Effects of a computerized working memory training program on working memory, attention, and academics in adolescents with severe LD and comorbid ADHD: a randomized controlled trial

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Background: Youths with coexisting learning disabilities (LD) and attention deficit hyperactivity disorder (ADHD) are at risk for poor academic and social outcomes. The underlying cognitive deficits, such as poor working memory (WM), are not well targeted by current treatments for either LD or ADHD. Emerging evidence suggests that WM might be improved by intensive and adaptive computerized training, but it remains unclear whether this intervention would be effective for adolescents with severe LD and comorbid ADHD.

Methods: A total of sixty 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 3 weeks after completion. The criterion measures of WM included auditory-verbal and visual-spatial tasks. Near and far transfer measures included indices of cognitive and behavioral attention and academic achievement.

Results: Adolescents in the WM training group showed greater improvements in a subset of WM criterion measures compared with those in the math-training group, but no training effects were observed on the near or far measures. Those who showed the most improvement on the WM training tasks at school were rated as less inattentive/hyperactive at home by parents.

Conclusions: Results suggest that WM training may enhance some aspects of WM in youths with LD/ADHD, but further development of the training program is required to promote transfer effects to other domains of function. Keywords: Working memory, computerized cognitive training, Learning Disabilities, ADHD.

Introduction

Population-based studies indicate that somewhere between 0.4% and 4% of youths meet the diagnostic criteria for coexisting learning disability (LD) and attention deficit hyperactivity disorder (ADHD), with high rates also reported in clinical samples (Pastor & Reuben, 2008). Youths with comorbid LD/ADHD manifest cognitive problems associated with each of the single disorders, and are at high risk for academic failure and poor psychosocial and occupational outcomes in adulthood (Sexton, Gelhorn, Bell, & Classi, 2011). Working memory (WM), a central component of the executive functions, is posited to be an important mechanism in both LD and ADHD (Castellanos & Tannock, 2002; Willcutt, Pennington, Chhabildas, Olson, & Hulslander, 2005). Defined as a limited-capacity, multicomponent cognitive system, WM allows us to hold and manipulate information ‘online’ for a few seconds to respond based on that internal representation of the information (Baddeley, 2010).

This cognitive function has been found to predict inattentive behaviors as rated by parents (Lui & Tannock, 2007). Working Memory is consistently found to be below average in LD and ADHD populations, and is a predictor of academic success (Gathercole, Brown, & Pickering, 2003; McGrath et al., 2011; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011). Whereas some studies report that clinical conditions, such as ADHD and different subtypes of LD, manifest unique profiles of WM impairments (Compton, Fuchs, Fuchs, Lambert, & Hamlett, 2012), others argue that any differences in WM profiles are subtle and just vary in severity (Willcutt et al., 2010).

Working memory capacity has generally been thought to be a fixed trait, but a growing body of research has suggested that it can be improved through intensive and adaptive computerized training (Klingberg, 2010). Using a WM training program
developed by Klingberg, Fernell, Olesen, and Johnson (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 (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). To our knowledge, there has been only one investigation of this WM program with a focus on LD as well as ADHD populations (Dahlin, 2011). This study found improvements in reading comprehension in the WM training group, although it was unclear as to what proportion of the sample was diagnosed with an LD. Another study indicated that WM training was associated with improvement in mathematical skills as assessed 6 months after the intervention (Holmes, Gathercole, & Dunning, 2009). However, these study results require replication within a randomized design.

We report the findings from a randomized controlled trial evaluating the effectiveness of WM training as provided and monitored by a licensed psychologist in a community agency and supervised by school staff. Outcomes from WM training were compared against those from an active comparison intervention that targeted mathematical skills. The objectives of this study were as follows: (a) to determine the feasibility of implementing a WM training program in a residential school setting with a hard-to-treat group of adolescents with combined LD/ADHD; (b) to determine whether computerized WM training improves WM in this treatment-resistant population of adolescents; (c) to examine the extent to which behavioral symptoms of inattention in the classroom and home environments could be reduced by improving WM; and (d) to evaluate transfer effects into academic achievement. It was hypothesized that WM training would enhance visual-spatial and auditory-verbal WM in those with LD and ADHD. It was also anticipated that WM training would be associated with concomitant improvements in behavioral symptoms of ADHD in the classroom, with greater effects on inattention compared with hyperactivity/impulsivity. It was expected that WM training would be associated with subsequent improvements in those aspects of numeracy and literacy that are dependent upon WM (e.g., reading comprehension, math reasoning, and spelling) and that math training would be associated with improvements on math tasks.

