schizophrenia, as well as stroke and traumatic brain injury (Gathercole & Alloway, 2006; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005).

Among the first theories to distinguish short-term memory (passive short-term maintenance and rehearsal of information) from WM was that of Baddeley and Hitch (1974). Their multi-component model of WM separates visual (visuo-spatial sketchpad) and phonological (phonological loop) components that are responsible for short-term storage, rehearsal and manipulation (Baddeley, 2003). These two components do not operate solely in parallel; evidence suggests that the phonological loop codes information for storage while visual spatial information is being manipulated (Baddeley, 2003). Most models of WM agree that there are both verbal and visuo-spatial components as well as storage and manipulation components involved in the construct (Baddeley, 2010).

WM is thought to be a main component of the executive functions, and is closely tied to attention (Awh, Vogel & Oh, 2006). Findings from behavioural and neuroimaging studies indicate that WM is integral to control of attention; it is necessary for attending to relevant information and filtering out irrelevant stimuli (Conway, Cowan, & Bunting, 2001; Kane & Engle, 2003). Baddeley and Hitch’s model addresses this connection through an attentional control system, the central executive. The central executive is thought to be a complex system of executive processes. A later addition to this model is the episodic buffer, which is capable of
holding and combining ‘episodes,’ or chunks of sensory information (visual, auditory, and possibly smell and taste). This limited-capacity buffer allows all the components of WM to interact and interface with information from long-term memory and perceptual information (Baddeley, 2003).

A different conceptual model, albeit compatible with Baddeley and Hitch’s model, conceptualizes WM as a part of long-term memory, with activated representations from long-term memory and a limited-capacity “focus of attention” (Cowan, 2005). Conway and Engle’s (1996) theory of WM, ‘A general capacity hypothesis’ proposed that independent of the task at hand, those who have a high WM capacity have more attentional resources available. More recently, based on patterns of brain activation that converge with psychometric data suggesting that verbal and spatial WM tasks tap into shared cognitive processes, this group suggests a ‘domain general’ position of WM (Chein, Moore, & Conway, 2011; Kane et al., 2004).

The training tasks in the current study, as well as the cognitive battery administered, have been designed to tap into multiple components of WM. Thus the current study is carried out within the theoretical framework of Baddeley’s multi-component model of WM.

**Working Memory Training**

Prior to the 1970s, WM was assumed to be a fixed trait (Santiago Ramon y Cajal, 1913). Since this time there have been many attempts to improve cognitive functioning in the area of memory through training, mainly in terms of chunking and rehearsal strategies. Studies found some improvement in memory performance through explicit training, but it was largely domain-specific, with no success in finding transfer effects (for example, Butterfield, Wambold, & Belmont, 1973; Ericsson, Chase, & Faloon, 1980). Burgeoning evidence now suggests that WM shows neuroplasticity even in adulthood (Klingberg, 2010; Olesen, Westerberg, & Klingberg,
2004). Intensive, systematic training of WM shows promise for improving WM
capacity/efficiency in children and adults (Klingberg, 2010). One of the main features that
support the effectiveness of one particular program is that it is adaptive and programmed to tax
WM at an optimal level. That is, the difficulty of each task is adjusted on a trial by trial basis,
according to individual level of performance. It is also specific to training one cognitive process
(WM) and is repeated for 30-45 minutes a day. These factors may be the main differences
between this specific program and other programs that have trained many cognitive processes at
once or are not taxing the individual’s WM capacity at an optimal level (Kerns, Eso, &
Thompson, 1999; Owen et al., 2010).

The WM training program developed by Cogmed Cognitive Systems (Sweden) was
originally designed to improve WM in those with ADHD. However, beneficial effects have been
found not only in ADHD populations, but in healthy adults and preschool children, stroke
patients, and children with low WM (see Klingberg, 2010 for a review). WM training is
associated with changes in dopamine receptor density and brain activity in the middle frontal and
parietal cortex and basal ganglia (Olesen et al., 2004). Studies have shown training induced
plasticity, through improvement on non-trained WM tasks (Holmes, Gathercole, & Dunning,
2009; Klingberg, Forssberg, & Westerberg, 2002; Klingberg, Fernell, Olesen, & Johnson, 2005;
Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009; Westerberg et al., 2007). On
two of these studies, the treatment effects were maintained at 3 and 6 month follow up (Holmes,
Gathercole, & Dunning, 2009; Klingberg et al., 2005). There is some indication that training can
have positive effects on behaviour, including inattentive behavior (Beck, Hanson, Puffenberger,
Benninger, & Benninger, 2010; Klingberg et al., 2005) and every day ‘cognitive failures’
(Gropper & Tannock, 2011). One study has found improvement in math performance at 6-
month follow up, but the study was not designed as a randomized controlled trial (Holmes, Gathercole, Place, Dunning, Hilton, & Elliott, 2009). Although this program has been investigated by a number of external researchers, there are a limited number of RCTs evaluating transfer effects.

**Working Memory in Neurodevelopmental Disorders.**

**Attention-Deficit/Hyperactivity Disorder.** Attention-deficit/hyperactivity disorder (ADHD) is one of the most common childhood neurodevelopmental disorders, affecting 3 to 7 percent of school-aged children, with diagnosis more common in boys (American Psychiatric Association [APA], DSM-IV-TR, 2000; Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007). The Diagnostic and Statistical manual requires that the following five criteria are met in order for a diagnosis of ADHD to be made: (1) Six or more specifically defined symptoms of inattention or of hyperactivity/impulsivity (2) onset of some symptoms that caused impairment before age 7 (3) impairment seen in two or more settings (4) clinically significant impairment in functioning and, (5) symptoms not better accounted for, or that do not occur only within the course of another psychiatric disorder (APA, DSM-IV-TR, 2000). Diagnostic specifiers include hyperactive, inattentive or combined subtypes. However, recent research suggests that ADHD is best described as a unitary factor, with all symptom categories overlapping and interacting with one another (Toplak et al., 2009). Thus ADHD can be categorized as general factor, with two specific factors of inattention and hyperactivity/impulsivity, which have relative contributions to the clinical presentation of ADHD (Gibbins et al, in press; Martel, Von Eye, & Nigg, 2010; Toplak et al., 2009).

Although previously thought of as a childhood disorder, ADHD often persists into adulthood, negatively impacting academic, social and occupational outcomes (Biederman et al.,
Adolescents with ADHD are more likely to not complete high school due to social and academic difficulties and experience higher levels of conflict with parents (Barkley, 2002). Cognitive deficits such as response inhibition continue into adolescence, with more severe cognitive impairments when combined with a Reading Disability (RD) (Rucklidge & Tannock, 2002).

Concerns about attention and hyperactivity account for about 30 to 50% of child referrals to mental health services (Mash & Barkley, 1996). ADHD is associated with a number of comorbid disorders, including Learning disabilities.

**Learning Disabilities.** Those who suffer from a Learning disability have at least average intellectual abilities; however, they often struggle to acquire academic skills such as reading, spelling, mathematics or writing. These struggles continue into adulthood and are associated with poor social, academic, and occupational outcomes (Goldstein, Naglieri & DeVries, 2011). Learning disabilities are sometimes noted as an ‘invisible’ disability, as it is associated with specific psychological processes which are impaired and hinder acquisition of academic skills, but the impaired process is not immediately identifiable, often because of corresponding strengths in intellectual abilities. Learning disabilities are heritable, are present in about 10% of school-age children and adolescents, and are associated with other mental health problems, including ADHD (Carroll, Maughan, Goodman, Meltzer, 2005; Maughan & Carroll, 2006). For the purposes of this study, LD is defined as resulting from impairments in one or more psychological processes related to learning, with at least average abilities in thinking and reasoning (Learning Disabilities Association of Canada). In addition, LD is associated with lower than expected academic achievement or achievement that is sustained with high levels of
support. This definition was selected due to the challenges associated with IQ-discrepancy
definitions of LD (Fletcher, Lyon, Fuchs, & Barnes, 2007).

