1. The Problem We Addressed. Youth who have severe difficulties with attention, learning, and behavior – particularly those who meet the diagnostic criteria for both Attention-Deficit/Hyperactivity Disorder (ADHD) and specific Learning Disabilities (LD) - are at high risk for poor educational, social, and occupational outcomes. ADHD and LD co-occur more often than expected by chance and manifest multiple cognitive deficits including poor working memory and slow processing speed [1-4]. We believe that one reason for their poor response to intervention is that the current intervention approaches (medication, special education) do not adequately address the underlying cognitive problems associated with ADHD and LD, such as poor working memory (WM). WM is 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 [5]. WM is known to be a strong predictor of current and future academic achievement [6-8]. WM impairments are over-represented in ADHD and LD populations of children, adolescents, and adults [9-11]. Thus, the key question is whether poor WM in youth with ADHD/LD can be ameliorated.

Importantly, burgeoning evidence suggests that WM shows neuroplasticity and can be increased in various clinical populations, including ADHD, by intensive individualized training [12-20]. Evidence also shows that this WM training may improve some ADHD symptoms and that effects may generalize to other cognitive functions [16, 17], indicating that WM training may have valuable therapeutic implications for this clinical population. However, it remains unknown whether WM training will be an effective intervention approach for youth with ADHD/LD.

2. Major objectives of the project

Accordingly, the major aims of this project were to determine whether systematic, individualized and intensive WM training would enhance WM in adolescents with ADHD/LD; whether effects would generalize to other cognitive functions; and whether this intervention approach would also reduce the symptoms of ADHD and/or enhance academic outcomes.
The primary objective was to determine whether the specified working memory training program (Cogmed) would improve working memory in adolescents with ADHD/LD. Given the demonstrated links between WM, inattention, and academic achievement [21] our secondary objectives were to determine whether this intervention would also improve the students’ concentration and school work, and whether the students would continue to show improvements once the training program had stopped.

Hypotheses: Based on the previous research on WM training, and WM theory, we predicted that:

i) Adolescents receiving the WM training program would show greater gains in WM compared to those receiving the active comparison program (Academy of Math).

ii) Adolescents receiving the WM training would also show greater gains in other cognitive functions (e.g., attention) and greater reductions in ADHD symptoms, compared to those receiving the comparison program (AOM).

iii) Adolescent receiving the comparison program (AOM) would show greater gains in arithmetic compared to those receiving the WM training program.

iv) All gains would be sustained for at least several months after the training has been completed.

3. Our Approach to the Problem: We chose to investigate the efficacy of WM training in a subpopulation of ADHD/LD: a ‘hard-to-serve’ adolescent population with ADHD/LD, who have not responded to currently available evidence-based medical and educational interventions (e.g., pharmacological treatment for ADHD, special education for ADHD and LD). Moreover, we opted to investigate the effects of providing the WM training in the school setting, rather than the typical approach of conducting it in the home setting. Our rationale was twofold: adequate control of the training at home would likely be problematic given the adolescent population; we believed that asking teachers to supervise the training at school would have greater ecological validity than asking parents of adolescents to assume that role. Moreover, if the intervention approach was found to be effective, that the evidence of its efficacy came from a school-based study would facilitate its roll-out to the education sector.

We selected the computerized Cogmed RM® WM training program developed by scientists in Sweden, since there is evidence that it does improve WM, attention, and schoolwork in children, adolescents, and adults with various clinical conditions [12, 13, 15-17, 19, 20]. Critical characteristics of this computerized training method (Cogmed- RM© from Cogmed Cognitive Medical Systems AB, Stockholm, Sweden) include the following: i) training is individualized and performed close to the capacity of the individual by using an adaptive staircase adjusting difficulty on a trial-by-trial basis; ii) training is conducted for at least 45 minutes per day, 5 days a week, for at least 5 weeks; iii) contingent reinforcement is integrated within the program; iv) the video-game like format is intrinsically motivating, particularly to children and adolescents; and v) trained psychologists monitor each individual’s progress on a weekly basis and guide the local support person (training aide) how best to adjust the training activities to optimize progress. We now have the capacity to offer and evaluate the efficacy of this WM intervention program in Canada; in the Toronto region, psychologists in the community mental health agency, Jewish Vocational Services (JVS
Toronto), are licensed to provide this WM training.

Accordingly, we established a collaborative partnership JVS-Toronto, to provide and monitor the WM training, and with the Ontario Provincial Demonstration Schools (OPDS), which are semi-residential schools, funded by the Ontario Ministry of Education to provide education for adolescents with ADHD/LD whose educational needs cannot be addressed within local school boards. The goal of the OPDS is to develop these students’ academic and social abilities to a level that enables them to return to educational programs operated by local school boards.