Method
Participants

A total of 60 adolescents (aged 12–17; 13% females) were recruited to participate in the study through a partnership with a semiresidential school, funded and operated by the provincial Ministry of Education in a major metropolitan area in Canada. The academic program of this school is designed to meet the academic and social needs of adolescents with severely impairing LD and coexisting ADHD. Students attend this school for 1 year, subsequently returning to home schools across the province, thus making it difficult to follow up students longer term. The sample represented the total number of adolescents enrolled in the school over the 2-year period of the study.

Eligibility criteria for the school include coexisting LD/ADHD previously diagnosed in the community, plus severe problems in learning and behavior as well as poor response to the available standards of care and intervention in their home communities, which included special education and pharmacological treatment. Students with comorbid diagnoses of conduct disorder, severe aggression, depression, or anxiety requiring specific and immediate treatments were considered ineligible.

Inclusion criteria for this study were as follows: (a) full time attendance at the residential school; (b) diagnosis of a specific LD and ADHD made in the community before entry to the school; (c) age between 12 and 17 years at inclusion; (d) IQ > 80 (based on WISC-IV scores); and (e) English as the primary spoken language. Exclusion criteria were uncorrected perceptual, motor, or language impairments that would impede usage of the computer program or intelligibility of spoken responses.

For this study, we asked the staff psychiatrist affiliated with the school to confirm the community-based diagnoses of LD and ADHD using the psychoeducational and medical reports required for entry into the school, as well as his knowledge of the student. Although an LD was confirmed for all participants, data to assist with diagnostic confirmation for a coexisting diagnosis of ADHD were lacking for nine participants.

Data from standardized academic test scores indicate that 82% of participants scored below the 25th percentile on all subjects (reading, spelling, and math), indicating pervasive academic impairments (WJ ACH, see Table 1). Notably, all academic scores were more than two standard deviations below the mean (WRAT-4) at baseline. Moreover, the adolescents were severely impaired in the area of WM (Table 1).

On the Working Memory Index (WISC-IV, WMI), 72% of students were below the 25th percentile, indicating room for improvement from WM training in all of these domains.

The majority of the students (n = 59, including the nine without a second confirmation of the ADHD diagnosis) were receiving long-acting stimulant medication for ADHD throughout the study, as prescribed by their community care physician. In addition, all students continued to receive intense academic remediation, provided as usual by this specialized school. As can be seen in Table 1, the mean score on the behavioral measures at baseline was in the clinical or abnormal range.

This 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. Written informed consent from parents, homeroom teachers, and adolescents was obtained for 60 of the 61 adolescents, who were then randomized to either the WM training group or the math-training group (see Figure 1). There were no significant group differences on baseline measures, with the exception of the CANTAB Spatial WM
Strategy score (SWM), which was stronger for the math-training group ($t(58) = 1.99, p > .05$); thus, the comparison and treatment groups were similar in terms of baseline cognitive skills and test measures.

Outcome measures

Assessments were conducted by trained psychometrists, who were not informed about the students’ randomization. Outcome measures were categorized into:

(a) ‘compliance measures’;
(b) ‘criterion measures’ (closely resembled the tasks trained in the WM program);
(c) ‘near transfer’ measures (indices of other cognitive functions or measures of WM that differed from the trained tasks), and
(d) ‘far transfer measures’ (indices of academic achievement or observable behavior in the classroom or home environments).

