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Effects of Computerized Cognitive Training on Working Memory in a School Setting

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Abstract. Academic performance and executive functioning are two factors strongly related to positive life outcomes; whereas, decreased cognitive functioning is associated with negative developmental outcomes. An important aspect of executive functioning is working memory, which is a strong predictor of academic abilities and life skills. The purpose of this study was to investigate the effectiveness of computerized cognitive training to improve working memory in a school setting. Participants consisted of a total of 81 students, with a mean age of 12.8 years, who were recruited from a private school in Southern California that focuses on providing education to children with learning disabilities. First, participants' working memory levels were assessed prior to the intervention. Next, an intervention consisting of 20 hours of computerized cognitive training across 10 weeks was implemented. Results from this study indicated that students with delayed working memory were able to make gains, in two distinct measures of working memory, whereas their peers with typical working memory were not. Additionally, results indicated that delayed students were able to approximate the visual working memory abilities of their typical peers by the end of the training. Results from this study support the use of computerized cognitive training as a promising intervention for children experiencing working memory deficits, particularly in the area of visual working memory. Implications of these findings are discussed.

Keywords: Working Memory; School Interventions; Computer assisted learning; Computerized Cognitive Training.

Introduction

Academic success is a pivotal component of a child's development. Recently, executive functions (EF) have been a major focus of school-based research that has examined factors associated with successful school performance. Welsh (2002) broadly defined executive functions as the cognitive processes that are critical for the development of goal directed behavior, allowing an individual to concentrate on tasks and to control impulses. Specifically, the core cognitive mechanisms that comprise an individual's EF includes planning, problem solving, verbal reasoning, task switching, initiation, cognitive flexibility, inhibition, monitoring of actions, attention, and working memory (Barkley, 1997; Chan, Shum, Toulopoulou, & Chen, 2008; Monsell, 2003; Traverso, Viterbori, Usai, 2015).

Research in education has focused on the cognitive mechanism of working memory (WM) in order to increase learning among children. Working memory can be generally described as a system with a limited capacity that stores and processes information (Baddeley, 1986). More specifically, WM is a higher cognitive process that involves short-term memory (i.e., the amount of information that can be held over a brief period of time) and also includes other processes such as attention, and is used to plan and carry out behavior (Miller, Galanter, & Pribram, 1960). Working memory often requires retrieving information while simultaneously performing distracting or interfering activities.

Basic forms of WM are present early during development and continue to increase rapidly during a child's school-age years (Carlson, Moses, & Claxton, 2004). Studies suggest that an individual's WM is related to a variety of real-word abilities such as theory of mind (Perner & Lang, 1999) and academic achievement (Biederman et al., 2004). In fact, performance on WM tasks has been found to be predictive of academic skills such as literacy (Swanson, 1994) and mathematics (DeStefano & LeFevre, 2004; Swanson & Jerman, 2006). Moreover, working memory has also been shown to reliably predict performance on reading and language comprehension (Daneman & Carpenter, 1980; King & Just, 1991); learning to spell and vocabulary building (Daneman & Green, 1986; Ormrod & Cochran, 1988); following directions (Engle, Carullo, & Collins, 1991); note-taking and writing (Benton, Kraft, Glover, & Plake, 1984; Kiewra & Benton, 1988); and reasoning and complex learning (Kyllonen & Christal, 1990; Shute, 1991).

Along with the demonstrated positive relationships between WM and academic abilities, studies have also found low WM to be associated with decreased academic abilities. For instance, children between the age of 7 and 14 years who perform poorly on measures of WM also tend to perform poorly on national assessments of expected standards in science and mathematics (Gathercole, Brown, & Pickering, 2003; St Clair-Thompson & Gathercole, 2006). Similarly, working memory problems have been identified as a central issue for children with mathematical disorders (given that WM plays such a large role in the ability to solve arithmetic problems; Passolunghi, 2006), as well as with children displaying reading disabilities and dyslexia (Melby-Lervag, Lyster, & Hulme, 2012; Swanson, 2006), and have also been related to neurodevelopmental disorders such as Attention-Deficit Hyperactivity Disorder (ADHD;

Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005) and Autism Spectrum Disorder (ASD; Kenworthy, et al., 2008).