Our original plan was to use a three-armed RCT to compare the effects of the Cogmed WM training program with the effects of two other active intervention programs (i.e., active comparison interventions) that focus on academic skills only: 1) a computerized software program known to improve math skills (Academy of Math®); and 2) extra, individualized tutoring in an area of academic weakness supervised by a trained and experienced staff person at OPDS. All 3 training programs were to be conducted for 45-60 minutes a day, 5 days a week, for 5 weeks; all students would receive individualized training, matched to their abilities, with lesson difficulty increasing as the student improved. All students would continue to receive the typical educational program (individualized and adaptive instruction) provided by OPDS. The study was powered to require about 120 students with LD/ADHD, aged 12-16 years, who would be randomized to one of the three intervention programs (WM training, math, tutoring), using unequal randomization (2: 1 students assigned to receive WM training). At the time of the initial study design, not all students at OPDS were expected to have ADHD plus LD; based on previous referral patterns, the majority were expected to have LD.

Based upon data from Dr. Klingberg’s previous studies [16, 17, 22], about 22 participants per cell are required to detect moderate to large size treatment effects (Cohen’s d: 0.6 to > 0.8). Required sample varies from a low of 16 to a high of 40, across the various outcome measures. We planned to use a 2:1 randomization strategy in favour of the WM training program, with stratification on 2 strata (school [3 levels]; comorbid ADHD [2 levels]). Accordingly, we aimed to recruit 60 students in the WM training arm (35 LD, 25 LD/ADHD) and 30 in each of the other 2 treatment arms (20 LD, 10 LD/ADHD). However as indicated below, several challenges to the initial start-up of this study resulted in a late start, which necessitated a modification in our design and sample size.

Challenges to Initial Start-Up. To conduct a study using Cogmed WM training software, a research contract is required between the investigators’ research institution and Cogmed America that then provides the software licenses free of charge. Unfortunately, it took over 12 months for the lawyers at Sickkids hospital to finalize and sign that research contract. Moreover, the study was not approved by the institutional REB for another 6 months; the primary challenge was to be able to ensure teacher rights to decline participation and withdraw from the study without employment consequences. Next, various complexities arose at OPDS with scheduling the start-up; specifically internal discussions were required to determine the timing, duration, and frequency of the WM training in terms of the school curriculum and calendar and whether teachers/teacher assistants or the residential counselors would supervise the training. Also, technical problems were encountered with installing the software centrally on the school server; and there were several changes in the Director ship of OPDS. All of
these issues were eventually resolved successfully but the initial start-up was delayed to January 2010.

Also, other changes occurred at OPDS, which in fact allowed us to simplify the original design and reduce the sample size. A marked change in referrals from school boards to OPDS occurred in the Fall of 2009; all of the students now attending Trillium had the combined profile of ADHD/LD (schools no longer appeared to be referring students with pure LD). Moreover the governance decided to locate all students with ADHD/LD at one OPDS (specifically at Trillium School), instead of being distributed between the three OPDS schools. This meant that we did not need to incorporate ‘diagnosis’ or ‘school’ as between-group factors in our research design and analysis.

Accordingly, in discussion with the community partners (Chief psychologist at JVS Toronto), and co-principal applicant (originally Ms Beth Davies, now Dr Nancy Sanders), we made the following changes to the study design and required sample size.

1. We eliminated one of the control groups (individual coaching) in view of the late start. Thus we compared WM training with Academy of Math training.
2. The planned total sample size was reduced to 60; approximately 35 receiving Working Memory Training; 25 receiving Academy of Math Training.
3. We reduced the training period for both programs to 20 one-hour sessions (instead of the usual 25), but which is still within the recommended duration of training and was approved by our consultant, Dr Torkel Klingberg (who developed the WM training program)
4. We were required to eliminate the follow-up assessments (except for one cohort) because of scheduling problems around examinations and other school activities.