Compliance measures. Two measures were used: the number of training sessions completed and the

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**Table 1 Participant characteristics**

<table>
<thead>
<tr>
<th></th>
<th>Math-training group</th>
<th>Working memory-training group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Males (n)</strong></td>
<td>21</td>
<td>31</td>
<td>52</td>
</tr>
<tr>
<td><strong>Females (n)</strong></td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td><strong>Age, year</strong></td>
<td>14.2 (1.1)</td>
<td>14.4 (1.3)</td>
<td>14.3 (1.2)</td>
</tr>
<tr>
<td><strong>VCI SS</strong></td>
<td>91.05 (16.58)</td>
<td>93.79 (11.42)</td>
<td>92.64 (13.73)</td>
</tr>
<tr>
<td><strong>PRI SS</strong></td>
<td>100.24 (19.70)</td>
<td>96.79 (20.04)</td>
<td>98.27 (19.57)</td>
</tr>
<tr>
<td><strong>WMI SS</strong></td>
<td>85.09 (14.63)</td>
<td>85.36 (11.67)</td>
<td>85.24 (12.91)</td>
</tr>
<tr>
<td><strong>PSI SS</strong></td>
<td>88.65 (14.42)</td>
<td>85.86 (10.35)</td>
<td>87.02 (12.14)</td>
</tr>
<tr>
<td><strong>SDQ hyp.</strong></td>
<td>7.90 (2.65)</td>
<td>7.50 (2.69)</td>
<td>7.66 (2.65)</td>
</tr>
<tr>
<td><strong>IOWA Connors IO teacher</strong></td>
<td>12.52 (3.60)</td>
<td>12.28 (4.04)</td>
<td>12.38 (3.84)</td>
</tr>
<tr>
<td><strong>IOWA Connors IO parent</strong></td>
<td>11.83 (3.37)</td>
<td>11.74 (3.43)</td>
<td>11.78 (3.56)</td>
</tr>
<tr>
<td><strong>IOWA Connors OD teacher</strong></td>
<td>10.86 (5.15)</td>
<td>10.50 (5.36)</td>
<td>10.64 (5.23)</td>
</tr>
<tr>
<td><strong>IOWA Connors OD parent</strong></td>
<td>11.44 (3.68)</td>
<td>10.04 (3.18)</td>
<td>10.66 (3.44)</td>
</tr>
<tr>
<td><strong>WJ oral comprehension SS</strong></td>
<td>103.43 (9.61)</td>
<td>106.09 (4.83)</td>
<td>102.91 (10.52)</td>
</tr>
<tr>
<td><strong>WJ word attack SS</strong></td>
<td>81.20 (8.14)</td>
<td>81.55 (14.13)</td>
<td>82.32 (10.19)</td>
</tr>
<tr>
<td><strong>WJ word identification SS</strong></td>
<td>70.33 (21.97)</td>
<td>69.09 (15.95)</td>
<td>71.43 (18.59)</td>
</tr>
<tr>
<td><strong>WJ reading fluency SS</strong></td>
<td>76.67 (6.40)</td>
<td>76.22 (8.51)</td>
<td>76.39 (7.05)</td>
</tr>
<tr>
<td><strong>WJ passage comp. SS</strong></td>
<td>74.67 (14.72)</td>
<td>75.18 (17.06)</td>
<td>75.20 (14.73)</td>
</tr>
<tr>
<td><strong>WJ spelling SS</strong></td>
<td>65.47 (15.28)</td>
<td>65.90 (12.64)</td>
<td>66.30 (13.84)</td>
</tr>
<tr>
<td><strong>WJ calculation SS</strong></td>
<td>78.53 (16.42)</td>
<td>72.27 (13.85)</td>
<td>75.00 (14.17)</td>
</tr>
<tr>
<td><strong>WJ math fluency SS</strong></td>
<td>70.27 (11.34)</td>
<td>70.20 (10.90)</td>
<td>69.18 (10.70)</td>
</tr>
</tbody>
</table>

*aRandomized participants, scores from psychological assessments required for admission into the school. Standard scores based on WISC-IV composites: Verbal Comprehension Index (VCI), Perceptual Reasoning Index (PRI), Working Memory Index (WMI), Processing Speed Index (PSI). WJ = Woodcock Johnson Test of Achievement. Baseline data: SDQ hyp. = Strengths and Difficulties Questionnaire Hyperactivity scale, IOWA Connors IO = Inattention/Overactivity subscale total, IOWA Connors OD = Oppositional/Defiant subscale total.