**Comorbidity between Attention-Deficit/Hyperactivity Disorder and Learning Disabilities.** Of particular concern are those diagnosed with both ADHD and LD. These diagnoses co-occur at rates between 15 and 40% and confer increased risk for poor social, health and education outcomes across the lifespan, (Goldston et al., 2007; Rabiner & Coie, 2000; Sexton, Gelhorn, Bell, & Classi, 2011; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) therefore early identification and intervention is especially important in this population. LDs and ADHD also share multiple cognitive deficits, including poor working memory and processing speed (McGrath et al., 2011; Willcutt et al., 2010a). Reading disabilities (RD) are among the most common LDs associated with ADHD (Sexton et al., 2011). Epidemiological evidence suggests that co-occurrence between RD and ADHD is between 0.4% (Carroll, Maughan, Goodman, & Meltzer, 2005) and 3.7% (Pastor & Reuben, 2008).

Evidence for shared genetic etiology, structural and functional brain abnormalities and cognitive deficits between reading disorders and ADHD has led to different theories concerning the etiology of the two disorders (Eden & Vaidya, 2008; Fisher & DeFries, 2002; McGrath et al., 2011). Those with both an RD and ADHD have more severe deficits in working memory, along with impairment in rapid naming, which are unique to this comorbid group (Bental & Tirosh, 2007; Rucklidge & Tannock, 2002). This suggests that there is a distinct cognitive subtype for the co-occurring disorders, arising from distinct etiological factors (Rucklidge & Tannock, 2002). The ‘multiple deficit model’ posits that the strong evidence for shared genetic risk factors (Fisher & DeFries, 2002) leads to a neuro-cognitive developmental pathway which increases the risk for both disorders (Shafritz, Marchione, Gore, Shaywitz, & Shaywitz, 2004; Shanahan et al.,
2006; Willcutt, Pennington, Chhabildas, Olson, & Hulslander, 2005). However there are some differences between impairments in the two disorders. For example, the ability to store auditory-verbal information is impaired in Reading disabilities but not in ADHD (Martinussen & Tannock, 2006).

Little is known about the effectiveness of educational remediation for those with both ADHD and LD. WM in those with ADHD appears to be only minimally improved by stimulant medication (Bedard, Jain, Johnson, & Tannock, 2007; Bedard, Martinussen, & Ickowicz, & Tannock, 2004). One study with ADHD populations showed some improvement in listening comprehension after treatment with stimulant medication (McInnes, Bedard, Hogg-Johnson, & Tannock, 2007). There has been some promise in treating the co-occurring ADHD/LD with stimulant medication, however this is not sufficient for academic remediation (Sexton et al., 2011).

**Working Memory in Attention-Deficit/Hyperactivity Disorder and Learning Disabilities.** Although the diagnosis of ADHD is based on overt behavioural symptoms, research indicates that there are a number of neurological and cognitive underpinnings that characterize children with ADHD. One such finding is that children with ADHD have delayed frontal lobe development, which is associated with executive functioning (EF) difficulties, including deficits in working memory (Barkley, 1997; Castellanos & Tannock, 2002). Many children with ADHD have both impaired visual-spatial and verbal WM deficits (Martinussen et al., 2005; Westerberg, Hirvikoski, & Forssberg, 2004). These deficits are thought to underlay behavioural symptoms of inattention and impede academic and social outcomes in children, adolescents and adults with ADHD (St. Clair-Thompson & Gathercole 2006; Martinussen & Tannock, 2006). Although not
all children diagnosed with ADHD have executive function difficulties and poor WM (Willcutt et al., 2010a), those who do, have lower IQ (Lambek et al., 2010).

As reviewed above, there is some overlap of underlying processing deficits in ADHD and LD, WM being a particularly salient, although not universal, deficit in this population. Although WM is a common area of difficulty in LDs, the pattern of impairment differs with the wide variation in subtype of LD. For example, Reading disabilities are strongly associated with deficits in WM (Gathercole, Alloway, Willis, & Adams, 2006). Children with language learning disorders have deficits in areas of WM, including central executive, and verbal and spatial storage (Martinussen & Tannock, 2006).

**Working Memory Training in Attention-Deficit/Hyperactivity Disorder and Learning Disabilities.** Traditional treatments for students with ADHD and LD involve medication and educational and behavioural intervention (Goldstein, Naglieri, & DeVries, 2011; Sexton et al., 2011), neither of which directly target the underlying cognitive difficulties associated with these disorders. Medication is not a typical treatment for LD alone, although there are a few studies that propose the utility of medication in RD (de Jong et al., 2009; Bental & Tirosh, 2008). In light of the association between WM and poor academic achievement, efforts have been underway to find interventions that target the cognitive difficulties in ADHD populations.

Evidence shows that WM training improves WM in children with ADHD and effects may generalize to other cognitive functions (see Table 1 for review). Three controlled trials conducted with children and adolescents who have ADHD found 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). However in one study, parents were not blind to which
program (control or experimental) their children were completing (Beck et al., 2010). Parents were blind to the condition in the other two studies, but one study had a small sample size and no follow up (Klingberg, 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, Gathercole & Dunning, 2009). To date, there have been no published studies on WM training in individuals with ADHD/LD; thus it remains unknown whether WM training will be an effective intervention approach for youth with ADHD/LD (Beck et al., 2010).

Therefore the current study is a randomized, controlled trial evaluating the effectiveness of WM training in a hard-to-treat group of adolescents with ADHD/LD, using varied outcome measures including tests of academic achievement.
Table 1

Behavioural Studies of WM training in ADHD and LD populations using a RCT design

<table>
<thead>
<tr>
<th>Reference</th>
<th>Population (age in years)</th>
<th>Control group</th>
<th>Transfer to WM</th>
<th>Transfer to other Cognitive Tasks</th>
<th>Transfer to behaviour</th>
<th>Transfer to Academics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gibson et al., 2011</td>
<td>ADHD (on meds) (11-16)</td>
<td>None (verbal vs spatial WM training groups)</td>
<td>Immediate free recall task (recency portion of the curve)</td>
<td>None measured</td>
<td>Du Paul ADIHD rating scale</td>
<td>None measured</td>
</tr>
<tr>
<td>Johnstone et al., 2010</td>
<td>ADHD (7-12)</td>
<td>Active control</td>
<td>None measured</td>
<td>None measured (Resting EEG changes)</td>
<td>CPRS-R, CBCL</td>
<td>None measured</td>
</tr>
<tr>
<td>Beck et al., 2010</td>
<td>ADHD and comorbid disorders (on meds) (7-17)</td>
<td>Waitlist control</td>
<td>None measured</td>
<td>None measured</td>
<td>BRIEF (WM, plan/organize and initiate) (parent rated)</td>
<td>None measured</td>
</tr>
<tr>
<td>Klingberg et al., 2005</td>
<td>ADHD (7-12)</td>
<td>Active control</td>
<td>Spanboard, Digit Span, Stroop, Raven’s Matrices</td>
<td>Connors (parent rated)</td>
<td>None measured</td>
<td>None measured</td>
</tr>
<tr>
<td>Klingberg et al., 2002</td>
<td>ADHD (meds) (7-15)</td>
<td>Active control</td>
<td>Span Board</td>
<td>Raven’s Matrices Stroop</td>
<td>None measured</td>
<td>None measured</td>
</tr>
</tbody>
</table>
Chapter 2
Research Objectives, Hypotheses and Methodology

Objectives and Hypotheses

The present study is one of the first studies to examine WM training in a school setting, and the first RCT with this specific population in a school setting. Thus the first objective of this study is to determine the feasibility of implementing a WM training program in a school setting with adolescents diagnosed with ADHD and LD. The second objective is to extend and replicate existing studies by determining whether computerized WM training improves WM and attention in a treatment-resistant population of adolescents with LD and comorbid ADHD. The third objective is to examine the benefits of WM training on a behavioural level, thus to investigate the extent to which behavioural symptoms of inattention in the classroom and home environments can be reduced by improving WM. The fourth objective is to evaluate transfer effects into math, reading and spelling achievement.