4. Synopsis of Study Design & Methodology

Participants:

A total of 60 adolescents (aged 12-17; 15% females) with a previously confirmed diagnosis of LD plus comorbid ADHD (LD/ADHD) attending the OPDS, their parents, and their home-room teachers consented to participate. Inclusion criteria were: i) Fulltime enrollment at Trillium OPDS; ii) Confirmed diagnosis of a specific LD with comorbid ADHD; iii) IQ > 80 (based on WISC-IV); iv) English as the primary spoken language. Exclusion criteria were: i) Uncorrected sensory impairments (vision, hearing); ii) Diagnosis of Conduct Disorder, severe aggression, depression/anxiety requiring specific and immediate treatment; and iii) Severe impairments in oral communication, impeding intelligibility of spoken responses. Diagnosis of LD/ADHD and IQ > 80 was confirmed in a previous assessment to request and permit acceptance into the OPDS. All (except for one) students were receiving medication for the treatment of ADHD and receiving intensive academic remediation for reading, mathematics, and written expression. Thus we sought evidence of benefits from the WM training program over and above those presumed to occur from the special education and medication treatments.

Design.
We used a randomized controlled cohort design to test WM training against an active comparison intervention program. Students were randomly assigned (biasing randomization to Cogmed WM training, by using a 2:1 ratio) over 1.5 school years to either: (1) the Cogmed Working Memory Training Program [Cogmed-RM©], which is the experimental program under investigation; or (2) a validated computerized program designed to enhance a specific academic skill set, namely mathematics [Academy of Math®], which controls for individualized attention, duration and modality of administering the intervention. Cohorts were defined by age/instructional grade level (junior, senior); only one cohort could be trained at a time due to school-related restrictions (curriculum demands and staff time). Four cohorts completed the 5-week training programs in the winter and spring terms of 2010, and in the fall and winter terms of 2011, respectively. All students continued to receive the specialized adaptive education curriculum provided at OPDS. Measures (parent and teacher ratings of ADHD symptoms, assessment of the adolescents’ WM, other cognitive functions, functional impairment, and academic achievement) were administered 1-2 weeks prior to commencing the designated training program (pre-test) and 3 weeks after completion of the training program (post-test) to minimize halo effects. No follow-up assessments were permitted by the OPDS due to curricular demands and exam schedules.

**Intervention Programs.**

**WM Training.** The Cogmed-RM© software-based training program includes a set of auditory verbal and visual-spatial WM tasks presented via computer. There are a total of 12 different WM training exercises that include both auditory verbal and visual spatial modalities. All tasks involve maintenance of simultaneous mental representations of multiple stimuli, unique sequencing of stimulus order in each trial and progressive adaptation of difficulty level as a function of individual performance. Tasks tap visuospatial WM (remembering the position of objects) as well as verbal WM (remembering phonemes, letters, and digits). This intensive training program incorporates an adaptive algorithm which automatically sets the initial difficulty level of each training task to the individual’s WM capacity. Then WM load is increased according to the individual’s performance.

Training was intensive, requiring a minimum of 20 sessions of approximately 45 min/day, conducted 4-5 days a week for 5 weeks. Training plans were individualized and modified based on current performance, but the typical plan included 12 tasks, with 15 trials of 8 tasks each day. Responses to each trial were automatically logged to an electronic file, which was uploaded by the supervising staff member at OPDS via the Internet to dedicated servers at JVS and Cogmed to verify compliance and log progress. In addition to an initial start-up session and a final wrap-up meeting, the supervising staff member at OPDS received daily on-line support (telephone and Internet-based) from a JVS-psychology ‘coach’, trained and certified by Cogmed.

**Treatment Integrity.** Evaluation of treatment integrity was optimized by the fact that both the WM and Academy of Math training programs are implemented via software programs, which record trial-by-trial and session-by-session data. These data, which provide a running record of both treatment integrity and compliance, was supplemented by written records from the training coaches. Treatment compliance was defined as at least 20 days of training. Also, we tracked any changes in medication or other treatment during the project: all except one student (no medication) received pharmacological treatment consistently throughout the training period. Treatment compliance was defined as completion of at least 20 session of training.


**Intervention Setting.**

Our partnership permitted a rigorous test of the efficacy of the target WM training program because we tested it in a school setting with a severely disabled, hard-to-serve, and needy adolescent sample of students with LD/ADHD. Both interventions were implemented within a supportive educational context. School personnel (e.g., principals, teachers, counselors) were highly trained and experienced and each student was provided with an individualized special-education program linked closely with the Ontario curriculum. Also as mentioned previously, all except one student was receiving medication (long-acting stimulant medication or atomoxetine) for the treatment of their ADHD. Thus, we sought evidence that the WM training program conferred additional benefits beyond those typically accrued from the specialized educational program and medication.

OPDS residential counselors served as day-to-day training aides, which was advantageous because they already had a good rapport and working relationship with the students. Community-based clinical psychologists (with Cogmed-certification) from JVS Toronto served as coaches, providing weekly feedback and advice to the aides regarding the Cogmed Working Memory Training Program. Evaluation of treatment integrity will be optimized by the fact that two interventions will be implemented via software programs, which record trial-by-trial and session-by-session data. Thus, these data, which provide a running record of both treatment integrity and compliance, will be supplemented by written records from the training aides and coaches. Treatment compliance will be defined as at least 20 days of training.