Cogmed Improvement Index, which is a built-in compliance measure, 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 the following: (a) Digit Span Forward (DSP) and Backward (DSB) from the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV; Wechsler, 2003) to measure auditory-verbal short-term and working memory, respectively; and (b) Spatial Span (SSP) from the Cambridge Neuropsychological Testing Automated Battery (CANTAB; Fray, Robbins, & Sahakian, 1996) to index measures of visuospatial short-term and working memory. Scores ranging from 0 to 9 represented the highest level at which the subject reproduced at least one correct sequence.

**Near transfer measures.** Effects were assessed using three measures: (a) CANTAB Spatial WM (SWM) was used to assess 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); (b) The Working Memory Rating Scale (Alloway, Gathercole, Kirkwood, & Elliott, 2009) was used to assess WM from a classroom-based perspective; (c) 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.

**Far transfer measures.** Academic progress was assessed using the Wide-Range Achievement Test-4-Progress Monitoring Version, which is a reliable, valid, and efficient tool to measure academic progress of students in Grades K–12 (WRAT-4PM; Roid & Ledbetter, 2006). It includes four brief tests, with parallel versions for repeat testing, in the areas of word reading, sentence comprehension, spelling, and mathematics. Raw scores were converted into Level Equivalent Scores (LE), which are standardized to allow for comparison across grade and age levels. Measures of attention and hyperactivity at home and school included as follows: (a) the Strengths and Weakness of ADHD-symptoms and Normal-behavior scale (SWAN, Swanson et al., 2001), a newly validated scale that provides a more precise measure of attention than other rating scales. Items are rated on a seven-point scale (Far Below Average = 1, Far Above Average = 7); (b) the IOWA Conners scale (Pelham, Millich, Murphy, & Murphy, 1989), a well-validated, treatment-sensitive scale that includes inattentive/impulsive/overactive and oppositional defiant items.

**Intervention programs**

**WM 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 WM. To date, this software program has the strongest empirical evidence for its effectiveness in training WM (Klingberg, 2010). Moreover, some evidence suggests that training effects transfer to other cognitive domains and produce changes in the neural networks underlying WM (Klingberg et al., 2005; Olesen, Westerberg, & Klingberg, 2004; Westerberg et al., 2007).

The WM training program consists of a set of visual-spatial and auditory-verbal WM tasks, with a fixed number of trials. The difficulty of each task is adapted to the individual’s ability on that task on a trial-by-trial basis. Thus, training takes place at the limit of the individual’s working memory capacity. Training plans were individualized and modified based on current performance, but the typical plans included 12 different WM training exercises. The average training time each day was approximately 45 min, excluding breaks. The software guides the individual through each task and provides the individual with immediate verbal feedback and scores. A certified Cogmed training coach, who was completely independent from the research team, supervised the WM training and monitored participants’ data on the server. See Klingberg, Forasberg, and Westerberg (2002) and Olesen et al. (2004) for a detailed program description.

**Mathematics training program.** We chose an active comparison program (Academy of Math; www.autoskill.com), believed to have beneficial effects on math skill development across 10 essential skill areas, including number sense, calculation, equations, measurement, and geometry (Torlakovic, 2011). Computerized placement tests identify skill gaps and create individual training plans that are monitored and automatically adjusted to optimize challenge and remediation. Within each skill area, procedural fluency, conceptual understanding, and strategic competence are targeted. Academy of Math includes features similar to those of the WM training program, including built-in reinforcement and individually based algorithms, adjusted based on student mastery. Students in both groups completed 45-min training sessions, 4–5 days a week for 5 weeks.

**Procedure**

Information given to students and teachers during recruitment indicated that the participant would receive one of two interventions, both of which were believed to be beneficial in different ways. Due to the school-based 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 (starting in September and February 2009–2011) were trained during this 2-year study. Unequal randomization within cohorts was carried out for several reasons (3:2 assignment to the WM training program): (a) to ensure maximum use of the WM training program (teachers and support staff were not told about preferential assignment); (b) greater attrition from the WM training program was expected; and (c) one objective was for the institutions involved to
An intention-to-treat (ITT) approach was used to compare treatment effects of the two programs, in which missing data were filled in using the Last Observation Carried Forward (LOCF) method. Missing data occurred when students suddenly moved schools or refused to participate in the program. The last score from the weekly parent and teacher questionnaires was carried forward as the posttest data point. For all other measures, pretest score was used as posttest, which may lead to an underestimate of the benefits of both programs. Group differences were tested by comparing outcome (posttest) scores between the two groups using a between-group analysis of covariance (One-way ANCOVA), 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.