Existing literature indicates that visual-spatial and verbal WM in pre-adolescents with ADHD is improved after training (Klingberg, 2005). Thus, it is hypothesized that at post-treatment, participants in the WM training group will improve on all measures of WM. WM is a prerequisite for the selection of relevant information and filtering out irrelevant information (controlled attention; Awh et al., 2006). Research also indicates that training improves aspects of these higher order cognitive control functions (Klingberg et al., 2005), therefore it is hypothesized that aspects of attention (selective attention, inhibitory control, set-shifting) will improve as a result of WM training. There is minimal evidence to date that suggests that WM training reduces behavioural symptoms of inattention and has an impact on academic
achievement (Klingberg et al., 2005; Holmes, Gathercole & Dunning, 2009). However, based on the theory that WM problems underlie and contribute to some of the surface behavioural symptoms of ADHD/LD (particularly inattention), it is hypothesized that those in the WM training group will show improvements in levels of attention in the classroom and home settings. Poor WM is a risk factor for academic under-achievement, and impacts development of academic skills that depend on WM (St. Clair-Thompson & Gathercole, 2006). It is hypothesized that WM training will confer more benefits in aspects of numeracy and literacy that depend upon WM (sentence comprehension, reading, spelling) but not basic math fact fluency. The expectation is that those in the math training group will show improvement on measures of math achievement.

**Methodological Issues**

**Research setting.** The school in which this research project was conducted is provincially funded and semi-residential; students who live in the vicinity commute daily, but the majority of students return to their homes all over Ontario only on weekends. The school accepts students between the ages of 12 and 17 who have a diagnosis of ADHD and an LD, and have not responded to evidence-based medical intervention nor to educational interventions available in the regular provincial school system.

The rationale for using the school setting was twofold. One reason was to control for potential parental bias present in other studies, such as differences with motivation and reward methods of parents, and compliance issues inherent with this age group when parents are the only monitors. A second reason was to anticipate future use of WM training should it be found to be effective: this intervention might be best incorporated into the education setting rather than done at home (typically after school) supervised by parents. Although there was a
strong rationale for carrying out the current study at this residential school, some limitations and difficulties apply. Efforts were made to distance teachers (who were filling out rating scales) from the training laboratories and the organization of training groups, but a full blind is not possible to attain in the school setting in which both groups are training simultaneously.

Maintaining training consistency in the school setting was a challenge due to the complexity and variability of the school schedule. Training time was first allotted to the after school ‘homework’ hours, in the students’ residence. All students had access to desktop computers at school and in their residences. Due to the levels of supervision required for adequate compliance, training time was changed and instead scheduled into the school day (during a ‘spare’ period), which increased compliance and facilitated regular training. A few students did train at a different time period if, for example, there were exams or school events that necessitated this change. Due to limited staff resources, only one cohort could train at one time, thus two cohorts trained in the spring, fall, and winter terms of 2010, and one trained in the winter term of 2011.

**Measures**

The measures in this study were based on Baddeley’s multicomponent model of WM, therefore outcome measures of WM include recall and manipulation of information in both the auditory-verbal and visual-spatial domains. Based on the results of previous studies (e.g. Westerberg et al., 2007), outcome measures were categorized into (1) ‘compliance measures’ (number of training sessions and level of training intensity as measured by the Cogmed Improvement Index score); (2) ‘criterion measures’ (closely resembling the tasks trained in the 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 or observable behaviour in the classroom or home environments).

**Compliance measures.** The WM training program has a built-in compliance measure, The Cogmed Improvement Index, which is provided automatically by the WM training program for each user. This score is calculated by subtracting the Start Index (results of day 2 and 3) from the Max Index (results from the two best training days). The program also records the number of training days each participant completed.

**Criterion measures.** In order to replicate previous findings, and extend those findings to this study’s population, the well validated, highly reliable Digit Span subtest from the Wechsler Intelligence Scale for Children - Fourth Edition (WISC-IV; Wechsler, 2003) was chosen to measure auditory-verbal short term and WM. Internal consistency is .87 and test-re test stability is .82. 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 was used to assess executive functioning, including measures of Spatial Span (forward and backwards) (CANTAB; Fray, Robbins, & Sahakian, 1996). The CANTAB battery has high internal consistency (.73-.95) and stability (.60-.70) (Luciana, 2003). The Spatial Span score, ranging from 0-9, represents the highest level at which a participant is able to correctly reproduce a sequence of boxes that light up on the screen in a certain order.

**Near transfer measures.** Previous research indicates that test performance was improved after WM training on a paper-based visual cancellation test (Westerberg et al., 2007). A similar measure, the D2 Test of Attention was chosen as a measure of individual attention and concentration. It is based on a visual cancellation test, although standardized and computerized
(Brickenkamp & Zillmer, 1998). This timed test of visual discrimination allows for measurement of processing speed, rule compliance, and quality of performance. Evidence supports the convergent and discriminant validity of this test (Bates & Lemay, 2004). Bates and Lemay (2004) found high internal consistency on test subscales, ranging from .90 - .97, with the exception of commission errors (Cronbach’s alpha of .61).

The CANTAB Spatial Working Memory task was used to assess WM strategy skills and errors. This computerized task is based on self-ordered pointing tasks (Petrides & Milner, 1982). Participants use a touch screen on the monitor to search for a token inside each box on the screen, without returning to the same box twice; therefore using spatial working memory to maintain updated information. There are four trials for each of three conditions: four, six and eight boxes. Performance is based on the number of errors made. A strategy score is produced for each subject. A low score indicates efficient strategy use, whereas high scores reflect poor strategy use.

The Working Memory Rating Scale (WMRS) was chosen as a behavioural measure of WM deficits in a classroom setting (Alloway et al., 2009; Alloway, Gathercole & Elliot, 2010). It is a newly developed scale consisting of 20 items that describe behaviours characteristic of children with working memory deficits. Teachers rate how typical each behaviour is of a particular child, using a four-point scale ranging from not typical at all (0) to very typical (3). Two studies indicate that the full 20-item scale has good internal reliability and differentiates children with and without WM problems (Alloway & Warn, 2008; Alloway, Gathercole, Kirkwood, & Elliot, 2009). However, a recent study (Normand & Tannock, 2011) did not replicate the factor structure of the original 20-item questionnaire. Normand and Tannock found a robust factor structure, high internal reliability and moderate concurrent validity for a
shortened, 6-item WMRS. Thus analyses were carried out with totals from both the full and abridged version of the WMRS.

**Far transfer measures.** The Wide-Range Achievement Test-4-Progress Monitoring Version (WRAT-4PM; Roid & Ledbetter, 2007), was used as a reliable and efficient tool for monitoring the academic progress of students in Grades K-12. A series of brief 15-item tests are offered in 4 areas of basic skills: word reading, sentence comprehension, spelling, and mathematical computation. Each WRAT4-PMV level consists of four parallel 15-item forms that are psychometrically equivalent; thus a different form will be used at each of assessment point. The WRAT4-PMV shows good internal consistency, ranging from .74 - .81 and test-retest stability coefficients between .77 and .89. It also shows high alternate-form reliability, equivalency of the forms within each of the six levels, and validity.