**Measures**

Our choice of outcome measures were guided in part by those used in other studies using the same WM training program, to permit replication of findings, and also by the specific questions of this project (e.g., effects on academic attainment). We used Westerberg’s approach to the classification of the selected outcome measures, which distinguished between ‘criterion’ measures (closely resembling the trained WM activities), ‘Near transfer’ measures (indices of other cognitive functions or of WM not resembling trained tasks), and ‘Far transfer’ measures (indices of observable behavior and academic attainment).

- **Criterion measures:**
  - WISC-IV Digit Span Forward (DSF) & Backward (DSB)
  - CANTAB Spatial Span Forward (SSPF) & Backward (SSPB)

- **Near Transfer measures**
  - CANTAB Spatial WM Task & Strategy Score
    - This task, which is based on the Self-Ordering-Pointing-Task [23], also indexes WM, but is distinct from other WM measures in that it is not affected by variation in dopamine levels on the dorsolateral prefrontal cortex [24]. Moreover, it differentiates between strategy skills and WM capacity.
  - Working Memory Rating Scale (WMRS) [7, 25]
    - The WMRS is a newly developed 20-item scale consisting of descriptions of behaviors characteristic of children with working memory deficits. Examples include: ‘The child raised his hand but when called upon, he had forgotten his response’; ‘She lost her place in a task with multiple steps’; and ‘The child had difficulty remaining on task’. Teachers rate how typical each behavior was of a particular child, using a four-point scale ranging from (0) not typical at all to (1) occasionally to (2) fairly typical to (3) very typical. The scale has good internal reliability and differentiates children with and without WM problems.
○ D2 Test of Attention [26]
  ▪ The D2 Test is a timed test of selective attention and is a standardized refinement of a visual cancellation test (Brickenkamp & Zillmer, 1998). In response to the discrimination of similar visual stimuli, the test measures processing speed, rule compliance, and quality of performance, allowing estimation of individual attention and concentration performance.

• Far Transfer measures
  ○ The Strengths and Weakness of ADHD-symptoms and Normal-behavior (SWAN) scale [27]
    ▪ The SWAN (differs from most behavior rating scales used for assessing developmental psychopathology in that the inattentive and hyperactive/impulsive symptoms of ADHD are reworded and the response scale is extended to reflect relative strengths (better than average) as well as weaknesses (worse than average). It is also sensitive to treatment effects.
  ○ IOWA Conners scale
    ▪ well-validated brief measure of inattentive, hyperactive, and non-compliant behavior, with good treatment sensitivity
  ○ Wide-Range Achievement Test-4-Progress Monitoring Version.
    ▪ WRAT4-PMV is an adaptation of the WRAT4 and is specifically designed to be 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 mathematics 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 test-retest stability coefficients, alternate-form reliabilities, equivalency of the forms within each of the six levels, and validity.

5. Statistical Approach

Data were analyzed first using the planned Intent-to-Treat approach, using last observation carried forward (LOCF) for the missing data due to attrition. Second, we then repeated the analysis, using an ‘as treated’ approach’. We believe this is justifiable in this context, since the demands of the curriculum and school schedule precluded us from collecting data at the point when the participants withdrew from the study (often after they had completed many training sessions). This meant using the pretest data as the (LOCF), which may well be an underestimate of the effects of either training program.

6. Preliminary Results

Below we present the robust major findings from this study, which will be presented at the upcoming International Society for Research in Child and Adolescent Psychopathology (University of Chicago, Chicago, IL: June 15-18, 2011). We will be conducting further analyses to investigate predictors of response to WM training.

Sample: Characteristics and Attrition. As shown in Figure 1, a total of 60 adolescents consented and participated in the training programs: 36 were allocated to Cogmed WM, and 24 to AOM. Attrition was modest (10%) with no differential attrition from the two intervention programs: 2 adolescents
(5% of those assigned to Cogmed) withdrew from the Cogmed WM training, and 4 (17%) from AOM. The two primary reasons for withdrawal from the study were: i) family moved and student had to leave the school (n = 3); and ii) adolescents unable to handle both the academic load plus the extra training program (n = 3).

As can be seen from the summary data presented in Tables 1 and 2, the randomization procedure was effective: there were essentially no differences at pre-test in the key characteristics and abilities of adolescents assigned to WM or AOM training. Notably, these adolescents were severely impaired in WM as indicated by the standard scores on the WM tests (Table 1).