Following a data check for outliers, skewness or kurtosis, a Winsorizing technique was applied to two outliers (for the variable D2 omission errors) and a logarithmic transformation was applied to five variables (D2 number of commission errors, total number of errors, total performance; CANTAB spatial span reverse; Parent-rated SWAN total). These variables met criteria for the assumption of normality after the logarithmic transformation was applied. Transformed and Winsorized data were consistent with findings using the original data; therefore, original data are presented to avoid problems inherent in these transformation techniques (Field, 2009).

Analyses were carried out using SPSS version 17, SPSS Inc., Chicago, IL, USA. 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 were obtained for all participants, except those who moved. Missing data were primarily due to participant dropout and teacher/parent noncompletion of the online questionnaires. The analyses for the teacher rating scales were based on a sample of 57, and parent-rating scales were based on a sample of 40.

### Results

#### Training compliance

Of the initial 60 participants, a total of eight (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 20 sessions) and non-completers, and an equal number of dropouts in the two groups. Seventy percent of participants in the WM training group reached the WM Training Index Improvement score of 17 (Mean Improvement score = 18.85, SD = 6.3), and 57% of AOM participants mastered over 10 skills (Mean number of skills mastered = 19.81, SD = 14.14).

#### Criterion indices

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

ANOVCAs were conducted [see Table 2 (DSB, SSP) and Appendix S1]. The independent variable, Group, included two levels: WM training group and math-training group. The dependent variables were posttest scores on target indices. The ANCOVA was significant for WISC-IV DSB, $F(1, 56) = 8.66$, MSE $= 7.54$, $p < .05$, (see Figure 2) and CANTAB SSP, $F(1,56) = 5.42$, MSE $= 7.24$, $p < .05$. The strength of the relationship between the Group and dependent variable was medium, as assessed by a
symptoms of inattention and hyperactivity/impulsivity at home. However, there was no significant relationship between the Cogmed Index score and teacher ratings of behavior at school, nor between the number of skills mastered by students receiving the AOM program and ratings by parents or teachers.

Supplemental analyses. All findings were consistent when analyzed using a repeated measures ANOVA by Time (pretest, posttest) and Group (WM, Math). Notably, significant main effects of Time were found for near transfer measures (CANTAB SWM; D2 Test of Attention Total Errors and Total items processed) as well as some far transfer measures (WRAT-4 Math and Reading LE scores; 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 behavior as observed by parents. To ensure that the inclusion of the nine participants without a confirmed coexisting diagnosis of ADHD did not have undue influence on findings, we reran the ITT analyses excluding these nine participants, noting that eight of these excluded participants were in the WM training group. Findings were unchanged except for one: WM training benefits on CANTAB SSP no longer reached conventional levels of statistical significance (F(1, 49) = 1.89, MS = 2.04, p = .17, partial $\eta^2 = .039$).

Discussion

This study provides the first evaluation of the effectiveness of WM training in a group of adolescents with severe LDs and co-occurring ADHD. These adolescents had not previously responded to the usual interventions (e.g., special education, medication) provided in their communities and hence were still highly symptomatic in terms of poor academic skills, working memory, and ADHD symptoms. Thus, they were accepted into a specialized school for 1 year in an attempt to improve their academic, social, and behavioral outcomes. Baseline findings emphasize the prevalence of WM difficulties in this subgroup of youths 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. For measures of visual-spatial WM at baseline, all students performed in the below average range on SWM, and 34% of participants were below average on SSP. Upon entry into the study, these adolescents continued to receive stimulant medication as prescribed by their community-based physicians while receiving intensive academic remediation at the school. We compared the outcomes from training WM versus training math skills. Thus, evidence of beneficial effects from WM training would be

No differences between the two groups were found on near transfer tasks (see Table A1 in the Appendix S1). WM training had no immediate effect on parent or teacher-rated behavior. No training effect was found when inattention, hyperactivity, and oppositional behavior items were analyzed as subscale totals or when these categories were totaled together. There were no effects found on academic measures; the posttest results for WRAT4 math were in the predicted direction for the math-training group, although not statistically significant (F(1, 56) = 2.34, MSE = 504.21, p = .13, partial $\eta^2 = .04$).