The Strengths and Weakness of ADHD-symptoms and Normal-behavior scale (SWAN, (Swanson et al., 2001), was used to measure symptoms of attention. This newly validated scale provides a more precise measure of attention than other rating scales. It is positively worded and it captures the variation presumed to exist in the normal population, variation related to strengths as well as weaknesses. It includes 9 inattention items and 9 hyperactive/impulsive items, as well as 9 oppositional items. Items are rated on a 7-point scale (Far Below Average = 1, Far Above Average = 7). The higher the score, the more inattentive or hyperactive/impulsive the participant is rated as being.

The IOWA Conners scale (Pelham, Milich, Murphy, & Murphy, 1989) was chosen as a second measure of teacher and parent-rated inattentive and hyperactive behaviour. This commonly used scale is well validated and treatment-sensitive. It includes five
inattentive/impulsive/overactive items and 5 oppositional defiant items, rated on a 4-point scale. Subtest internal consistency ranges from .85 - .91 and test-re-test reliability is between .69 and .80.

**Intervention Programs**

*Working memory training program.* We selected a software program (Cogmed RoboMemo; Pearson Education, Upper Saddle River, NJ) developed by Cogmed Cognitive Medical Systems AB (Stockholm, Sweden), a computerized program designed to train visual-spatial and auditory-verbal WM. To date, this is the WM training program backed by the most empirical evidence for its effectiveness in training WM (Klingberg, 2010). Moreover, there is evidence for improvements in other cognitive domains after training with this program and for training-induced plasticity in the neural networks underlying WM (Klingberg et al., 2005; Olesen et al., 2004; Westerberg et al., 2007). This program consists of various WM tasks designed in a video game format that is engaging for children and adolescents. Built-in contingent reinforcement adds to motivation levels (which a Cogmed Coach ensures are maintained).

Similarly to the math training group, students were rewarded with extra recreational time and a pizza party at the completion of training. The key to this specific program is that it adapts to the individual level of performance, maintaining an optimal level of challenge by adjusting difficulty on a trial-by-trial basis. Training is carried out for approximately 45 minutes a day, 4 to 5 days a week for 5 weeks. The typical training battery included 12 different WM training exercises, 8 of which were completed every day, with 15 trials of each task. The program is designed so that training is individualized, thus exercises are modified based on current performance. All responses were logged and the data from each training session was uploaded to a secure server so that compliance could be verified by the certified Cogmed training coach. A detailed description
of the tasks included in the RoboMemo Cogmed program can be found in Klingberg, Forssberg, and Westerberg (2002) (Klingberg et al., 2002) and Olesen et al., 2004. Licenses to use the Cogmed software were provided by Cogmed America, and the software was installed by school personnel.

**Mathematics training program.** Academy of Math (www.autoskill.com) was chosen as an active comparison group. It is believed to have beneficial effects on math skill development in terms of procedural fluency in operations, strategic competence in word problems and conceptual understanding (Swope & Loh, n.d.). It is based on content standards of the National Council of Teachers of Mathematics, therefore includes practice with number and operation, algebra, measurement, geometry and data analysis and probability. The program includes an automated placement test, identifies performance goals and also creates a personalized training plan. Skills are then presented in component tasks, which are mastered one by one. The training plan is designed to enhance motivation and keep students on track with their training. School personnel and participants also implemented a reward system, in which students received extra recreational time after each week of training and a pizza party upon completion of the program. The school regularly used the reading version of Academy of Math (Academy of Reading), and therefore the staff were familiar with the set up and format of the program. In addition to its benefits in the area of math skills, Academy of Math was selected as the math training program because it includes features similar to those of the WM training program, including built in reinforcement, computerized and adaptive format, (adjusts difficulty level to the abilities of the individual student) and time requirements.
Chapter 3

Effects of a Computerized Working Memory Training Program on Working Memory, Attention, and Academics in Adolescents with Severe ADHD/LD

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Conflicts of interest

i) Cogmed America provided the software licences without cost to the study; &
ii) Dr Tannock’s current and past three-year involvement with industry is as a consultant for Eli Lilly, Shire Pharmaceuticals, Janssen-Cilag, and Purdue University for which she has received honoraria (less than US $10,000 per year, all of which is donated to The Hospital for Sick Children’s Foundation to support ADHD research).

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Abstract

Objective: Youth with severe, combined Attention Deficit Hyperactivity Disorder (ADHD) and Learning disabilities (LD) are at risk for poor academic and social outcomes. Cognitive deficits underlying these difficulties, including low working memory (WM), are not well-targeted by current treatments for either ADHD or LD. Studies have suggested that WM can be improved by intensive and adaptive computerized training. This study was a randomized, controlled trial to investigate the effect of WM training in youth with ADHD/LD on cognitive, behavioural and academic outcomes. Method: A total of 60 12 to 17 year olds with LD/ADHD (52 male, 8 female, IQ>80) were randomized to one of two computerized intervention programs: working memory training (Cogmed RM) or math training (Academy of Math) and evaluated before and at three weeks after completion. The criterion measures were WISC-IV Digit Span (auditory-verbal WM) and CANTAB Spatial Span (visuo-spatial WM). Near and far transfer measures included indices of cognitive and behaviour attention and academic achievement. Results: Adolescents in the WM training group showed greater improvements in criterion measures of WM (WISC Digit Span Backwards and CANTAB Spatial Span Forwards) compared to those in the math training group, but no training effects were observed on any other measures. However those who showed most improvement on the WM training tasks were rated as less inattentive/hyperactive by parents. Conclusions: Results from this randomized controlled trial indicate that WM training may be a promising adjunctive treatment for treatment-resistant youth with ADHD/LD, however more research is needed to assess transfer to behaviour and academics.
Introduction

Youth who have difficulties with attention and learning, particularly those who meet the criteria for Attention Deficit Hyperactivity Disorder (ADHD) and a Learning disability (LD), are at risk for academic, social, and occupational difficulties that persist into adolescence and adulthood (McNamara, Willoughby, & Chalmers, 2005; Molina et al., 2009; Goldstein, 2011). Attention and learning disorders commonly co-occur and are associated with several cognitive difficulties including poor working memory (WM) and processing speed (Jensen, Martin, & Cantwell, 1997; Willcutt et al., 2010b). Adolescents with combined ADHD and LD are notoriously difficult to treat. Current treatments, including medication and academic and behavioural remediation, are limited in long-term maintenance of gains and impact on academic achievement (Molina et al., 2009; Pelham & Gnagy, 1999; Wigal et al., 1999). Academic remediation has shown some success for LD, however difficulties with attention and behaviour are associated with poor outcomes in prevention/intervention programs (Alexander & Slinger-Constant, 2004; Rabiner & Malone, 2004; Naylor, Felton, & Wood, 1990). This is possibly because they are not targeting the underlying cognitive deficits fundamental to these diagnoses, nor are they targeting behavioural and academic challenges simultaneously (Rabiner & Malone, 2004). Research suggests that intervention for academic problems needs to be accompanied by support for self-monitoring and self-regulation (Reid & Lienemann, 2006); this is another factor that may be limiting effectiveness of current treatments in this population. Medication does not ameliorate all symptoms associated with ADHD, nor are benefits sustained if patients decide to discontinue their medication (Smith, Barkley, & Shapiro, 2006). Effects of medication and last only as long as the active period of medication. Thus, non-pharmaceutical interventions that
address underlying cognitive difficulties are a promising avenue of additional treatment for youth with combined ADHD/LD.