**WM training improved performance on criterion indices (Working Memory)**
Consistent with our predictions, those receiving the WM training program showed significant improvements in some (but not all) components of WM as indexed by changes in the standard scores on the WISC Digit Span Backwards (increased ability to manipulate auditory-verbal information) \((F(1, 57) = 8.99, p < .05)\) and CANTAB Spatial Span Forwards (increased ability in the amount of visual-spatial information that can be held in mind momentarily) \((F(1, 57) = 4.26, p < .05)\). These findings are displayed in Table 3 and Figures 2 -3. There were no differential effects of intervention on the WISC Digit Span Forwards (auditory-verbal storage).

These findings indicate transfer (albeit minimal) of training skills to WM activities that are similar to the trained activities in terms of the cognitive and response requirements, but which were administered outside of the training context and used different stimuli, pacing, and response modality.

**WM training improved some other cognitive functions (attention)**
Notably, the WM training program also resulted in improvements in another type of cognitive processing, as indicated by the number of omission errors of the D2 Test of Attention \((F(1, 57) = 6.50, p < .05)\). No effects of intervention were found for behavioral ratings of working memory (WMRS) or on WM strategies or performance as indexed by the CANTAB-SWM task.

**WM training had no immediate effects on academic attainment or on ADHD symptoms**
We found no evidence that either the WM or AOM intervention programs had differential effects on academic attainment as indexed by the WRAT4-PM or on behavior as rated by the parents and teachers, measured after the completing the training programs. However, change scores (posttest minus pretest) on the Cogmed WM Index was correlated significantly with change scores in teacher ratings of classroom behavior, using the SWAN \((r = .38, p < .05)\). The Cogmed WM Index is a composite score measuring change in performance over the duration of training. All of the adolescents in the WM training program attained the minimum required Index score of 17 which indicates compliance with the training program. However, there was substantial variation in these scores; those adolescents with a higher Cogmed WM Index were rated by their teachers as showing greater reduction in symptoms of inattention and hyperactivity/impulsivity.

**DISCUSSION**
As noted previously, we faced many challenges in conducting this study (including most recently, being in the earthquake in Christchurch New Zealand, which I fortunately survived). However, I am delighted to report that we did complete the approved modified proposal successfully. Our findings are generally consistent with previous findings from studies using this WM training program, even when the data are derived from a severely disabled population of adolescents with ADHD/LD.

Our study is unique in its focus on WM training in youth with severe ADHD/LD and attending a special school because of their record of non-response to evidence-based intervention (medication, special education) provided in the regular school setting. Our RCT investigated the efficacy of intensive WM training, conducted in a specialized school setting with a sample of heretofore treatment-resistant adolescents with ADHD/LD. These youth were already receiving medication for their ADHD and attended a semi-residential school with highly-trained educational staff and school counselors who provided individualized academic remediation in reading, mathematics, and written expression. Thus we were seeking evidence that WM training would confer benefits to these youngsters cognitive processing (particularly WM), behavior, and academic attainment, over and above those presumed to be accrued from the existing interventions (medication, special education). Moreover, we tested the efficacy of intensive WM training against an active comparison intervention (intensive math training). Both intervention programs were computerized and adaptive; both were administered and supervised by professional educational (OPDS) and psychological (JVS-Toronto) staff. Thus the research team was independent of the intervention programs. We used a rigorous array of outcome measures, ranging from objective and standardized tests of WM, Attention, Academic Attainment, as well as parent and teacher rating scales of behavior (SWAN, IOWA) and working memory (WMRS).

The major findings were that the WM training program improved the youths’ performance on standardized neuropsychological tests of WM and that effects generalized to a measure of focused attention. That the WM training program induced any improvements in working memory and attention is important from both educational and clinical perspectives, because heretofore, these youngsters have not been able to benefit from education within the regular school system.

By contrast to previous studies of WM training, we did not find evidence of improvements in behavioral symptoms of ADHD or in academic attainment. Methodological differences likely account for the discrepant findings. Previous findings of beneficial effects of WM training on behavioral symptoms of ADHD were restricted to behavioral ratings by parents, who were involved in supervising the intervention and thus were not free from bias; no effects were reported by teachers. Also, evidence of beneficial effects of WM training on academic outcome are sparse and restricted to longer-term effects. We tested only the immediate effects of training (3 weeks after the training stopped) and not subsequent effects several months later. We acknowledge that this is a substantive limitation of the current study. However in a completely separate study of this WM training program involving college students with ADHD/LD (funded in part by the Canada Research Chairs Program), 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 in preparation).