Two-tailed partial correlations revealed a significant relationship between Cogmed Index scores and change scores on parent ratings of behavior at home, using the IOWA scale ($r = -.52, p < .01$), controlling for pretest scores. This negative correlation indicates that those adolescents who showed most improvement on the WM training tasks at school were rated by their parents as showing greater reduction in symptoms of inattention and hyperactivity/impulsivity. However, there was no significant relationship between the Cogmed Index score and teacher ratings of behavior at school, nor between the number of skills mastered by students receiving the AOM program and ratings by parents or teachers.

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over and above any benefits arising from these other community-based interventions.

Overall, attrition was low; most participants in the WM training group did complete the requisite 20 sessions and the majority reached the optimal training Index Score of improvement. The major finding was that WM training had a robust benefit on the students’ performance on a measure of auditory-verbal WM that resembled the training activities, as well as an effect on visual-spatial WM for those with a confirmed co-occurring ADHD diagnosis. However, there was no evidence for the transfer of training to other cognitive abilities, behavior, or academic function. Students receiving math training showed improvement on math scores in the hypothesized direction, albeit nonsignificant.

The 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 visual-spatial storage (SSP). For the WM training group, 16% (DSB) and 28% (SSP) of scores increased from below, to at or above the 16th percentile. Based on previous research (Klingberg et al., 2002, 2005), we also anticipated treatment-related improvement on spatial WM strategy (SWM); however, there were no significant group differences on this outcome measure. A possible explanation for these findings is that longer or more intensive training may be required to ameliorate severe difficulties in WM.

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. However, 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 with previous studies of WM training (Holmes et al., 2009; Klingberg et al., 2005), we did not find robust evidence of improvements in behavioral symptoms of inattention or academic attainment. However, we found a moderate correlation between WM Index improvement and parent ratings of behavior at home using the IOWA Conners. It is possible that the adolescents were able to transfer the effort involved in WM training to their self-regulation of behavior in the home setting on weekends, but parental bias cannot be ruled out. Consistent with previous findings from RCT studies, no beneficial effects on behavior after training were reported by teachers. Treatment-related improvements in WM were not accompanied by gains in academic outcomes. Nevertheless, previous research suggests that such changes may occur later, thereby requiring longer term follow-up (Holmes et al., 2009).

**Limitations**

We acknowledge that the lack of long-term follow-up is a substantive limitation of this 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. Our math outcome measures were limited in their scope, thus reducing measurement sensitivity for changes in the math-training group.

**Clinical implications**

Our findings add to the accumulating evidence that WM training can indeed enhance some components of WM, as measured by neuropsychological measures. These findings support the premise that WM shows remarkable neuroplasticity across a wide age range, and in treatment-resistant youths with LD and co-occurring ADHD. Results from this study suggest that it is possible to administer this training program in a school setting with adolescents who have diagnosed learning and attention difficulties. This study did not, however, find any improvement in behavior or academic measures, thus further development of the training program is required to promote transfer effects to other domains of function.

**Supporting information**

Additional Supporting Information may be found in the online version of this article:

Appendix S1 ANCOVA outcome data.

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Key points

- Working memory (WM) is closely linked with attention and is a strong predictor of academic achievement.
- WM impairments are common in individuals with Specific Learning Disabilities and coexisting attention-deficit/hyperactivity disorder (LD/ADHD).
- Current treatment approaches for LD or ADHD do not target WM.
- Recent innovation in intervention suggests that intensive and individualized training may improve WM, but it remains unknown whether such training would improve WM in adolescents with severe and treatment-resistant LD/ADHD.
- The current findings indicate that WM training may result in modest and circumscribed improvements in WM in this hard-to-serve group of adolescents; training effects do not appear to transfer to other domains of function.

References


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