Working memory, a main component of the executive functions, is posited to be an important mechanism in ADHD and LD (Castellanos & Tannock, 2002; McGrath et al., 2011; Willcutt, Pennington, Chhabildas, Olson, & Hulslander, 2005). It is defined as a limited-capacity, multi-component cognitive system that allows us to hold and manipulate information “on-line” for a few seconds in order to make a response based on that internal representation of the information (Baddeley, 2010). This cognitive function is necessary for organization and planning, completing tasks and remembering instructions, and has been found to predict inattentive behaviours as rated by parents (Lui & Tannock, 2007). A recent laboratory study demonstrated that tasks that over-extended a participant’s WM capacity (storage/rehearsal) were associated with decreases in attentive behaviour in both ADHD and normal populations, however the WM capacity was lower for those with ADHD (Kofler, Rapport, Bolden, Sarver, & Raiker, 2010). WM is consistently found to be below average in ADHD populations and is a strong predictor of academic success (Gathercole, Brown, & Pickering, 2003; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011).

WM capacity has generally been thought to be fixed, but recent studies have suggested that it can be improved by intensive and adaptive computerized training (Klingberg et al., 2005). Using a WM training program developed by Klingberg and colleagues (2005), several studies have indicated treatment-related improvements in visual-spatial and auditory-verbal WM, as well as generalization to other more complex reasoning abilities (see review by Klingberg, 2010). These studies also suggest that WM training may improve behavioral symptoms of inattention, at least as reported by parents (Klingberg et al., 2005). One study indicated that WM training was
associated with improvement in mathematical skills as assessed six months after the intervention, however these results require replication within a randomized controlled design (Holmes, Gathercole, & Dunning, 2009).

The current study is a randomized, controlled trial evaluating the effectiveness of WM training in a hard-to-treat group of adolescents with ADHD/LD. The study design included an active comparison group, comparing the target WM training program to a skill-based program, which targets mathematical skill development. Our study provided a rigorous evaluation of the benefits of WM training in this adolescent population, over and above medical- and education-based interventions. The objectives for this study were: (1) to determine the feasibility of implementing a WM training program in a residential school setting with adolescents diagnosed with ADHD and LD; (2) to determine whether computerized WM training improves WM and attention in a treatment-resistant population of adolescents with Learning disabilities (LD) and comorbid ADHD; (3) to examine the extent to which behavioural symptoms of inattention in the classroom and home environments could be reduced by improving WM and (4) to evaluate transfer effects into math, reading and spelling achievement.

**Method**

**Participants**

A total of 60 adolescents (aged 12-17; 13% females) were recruited through a partnership with a residential, provincially funded school in a major metropolitan area in Canada and operated by the provincial Ministry of Education. This school was tailored towards the needs of adolescents with ADHD and LD who were experiencing severe academic and behavioural difficulties. The sample represented the total number of adolescents enrolled in the school over
the two-year period of the study. Students attended this school for one year and then returned to their home schools, which are spread out over the province, thus making longer-term follow-up difficult. Participants were all taking stimulant medication throughout the trial, thereby allowing for detection of treatment effects beyond the benefits provided by medication and intensive academic remediation.

Inclusion criteria were: (1) full time attendance at the residential school; (2) diagnosis of a specific LD with comorbid ADHD (all subtypes); (3) age between 12 and 17 years at inclusion; (4) IQ > 80 (based on WISC-IV scores); and (5) English as the primary spoken language. Exclusion criteria were: (1) uncorrected perceptual, motor or language impairments that would impede usage of the computer program or intelligibility of spoken responses; and (2) diagnosis of conduct disorder, severe aggression, depression or anxiety requiring specific and immediate treatment. Diagnoses of ADHD and an LD, as well as IQ scores, were confirmed through the psycho-educational reports required for entry into the school program.

These adolescents were severely impaired in the area of WM (WISC-IV WMI SS=85, 16th percentile) and Processing Speed (WISC-IV PSI SS=87, 19th percentile). Results from baseline testing indicate that 97% (DSB) and 93% (DSF) of their scaled scores fell below the 50th percentile; further, 77% (DSB) and 57% (DSF) of their scaled scores fell below the 16th percentile.

Written informed consent to enter the study was obtained from the homeroom teachers and parents of 61 adolescents, 60 of whom gave consent and were randomized to either the working memory training group or the math training group (see Fig. 1). There were no significant group differences on baseline measures, with the exception of one CANTAB measure (Working Memory Span strategy, t(58) = -1.99, p > .05); thus randomization was effective in
ensuring that comparison and treatment groups were similar in terms of baseline cognitive skills and test measures (see Table 2 for baseline sample characteristics).

The study was approved by Institutional Research Ethics Boards at all three institutions involved; the school, the community agency providing the WM program, and the paediatric research centre.

**Outcome Measures**

Each participant underwent individual assessment with a set of cognitive and academic tasks in the school setting before and three weeks after completion of the training programs. Assessments were conducted by trained evaluators, who were not informed about the students’ randomization. Outcome measures were categorized into: (1) ‘compliance measures’ (number of training sessions and level of training intensity as measured by the Cogmed Improvement Index score); (2) ‘criterion measures’ (closely resembled the tasks trained in the 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 or observable behaviour in the classroom or home environments).

**Compliance measures.** The WM training program had a built-in compliance measure, The Cogmed Improvement Index, which was provided automatically by the program for each user. This score was calculated by subtracting the Start Index (results of day 2 and 3) from the Max Index (results from the two best training days).

**Criterion measures.** Tasks included: (1) *Wechsler Intelligence Scale for Children - Fourth Edition* Digit Span Forward (DSF) and Backward (DSB), measures of auditory-verbal short-term and WM (WISC-IV; Wechsler, 2003); and (2) *Cambridge Neuropsychological*
Testing Automated Battery Spatial Span Forward (SSPF) and Backward (SSPB), measures of visual-spatial short-term and WM (CANTAB; Fray, Robbins, Sahakian, 1996).

**Near transfer measures.** Effects were assessed using three measures: (1) Computerized CANTAB Spatial WM Between Errors & Strategy Score was used to assess and differentiate between strategy skills and WM capacity. This task, based on the self ordered pointing task (Petrides & Milner, 1982), is different from other WM tasks in that it is not affected by varying levels of dopamine in the dorsolateral prefrontal cortex (Diamond, Briand, Fossella, & Gehlbach, 2004); (2) The newly developed Working Memory Rating Scale (Alloway et al., 2009; Alloway, Gathercole & Elliot, 2010) was used to assess WM from a classroom-based perspective. This reliable and valid teacher-rated scale consists of twenty items that describe characteristics typical of those with working memory difficulties; (3) The D2 Test of Attention (Brickenkamp & Zillmer, 1998) was used as a measure of individual attention and concentration performance. This timed test of visual discrimination allows for measurement of processing speed, rule compliance, and quality of performance, which offer an estimate of individual attention and concentration performance.

**Far Transfer Measures.** Academic progress was assessed using the Wide-Range Achievement Test-4-Progress Monitoring Version (WRAT-4PM; Roid & Ledbetter, 2007). This test, adapted from the WRAT-4, is a reliable, valid and efficient tool to measure academic progress of students in Grades K-12. It includes 4 brief tests in the areas of word reading, sentence comprehension, spelling and mathematics. A different, psychometrically equivalent form was used in the pre- and post-assessment batteries. Raw scores were converted into Level Equivalent Scores, which are standardized to allow for comparison across grade and age levels. Measures of attention and hyperactivity at home and school included: (1) the Strengths and
Weakness of ADHD-symptoms and Normal-behavior scale (SWAN, Swanson et al., 2001), which was used to measure symptoms of attention. This is a newly validated scale, which provides a more precise measure of attention than other rating scales. It includes 9 inattention items and 9 hyperactive/impulsive items, as well as 9 oppositional items. Items are rated on a 7-point scale (Far Below Average = 1, Far Above Average = 7); (2) the IOWA Conners scale (Pelham et al., 1989), a well validated, treatment-sensitive scale which includes five inattentive/impulsive/overactive items and 5 oppositional defiant items, rated on a 4 point scale.