Implications for Practice, Policy, and Theory
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 (including adolescence and adulthood). Results from this study also suggest that WM training may be a promising adjunctive treatment for treatment-resistant youth with ADHD/LD, which can be administered successfully in a publically-funded school setting (funded by the Ontario Ministry of Education). This latter finding is important, because it suggests that governmental educational policy might want to consider providing this intervention for severely impaired and treatment-resistant sub-group of students, such as those with ADHD/LD and very poor WM. Of note is the fact that the company providing the software licenses (Cogmed America) is now under the ownership of a major educational publisher (Pearson).

Acknowledgements:

First, we would like to thank the Provincial Centre of Excellence for Child and Youth Mental Health for funding this project. We knew from the start, that the project timelines would be markedly delayed by the late start-up which was beyond our control. Thus we thank CHEO for permitting us an extension of the funding period (until March 31st, 2011) with a further extension to May 31st, 2011, to submit this final report (because of the challenge of being in the NZ earthquake without any resources). Second, we would like to thank the Ontario Provincial Demonstration Schools and JVS-Toronto for collaborating and helping us complete the project. And of course we extend special thanks to the participating students, teachers and parents without whom we could not have conducted the project.
Eligible sample (n=61)

- I student whose parents consented, declined to participate

Randomization

Math Training Comparison Group

- Allocated sample: n=24
  - Attrition: n= 4 (1 moved/left school, 3 withdrew)
  - Completers: n=20

Working Memory Training Group

- Allocated sample: n=36
  - Attrition: n = 2 (2 moved & left school)
  - Completers: n=34

Analysis

- Intent-to-Treat: n = 24
- As Treated: n = 20
- Intent-To-Treat: n = 36
- As Treated: n = 34

Fig. 1 Flow of participants through the trial
Figure 2: Effects of WM training on manipulation of auditory-verbal information

Digit Span Backwards Change by Group

- Cogmed
- Academy of Math
Figure 3: Effects of WM training on ability to hold visual-spatial information in mind temporally

Spatial Span Change by Group

Average CANTAB SSP score

PRE

POST

Cogmed

Academy of Math
<table>
<thead>
<tr>
<th></th>
<th>Math Training (AOM)</th>
<th>WM Training (Cogmed)</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>WM SS mean (SD)</td>
<td>84.5 (13.2)</td>
<td>84.6 (10.3)</td>
<td>84.6 (11.5)</td>
</tr>
<tr>
<td>DSF SS mean (SD)</td>
<td>6.8 (2.1)</td>
<td>6.9 (2.4)</td>
<td>6.9 (2.3)</td>
</tr>
<tr>
<td>DSB SS mean (SD)</td>
<td>6.5 (2.4)</td>
<td>6.4 (1.9)</td>
<td>6.4 (2.1)</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>
</tr>
</tbody>
</table>

*Randomized participants*
<table>
<thead>
<tr>
<th></th>
<th>Math Training (AOM)</th>
<th>WM Training (Cogmed)</th>
<th>$t$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSF SS</td>
<td>6.8 (2.1)</td>
<td>6.9 (2.4)</td>
<td>.12</td>
<td>.90</td>
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<tr>
<td>DSB SS</td>
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<td>6.4 (1.9)</td>
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<td>.85</td>
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<td>6.5 (1.4)</td>
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<td>.54</td>
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<td>CANTAB WMS BE</td>
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<td>25.4 (20.1)</td>
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<tr>
<td>CANTAB WMS ST</td>
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<td>31.1 (5.8)</td>
<td>-2.4</td>
<td>.02*</td>
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<td>SWAN total</td>
<td>86.0 (34.9)</td>
<td>87.5 (32.2)</td>
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<td>.87</td>
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<td>.55</td>
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<td>23.9 (8.3)</td>
<td>23.0 (7.6)</td>
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<td>.71</td>
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<tr>
<td>IOWA IN/HY total</td>
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<td>12.4 (4.1)</td>
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<td>.71</td>
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<td>5.6 (2.5)</td>
<td>5.6 (2.4)</td>
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<td>.69</td>
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<tr>
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<td>3.2 (1.4)</td>
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<td>.20</td>
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<tr>
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<td>5.7 (3.8)</td>
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<td>4.6 (2.7)</td>
<td>4.0 (2.4)</td>
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<td>96.3 (9.0)</td>
<td>98.1 (10.0)</td>
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<td>.48</td>
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<td>D2 Omission errors</td>
<td>9.1 (11.4)</td>
<td>16.4 (17.3)</td>
<td>1.8</td>
<td>.07</td>
</tr>
<tr>
<td>D2 Commission errors</td>
<td>6.0 (4.6)</td>
<td>6.9 (11.2)</td>
<td>.37</td>
<td>.71</td>
</tr>
<tr>
<td>D2 Total performance SS</td>
<td>105.3 (42.8)</td>
<td>94.9 (17.2)</td>
<td>-1.3</td>
<td>.20</td>
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<tr>
<td>IC Classroom behavior</td>
<td>23.1 (12.4)</td>
<td>22.2 (11.6)</td>
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<tr>
<td>WMRS Total Score</td>
<td>37.6 (12.9)</td>
<td>41.8 (19.0)</td>
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<td>.39</td>
</tr>
</tbody>
</table>