**Intervention Programs**

**Working memory training program.** We selected a software program (Cogmed RoboMemo; Pearson Education, Upper Saddle River, NJ) developed by Cogmed Cognitive Medical Systems AB (Stockholm, Sweden), a computerized program designed to train visual-spatial and auditory-verbal WM. To date, this is the WM training program backed by the most empirical evidence for its effectiveness in training WM (Klingberg, 2010). Moreover, there is evidence for improvements in other cognitive domains after training with this program and for training-induced plasticity in the neural networks underlying WM (Klingberg et al., 2005; Olesen et al., 2004; Westerberg et al., 2007). This program consists of various WM tasks designed in a video game format that is engaging for children and adolescents. Built-in contingent reinforcement adds to motivation levels (which a Cogmed Coach ensures are maintained). The key to this specific program is that it adapts to the individual level of performance, maintaining an optimal level of challenge by adjusting difficulty on a trial-by-trial basis. Training is carried out for approximately 45 minutes a day, 4 to 5 days a week for 5 weeks. The typical training battery included 12 different WM training exercises, 8 of which were completed every day, with 15 trials of each task. The program is designed so that training is individualized, thus exercises
are modified based on current performance. All responses were logged and the data from each training session was uploaded to a secure server so that compliance could be verified by the certified Cogmed training coach. A detailed description of the tasks included in the RoboMemo Cogmed program can be found in Klingberg, Forssberg, and Westerberg (2002) (Klingberg et al., 2002) and Olesen et al., 2004. Licenses to use the Cogmed software were provided by Cogmed America, and the software was installed by school personnel.

Mathematics training program. This sample of adolescents experienced severe learning difficulties and were in the specialized school program to receive intensive remediation. Therefore, we chose an active comparison program (Academy of Math; www.autoskill.com), believed to have beneficial effects on math skill development (Swope & Loh, n.d.). This computerized program is based on content standards of the National Council of Teachers of Mathematics. It is designed to improve mathematical fluency, conceptual understanding and strategy use. The school regularly used the reading version of this software program (Academy of Reading), and therefore the staff were familiar with the set up and format of the program. In addition to its benefits in the area of math skills, Academy of Math was selected as the math training program because it includes features similar to those of the WM training program, including built in reinforcement, computerized and adaptive format, (adjusts difficulty level to the abilities of the individual student) and time requirements.

Procedure

Initial information about the study was delivered verbally and in written format to students and teachers (in separate presentations). Information indicated that the participant would receive one of two interventions, both of which were believed to be beneficial, but in a different way. Due to the nature of the school setting, it was not possible to keep teachers and parents
officially ‘blind’ to condition. However, teachers and parents were not informed of the results of randomization and wording in the presentation of the study did not provide any indication that more benefit was expected from either program.

Four cohorts of students, based on age and grade level, were trained during this 2-year study. Unequal randomization within cohorts was carried out (3:2 assignment to the WM training program) in order to: (1) ensure maximum use of the WM training program, as the school (principal collaborator, teachers were not told about preferential assignment) preferred to have more students receiving WM training; (2) greater attrition from the WM training program was expected; and (3) one objective was for the school, the community agency and the research group to gain experience in administering the WM training program in a school setting (see review on unequal randomization by (Dumville, Hahn, Miles, & Torgerson, 2006). Randomization was carried out separately for each cohort, with stratification for sex.

After randomization, results were revealed to training aides at the school and each group began their respective training programs. All students were supervised by training aides (school counselors). Training aides for the Cogmed program received calls from a certified Cogmed Coach (licensed psychological associate from our collaborating community agency) once a week to provide feedback regarding the students’ progress, as well as to provide support and ensure compliance. Thus the research team was independent of the intervention program implementation team.

Training was completed during school hours, during a specific ‘spare period.’ Students had access to desktop computers equipped with high quality headphones, so that they were able to complete the training together in the school computer lab. In order to prevent students from comparing their own progress with their neighbours, WM and Math training students were seated
alternately in carrels; that is, Math training students were seated next to WM training students. All students continued to receive individualized special-education programming linked closely with the provincial curriculum and provided by highly trained teachers and staff. Programming was carried out in classrooms with fewer students than would be typical in regular middle and high schools.

Parent and teacher questionnaires were filled out online via a secure software program, using ID coding for confidentiality (surveymonkey.com, n.d.) one week prior to the study, three weeks after completion of the study and each week throughout the duration of the study. Parent-ratings were based on weekend observations only. The online questionnaire process was explained over the phone to parents, and parents and teachers also received instructions and the link via email. The cognitive and academic battery was administered one week prior to the study and approximately three weeks after training was completed.

**Statistical Analyses**

We used an Intention to Treat (ITT) approach to compare treatment effects of the two programs, in which missing data were filled in using the Last Observation Carried Forward (LOCF) method. This method is justified as we were unable to obtain data at time of attrition (attrition was due to moving or refusal to participate in the program). The last score from the weekly parent and teacher questionnaires was carried forward as the post-test data point. For all other measures, pre-test score was used as post-test, which may lead to an underestimate of the benefits of both programs. Group differences were tested by comparing outcome score between the two groups using a between-group analysis of covariance, with age and baseline score as covariates. Two-tailed tests were used in partial correlation analyses because both programs were thought to have beneficial effects.
A Winsorizing technique described in Tabachnick and Fidell (2007) was applied in order to minimize the effect of two outliers in the variable *D2 Omission Errors*. A preliminary analysis evaluating the homogeneity of slopes assumption indicated that the relationship between the covariate and the dependant variable did not differ significantly as a function of the independent variable for any of the target variables. All variables met the criteria for assumptions of homogeneity of variance. Levels of skewness and kurtosis were checked (absolute value of skewness and kurtosis/SE > 2). A logarithmic transformation was applied to 5 variables: D2 number of commission errors, total number of errors, total performance; CANTAB spatial span reverse; and Parent-rated SWAN total. These variables met criteria for the assumption of normality after the transformation was applied. Outcomes using transformed and Winsorized data were consistent with outcomes using the original data, therefore original data is presented to avoid problems inherent in these transformation techniques (Field, 2009).

Analyses were carried out using SPSS version 17. All analyses were repeated using an ‘as treated’ approach, which excluded non-completers. There were essentially no differences in outcomes between the ITT and actual treated data; outcomes using ITT data are presented below.

Post intervention data was obtained for all participants, except the ones who moved. Missing data was primarily due to participant drop-out and teachers or parents not completing the online questionnaires. The analyses for the teacher rating scales were based on a sample of 57, as 2 teachers declined to participate, and 4 pre-test scales were not completed. Fourteen out of 60 parents could not be reached, 40 of 46 of those reached agreed to (and did) participate, therefore parent-rating scales were based on a sample of 40.
Results

Training Compliance

Out of the initial 60 participants, a total of 8 (13%) withdrew from the study; one withdrew due to computer difficulties, four due to challenges with academic load in addition to training time, and three moved and left the school during the intervention. See Figure 1 for flow of participants through the trial. There were no significant differences in participant characteristics between completers (completion of a minimum 19 sessions) and non-completers and an equal number of drop-outs in the two groups. Seventy percent of participants in the WM training group reached the WM Training Index Improvement score of 17, and 57 percent of AOM participants mastered over 10 skills (see Table 3 for further compliance indices).

Criterion Indices

Consistent with our predictions, those who received the WM training showed improvements on some criterion measures of working memory. However, effects were not found on all indices of WM.