CANTAB SSPL SS = Spatial Span length time, CANTAB WMS BE = Working memory span Between errors, CANTAB WMS ST = Working memory span strategy, D2 Total IP SS = D2 total items processed standard score, IC Classroom behavior = IOWA teacher behaviour total (routines etc.).
### Table 3
Comparison of Pre- and Post-Intervention Scores

<table>
<thead>
<tr>
<th>Group</th>
<th>Baseline</th>
<th>Post Treatment</th>
<th>$F^*$</th>
<th>$p$</th>
<th>Eta Squared</th>
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<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
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<tr>
<td>DSF SS</td>
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<td>7.0 (2.4)</td>
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<td>6.7 (2.1)</td>
<td>7.2 (2.5)</td>
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<td>DSB SS</td>
<td>Experimental</td>
<td>6.3 (2.0)</td>
<td>7.6 (3.0)</td>
<td>8.9</td>
<td>.00*</td>
</tr>
<tr>
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<td>Control</td>
<td>6.3 (2.4)</td>
<td>5.7 (2.3)</td>
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<td></td>
</tr>
<tr>
<td>CANTAB SSPL SS</td>
<td>Experimental</td>
<td>6.7 (1.4)</td>
<td>7.3 (1.2)</td>
<td>4.2</td>
<td>.04*</td>
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<td>Control</td>
<td>6.8 (1.5)</td>
<td>6.8 (1.3)</td>
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<tr>
<td>CANTAB WMS BE</td>
<td>Experimental</td>
<td>25.6 (20.8)</td>
<td>16.7 (13.6)</td>
<td>1.0</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>27.8 (16.2)</td>
<td>22.7 (15.8)</td>
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<tr>
<td>SWAN total</td>
<td>Experimental</td>
<td>86.4 (34.4)</td>
<td>86.8 (33.3)</td>
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<td>.69</td>
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<td>Control</td>
<td>83.1 (36.8)</td>
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<td>SWAN IN total</td>
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<td>22.1 (9.2)</td>
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<td>22.7 (8.2)</td>
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<td>IOWA total</td>
<td>Experimental</td>
<td>23.9 (7.7)</td>
<td>22.3 (6.8)</td>
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<td>24.6 (8.7)</td>
<td>23.2 (7.9)</td>
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<tr>
<td>IOWA IN/HY total</td>
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<td>12.6 (4.3)</td>
<td>11.5 (3.6)</td>
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<td>12.2 (4.0)</td>
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<td>WRAT 4 Math raw</td>
<td>Experimental</td>
<td>5.7 (2.3)</td>
<td>6.1 (2.2)</td>
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</tr>
<tr>
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<td>Control</td>
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<td>6.8 (2.6)</td>
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<tr>
<td>WRAT 4 Spell raw</td>
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<td>3.6 (2.0)</td>
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<tr>
<td>WRAT 4 SC raw</td>
<td>Experimental</td>
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<td>6.3 (3.0)</td>
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<tr>
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<td>5.8 (3.6)</td>
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<tr>
<td></td>
<td>Group</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>F</td>
<td>p</td>
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<td>WRAT 4 Read raw</td>
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<td>4.2 (2.4)</td>
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<td>Control</td>
<td>4.7 (2.7)</td>
<td>5.4 (2.7)</td>
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<tr>
<td>D2 Total IP SS</td>
<td>Experimental</td>
<td>97.4 (10.3)</td>
<td>103.9 (10.8)</td>
<td>.91</td>
<td>.35</td>
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<tr>
<td></td>
<td>Control</td>
<td>96.5 (9.1)</td>
<td>104.7 (9.8)</td>
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<tr>
<td>D2 Omission errors</td>
<td>Experimental</td>
<td>17.1 (17.6)</td>
<td>9.4 (8.1)</td>
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<td>.01*</td>
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<tr>
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<td>Control</td>
<td>9.3 (11.6)</td>
<td>10.2 (9.2)</td>
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<td>D2 Commission err.</td>
<td>Experimental</td>
<td>7.1 (11.5)</td>
<td>6.3 (5.9)</td>
<td>.12</td>
<td>.73</td>
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<td>Control</td>
<td>5.9 (5.0)</td>
<td>4.5 (4.0)</td>
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<tr>
<td>D2 Total perform SS</td>
<td>Experimental</td>
<td>94.4 (17.7)</td>
<td>104.4 (11.2)</td>
<td>1.5</td>
<td>.23</td>
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<td>105.8 (43.6)</td>
<td>105.2 (10.0)</td>
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<tr>
<td>Classroom behavior</td>
<td>Experimental</td>
<td>21.0 (11.3)</td>
<td>18.4 (6.3)</td>
<td>.28</td>
<td>.60</td>
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<td>Control</td>
<td>22.6 (13.4)</td>
<td>18.1 (7.6)</td>
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<tr>
<td>WMRS Total Score</td>
<td>Experimental</td>
<td>42.0 (19.2)</td>
<td>42.5 (13.2)</td>
<td>.02</td>
<td>.90</td>
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<td>Control</td>
<td>39.5 (13.0)</td>
<td>39.4 (10.6)</td>
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</table>