One-way analyses of covariance (ANCOVA) were conducted (see Table 4). The independent variable, Group, included two levels: WM training group and math training group. The dependent variables were post-test scores on target indices. The ANCOVA was significant for WISC-IV Digit Span Backwards, $F(1, 56) = 8.66, \text{MSE} = 7.54, p < .05$, (see Figure 2) and CANTAB Spatial Span Forward, $F(1,56) = 5.42, \text{MSE} = 7.24, p < .05$. The strength of the relationship between the group and dependent variable was medium, as assessed by a partial $\eta^2$, with group accounting for 13% and 8% of the variance of the post-test scores for DSB and SSPF, respectively, holding constant the pre-test scores. Using the Binomial Effect Size Display calculation (BESD; Rosenthal & Rosnow, 1991), the WM training group experienced a 36%
greater improvement compared to the math training group for DSB and 28% for SSPF. No differences between the two groups were found at post-test for WISC-IV Digit Span Forwards (auditory-verbal short term storage) or CANTAB Spatial Span Backwards (visual-spatial WM). These results indicate some transfer effects to tasks which are similar to those which were trained, but administered in a different context, modality, and pace.

**Near and Far Transfer Indices**

No differences between the two groups were found on near transfer tasks including CANTAB Spatial WM Between Errors and Strategy, D2 Test of Attention and the WMRS. WM training had no immediate effect on parent or teacher-rated behaviour. There were no effects found on academic measures, although there was a trend towards the predicted improvement in WRAT4 Math scores for the math training group ($F(1, 56) = 2.34, \text{MSE} = 504.21, p = .13, \text{partial } \eta^2 = .04$).

Two-tailed partial correlations revealed a significant relationship between Cogmed Index scores (highest score minus first score) and change scores on parent ratings of behavior at home, using the IOWA scale ($r = -.52, p < .01$), controlling for pre-test scores. This negative correlation indicates that those adolescents who showed most improvement on the WM training tasks were rated by their parents as showing greater reduction in symptoms of inattention and hyperactivity/impulsivity at home.

All outcomes were consistent when analyzed using a repeated measures ANOVA by Time (pre-test, post-test) and Group (WM, Math). Significant main effects of Time were found for some near transfer measures, CANTAB WM Between Errors and Strategy and D2 Test of Attention Total Errors and Total items processed; and far transfer measures including WRAT4 Math and Reading LE scores and Parent SWAN and IOWA total scores. The significant effects
of Time indicate that regardless of training program, students who were in this intensive remedial school program combined with stimulant medication treatment showed some gains over the study period in the area of cognitive attention, reading and math as well as behaviour as observed by parents.

**Discussion**

This study sought to evaluate the effectiveness of WM training in a group of adolescents with ADHD and an LD. These adolescents were not responding to typical special education programming for their exceptionality and therefore were placed in a specialized semi-residential school for one year. Treatment effects found were over and above the benefits of medication and intensive remediation, and were compared to those of a math training group.

Baseline findings emphasize the prevalence of WM difficulties in this subgroup of youth with severe LD/ADHD; the sample mean scaled score for WISC-IV WMI was 85, with 77% and 57% of scaled scores below the 16th percentile on WISC-IV DSB and DSF respectively. Overall, attrition was low; most participants in the WM training group did complete the requisite 19 sessions and the majority reached the optimal training Index Score of improvement.

Treatment related effects for the WM training program were found on two primary ‘criterion measures,’ a test of auditory-verbal WM (DSB) and short-term visuo-spatial storage (CANTAB Spatial Span Forwards). The training did not, however, normalize scores on Spatial Span Forwards or DSB, as the average post-training score for the WM group post-training fell in the 16th percentile. Based on previous research (Klingberg et al., 2002; Klingberg et al., 2005) we anticipated treatment related improvement on short-term auditory-verbal storage (DSF), and visuo-spatial WM (CANTAB Spatial Span Backwards), however there were no significant group differences on these outcome measures. Short-term storage measures such as DSF do not require
a manipulation and therefore are not tapping into the more complex WM function (storage and manipulation) that is targeted during training. Another possible explanation for these findings is that this group’s difficulties with short-term memory were not primarily storage issues, but related to phonological processing difficulties.

We did not find any transfer effects to other measures of WM or attention. It is possible that the training effects on strategy development had not taken effect directly after the intervention or may vary depending on the level of strategy developed by the participant. Moreover, Gibson et al. (2011) suggest that more complex WM tasks are not targeted as specifically through training as the simple tasks (such as Digit Span).

In contrast to previous studies of WM training, we did not find evidence of improvements in behavioral symptoms of inattention or academic attainment. Methodological differences, including study design and length of follow-up, may account for the discrepant findings. Consistent with previous findings from RCT studies, no beneficial effects on behaviour after training were reported by teachers. Treatment-related improvements in WM were not accompanied by gains in academic outcomes; however, previous research suggests that such changes may occur later, thereby requiring longer-term follow-up (Holmes, Gathercole & Dunning, 2009).

Limitations

We acknowledge that the lack of long-term follow up is a substantive limitation of the current study. Due to sample size considerations for statistical analysis and limited consistency in specific type of LD diagnoses (from Psycho-educational reports) we did not categorize participants into groups based on type of LD, an interesting predictor variable to use for future studies.
Clinical implications

Our findings add to the accumulating evidence that WM training can indeed enhance WM, as measured by neuropsychological measures, supporting the premise that WM shows remarkable neuroplasticity across a wide age range. Results from this study suggest that WM training may potentially be a useful adjunctive treatment, which can be administered successfully in a publically-funded school setting, for treatment-resistant youth with ADHD/LD.
### Tables and Figures

Table 2

*Subject Characteristics*\(^{a}\)

<table>
<thead>
<tr>
<th></th>
<th>Math training group</th>
<th>WM training group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boys</td>
<td>21</td>
<td>31</td>
<td>52</td>
</tr>
<tr>
<td>Girls</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Age, yr, mean (SD)</td>
<td>14.2 (1.1)</td>
<td>14.4 (1.3)</td>
<td>14.3 (1.2)</td>
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<tr>
<td>VCI SS mean (SD)</td>
<td>91.05 (16.58)</td>
<td>93.79 (11.42)</td>
<td>92.64 (13.73)</td>
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<td>PRI SS mean (SD)</td>
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<td>96.79 (20.04)</td>
<td>98.27 (19.57)</td>
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<td>WMI SS mean (SD)</td>
<td>85.09 (14.63)</td>
<td>85.36 (11.67)</td>
<td>85.24 (12.91)</td>
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<td>88.65 (14.42)</td>
<td>85.86 (10.35)</td>
<td>87.02 (12.14)</td>
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</tbody>
</table>

\(^{a}\)Randomized participants. Standard scores based on WISC-IV composites: Verbal Comprehension Index (VCI), Perceptual Reasoning Index (PRI), Working Memory Index (WMI), Processing Speed Index (PSI).
Table 3

*Compliance Outcome Measures*

<table>
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<tr>
<th></th>
<th>Mean number of trails completed (SD)</th>
<th>Percent of Program Completed (number of skills mastered out of total skills)</th>
<th>Index Improvement Score (highest score − baseline score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math training group</td>
<td>20 (0)</td>
<td>19.81 (14.14)</td>
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<tr>
<td>WM training group</td>
<td>20.37 (1.0)</td>
<td>NA</td>
<td>18.85 (6.30)</td>
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Table 4

*Treatment Outcome Measures*

<table>
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<th>Group</th>
<th>Criterion Measures</th>
<th>Near Transfer Measures</th>
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<tr>
<td></td>
<td>Baseline Mean (SD)</td>
<td>Post Treatment Mean (SD)</td>
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<tr>
<td>Math training</td>
<td>DSF SS</td>
<td>6.72 (2.07)</td>
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<td>7.49 (2.65)</td>
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<tr>
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<td>DSB SS</td>
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<td>7.43 (2.97)</td>
</tr>
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<td>Math training</td>
<td>CANTAB SSPF</td>
<td>6.96 (1.24)</td>
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<td>6.40 (1.59)</td>
<td>7.11 (1.3)</td>
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<td>Math training</td>
<td>CANTAB SSPB</td>
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</tr>
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<td>6.03 (1.29)</td>
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<td>CANTAB WM Strategy</td>
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<td>D2 Items Process. SS</td>
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<td>D2 Total num. errors</td>
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<td>WM training</td>
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<tr>
<td>-------------------------</td>
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<tr>
<td><strong>D2 Total perform SS</strong></td>
<td><strong>105.88 (43.58)</strong></td>
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<td><strong>103.63 (11.41)</strong></td>
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<td><strong>16.00 (11.81)</strong></td>
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**Far Transfer Measures**