*Note: The F and p values that are reported are for the training group (G: WM vs AOM) by time (T: pretest vs posttest) interaction. In all cases the significant GxT interaction reflect greater improvements for adolescents receiving WM training.
APPENDIX 1

Description of WM tasks in the Cogmed Working Memory Training Program

Participants respond to all of these computer-based tasks by using a mouse to move the cursor to the memory stimuli and by clicking on them.

1. Reproducing a light sequence in a visuo-spatial grid
Lamps arranged in a four-by-four grid are displayed. Participants watch several lights go on and then reproduce the same sequence.

2. Reproducing a light sequence in a rotated grid
A rotating version of the visuo-spatial grid task described above. After the sequence of lights goes on, the grid panel rotates 90 degrees clockwise and participants reproduce the sequence in the panel's new position.

3. Indicating numbers in reverse order
A keyboard with numbers is displayed and then digits are read aloud. Participants respond by indicating the same numbers but in reverse order.

4. Indicating numbers in reverse order with a non-visible keyboard
This is a variation of the previous task; the keyboard with numbers is not displayed as the digits are read aloud, becoming visible only when participants respond.

5. Identifying letter positions in a sequence
Letters are read aloud, one at a time. Participants have to remember the letters in the order in which they are read. A row of lights is then visible and a flashing light cues the participant to indicate the letter that was read in the sequence. For example, if light number 3 lights up, then participants report the 3rd letter that they have just heard.

6. Identifying letter sequences in a pseudoword
Participants keep track of letters displayed in columns. A sequence of letters is read aloud while a light (above each column) flashes for each letter that is spoken. Participants click on the letter that is said first, then second, third, and so on until the entire sequence is reproduced.

7. Reproducing a light sequence in a rotating circle
A set of lamps are arranged in a rotating circle. Participants watch several lights go and then reproduce the same sequence, even though the lamps are constantly shifting positions.

8. Reproducing a light sequence on moving stimuli
A number of moving asteroids lights up in succession. Participants must reproduce the order in which the asteroids light up, even though the asteroids are in constant motion.

9. Reproducing a light sequence in a 3D visuo-spatial grid
Lights are symmetrically positioned in a 3D ‘room’ with five inner walls. Participants watch several lights go on and then reproduce the same sequence.

10. Reproducing a light sequence in a 3D visuo-spatial cube
Lights are symmetrically positioned in a 3D Cube with 12 segments. Participants watch several lights go on and then reproduce the same sequence.

11. Identifying letter positions in a circle
A set of lamps is arranged in a circle. Flashing lights appear as a sequence of letters is read aloud. A letter is then displayed in the middle of the circle. The participants must recall which light was associated with that particular letter by clicking on the appropriate light.

12. Reproducing a sequence of numbers on a visual grid
A four by four grid is presented with 16 latches. A sequence of latches is opened displaying a set of numbers. The participant must sort the numbers by clicking on the latch that contained the numbers in numerical order.

13. Rapidly reproducing a visual-spatial sequence
In this animated task, a number of monsters are hidden in craters. Clouds of smoke reveal their locations. The participant must recall the sequence by clicking on the craters before the monsters appear.
REFERENCES