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<th>WM training</th>
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<td><strong>504.21</strong></td>
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<td>WM training</td>
</tr>
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<td><strong>485.02</strong></td>
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<td><strong>59.76</strong></td>
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<td>WM training</td>
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<td><strong>496.23</strong></td>
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<td><strong>8.97</strong></td>
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<td><strong>495.44</strong></td>
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<td>WM training</td>
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Teacher SWAN total

<table>
<thead>
<tr>
<th>Math training</th>
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</thead>
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<tr>
<td>87.90 (34.52)</td>
<td>86.43 (27.98)</td>
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<tr>
<td>WM training</td>
<td>85.34 (33.81)</td>
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<td>83.97 (33.27)</td>
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Teacher IOWA total

<table>
<thead>
<tr>
<th>Math training</th>
<th>WM training</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.38 (8.17)</td>
<td>21.62 (6.86)</td>
</tr>
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<td>21.34 (5.27)</td>
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<td>WM training</td>
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<td>22.25 (7.53)</td>
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Parent SWAN total

<table>
<thead>
<tr>
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<th>WM training</th>
</tr>
</thead>
<tbody>
<tr>
<td>101.41 (24.05)</td>
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<td>110.77 (81.99)</td>
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<td>.02</td>
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<tr>
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<td>108.91 (27.37)</td>
<td>107.87</td>
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Parent IOWA total

<table>
<thead>
<tr>
<th>Math training</th>
<th>WM training</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.28 (6.36)</td>
<td>19.35 (7.13)</td>
</tr>
<tr>
<td>18.95 (4.99)</td>
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<td>21.78 (6.01)</td>
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<tr>
<td>18.61 (4.99)</td>
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</table>

**Note:** $M_{adj}$ = adjusted means, MS = mean squares, SS = Standard Score, DSF = WISC-IV Digit Span Forward, DSB = WISC-IV Digit Span Backward, CANTAB SSPF = Spatial Span Length Forward, CANTAB SSPB = Spatial Span Length Reverse. CANTAB WMS BE = Working Memory Span Between Errors, CANTAB WM Strategy = Working Memory Span Strategy **$p > .01$, *$p > .0$**
Figure 1. Flow of participants through the trial
Figure 2. Effects of WM training on manipulation of auditory-verbal information for WM training and math training groups, expressed as Digit Span Backward Change.
Chapter 4

General Discussion

Summary

This study investigated the effects of a computerized WM training program on WM, attention, behaviour and academic skill in adolescents with severe ADHD/LD. The results provided evidence that WM can be enhanced in this subgroup of hard-to-treat adolescents, by intensive and adaptive training. The main findings were that those in the WM training group showed improvements as compared to the math training group on some aspects of WM, including auditory-verbal WM and short-term visuo-spatial storage. No group differences were found for other WM tasks, tasks of attention or behavioural and academic measures.

Research setting. One objective of this study, in addition to the main results presented above, was to assess the feasibility of carrying out an intensive WM training program in a school setting with adolescents who have ADHD/LD. One barrier we found in this setting was variability of the school-programming schedule, making consistent training difficult. In terms of school-based implementation, we found that having consistent rewards and motivators (framed as personal challenge, a positive exercise rather than homework-like) was essential to maintaining participation and that it may be beneficial for students to train in separate carrels or rooms to limit distraction.

Study strengths. Implementing the training in a school setting allowed for equal levels of supervision among participants in both groups, thus eliminating the individual differences inherent with parental supervision in the home setting. We also obtained weekly parent/teacher behaviour ratings in order to allow a more sensitive analysis of when behavioural changes were occurring, although this could not be determined because no group differences were found.
Another strength of this study was that all participants were taking medication and were receiving specialized academic and behavioural intervention, thereby eliminating medication and intervention as extraneous variables and demonstrating effectiveness over and above these interventions. We also compared the WM training group to a math training group, which also carried out computerized, adaptive training that conferred marginally significant improvements on math outcome measures. Thus any effects found were over and above the specialized medical, behavioural, and academic interventions that are typically offered to students with ADHD/LD, albeit in a less intensive format than what would be found in the regular school system.

There is only one RCT to date that investigated WM training in those with co-occurring ADHD/LD (Beck et al., 2010). They found significant post-treatment changes on parent-rated measures of ADHD symptomatology and executive functioning. However, training was in the home setting, and the waitlist control design did not allow for parent-ratings to be free from bias.

There is minimal of evidence from randomized, controlled studies to indicate change in inattentive behaviour following WM training. Previous findings (from RCT designs) regarding behaviour change with ADHD populations were restricted to behavioral ratings by parents, who were involved in supervising the intervention and thus were not free from bias (Beck et al., 2010; Klingberg et al., 2005). One study reported reduced ‘significant other’ (aunt, uncle) ratings of ADHD symptom frequency in a high intensity WM training group as compared to a low intensity WM training group (Johnstone, Roodenrys, Phillips, Watt, & Mantz, 2010).

For adolescents with severe learning challenges, gains in academic skills may occur slowly over time and thus studies that capture growth over a year or more may be more successful at understanding the impact of the training on academic functioning. It is also important to remember that WM is likely only one component involved in more complex
academic skills such as writing and comprehension. Other aspects of these tasks (e.g.,
vocabulary knowledge in comprehension, orthographic knowledge in writing) may still constrain
performance despite improvements in WM.

**Limitations**

The absence of long-term follow up is a limitation of the current study. However, in a separate study of this WM training program involving college students with ADHD/LD, we did find evidence that the benefits in cognitive and everyday functioning were sustained for at least 2 months following the post-intervention evaluation (Gropper & Tannock, 2011). Parents and teachers could not be kept fully blind as to which program students were completing. However, the study was presented in a manner that indicated no preferential outcomes from one program over the other.

**Future Directions**

The evidence to date regarding the transfer of effects to cognitive and behavioural attention, more complex reasoning and academic achievement is minimal and further investigation through longitudinal, randomized controlled trials is needed to assess practical benefits of WM training in everyday home and school settings. Possible future directions could include investigating variation in training tasks, conditions and training time. Although it is substantially more complex and varied, the curriculum program, Tools of the Mind, designed to improve executive functioning in kindergarten age children, is a pertinent example of variation in training conditions. This curriculum only conferred improvements outside of trained tasks when training and supports were interwoven into the school day (Bodrova & Leong, 2007). It is possible that combining WM training with specific coaching, or teacher support/training would
emphasize and bring to awareness to everyday use of WM, and maximize practice and maintenance of gains throughout the day.

Another possible avenue for future study is the quality and complexity of WM training tasks included in the training program. It is possible that modifying WM training to include more complex WM tasks, employing a wider range of executive functions, will produce greater transfer effects (Gibson et al., 2011; Diamond & Lee, 2011). It is also possible that if the tasks require more controlled, effortful processing (engaging other executive aspects of WM), that this training will tap into more complex WM rather than short term storage.

**Clinical Implications**

Our findings add to the accumulating evidence that WM training can indeed enhance WM, as measured by neuropsychological measures, supporting the premise that WM shows remarkable neuroplasticity across a wide age range. Results from this study suggest that WM training may be a potentially useful adjunctive treatment for treatment-resistant youth with ADHD/LD, which can be administered successfully in a publically-funded school setting.
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