Given the importance of working memory in supporting strong academic performance, an emerging empirical question is whether working memory can be "trained" or enhanced. The process of increasing WM capacity in children can involve teaching memory techniques or perhaps exposing children to repeated trials of WM tasks. Teaching memory techniques usually involves having children learn mental rehearsal strategies such as chunking, mnemonics, visual imagery, and method of loci (Brown, Campione, Bray, & Wilcox, 1973; Butterfield, Wambold, & Belmont, 1973; De La Iglesia, Buceta, & Campons, 2005; Hulme, 1992; Klingberg, 2010). However, this is not usually beneficial for young children, given that they do not use mentally based strategies until approximately seven years of age (Gathercole, 1998). On the other hand, exposure to repeated WM trials along with reinforcement contingencies and feedback has been shown to positively impact children's task performance, working memory, literacy, and mathematical abilities (Klingberg, 2010; Prins et al., 2011; Rabiner et al., 2010).

Building Working Memory with Computerized Cognitive Training (CCT)

One way to potentially increase the effectiveness of WM training has been to use an adaptive computer-based program to provide the training stimuli and feedback (Bigorra, Garolera, Guijarro, & Hervas, 2016; Kirk, Gray, Riby, & Cornish, 2015; Rabiner, Murray Skinner, & Malone, 2010; Shalev, Tsal, & Mevorach, 2007). Typically, these programs begin with a low-difficulty task and the computer adjusts the difficulty as the child exhibits increases or decreases in his/her WM ability. Specifically, the adaptive nature of the computer program allows it to make adjustments in difficulty based on the performance of the user. For example, if the user completes an exercise correctly, the next exercise presented would be more difficult. Conversely, if the exercise is completed incorrectly the next exercise would be less difficult. Therefore, the training is always targeted to the child's WM capacity and the challenge is never too hard nor too easy which may reduce motivation and/or training efficacy. It has been argued that adaptive training is important because without the automatic performance-related adjustment, faster reaction times may be produced, which is reflective of an increase in attention, but not an increase in WM capacity (Kristofferson, 1972; Phillips & Nettelbeck, 1984).

The results from CCT have demonstrated increases in attention, WM, scholastic skills, and decreases in diagnostic symptoms in children with ADHD (Klingberg et al., 2005; Rabiner et al., 2010; Shalev, Tsal, & Mevorach, 2007; Slate, Meyers, Burns, & Montgomery, 1998). Additionally, Klingberg and colleagues (2002) showed an improvement in inhibitory control and reasoning abilities in 7 to 12 year old children with ADHD through an intense WM training schedule (25-40 minutes per day during 5 weeks).

Although Klingberg (2002) supports the efficacy of WM training as an intervention for children with low WM capacity, other researchers are not as convinced (Levarg & Hulme, 2012; Morrison & Chein, 2011; Shipstead, Redick, & Engle, 2010). Altogether the research represents a combination of mixed effectiveness, with some research demonstrating evidence for limited training effects, and other studies showing evidence for distantly related transfer effects. One of the issues raised by the conflicting research involves whether the setting in which WM training occurs impacts its practical benefits or not.

Computerized Cognitive Training in a School Setting

To investigate the effective integration of CCT in different settings, a growing trend has been to move WM training and CCT towards applied settings such as schools. Working memory training has been explored by introducing it at schools for children with attention problems or those with ADHD. One study that best exemplifies this transition was reported by Mezzacappa and Buckner (2010). The researchers conducted a small pilot study in a school setting to investigate the potential for CogMed's RoboMemo to increase the WM functioning among young children from an economically disadvantaged neighborhood in Boston, MA. Mezzacappa and Buckner (2010) utilized a small group of participants and investigated WM functioning before and after the CCT training. These students were involved in the WM training five days a week for 45 minutes each session, over a five-week span. The researchers were able to implement the CCT within the school curriculum as a pullout program from regular classes, which has generally not been the case with other studies. Other researchers have introduced the CCT materials at the school, and had students complete the program at home (Klingberg et al., 2005); or had the programs at the school, but offered outside of the curriculum (Steiner, Sheldrick, Gotthelf & Perrin, 2011). After the five-week training period, students showed an improvement on all measures analyzed by Mezzacappa and Buckner (2010). Teacher's ratings of the student's behaviors improved by a large magnitude and student’s performance on the Finger-Windows task (a visual spatial WM task) also showed improvement.

Another pilot study, which utilized a pull out program at a specialized school for students with learning disabilities, was conducted in southern California (Wong et al., 2012). This study investigated changes in WM functioning before and after the use of a CCT intervention. The students in the study were involved in the WM training for a total of 20 hours across 10 weeks. The results demonstrated significant benefits in working memory for the participants.

Overall, given that CCT and WM training are still relatively new areas of research, it is important to conduct larger follow-up studies in order to establish the effectiveness of CCT within an applied setting. Clearly, children are required to use their WM capabilities in order to meet the demands of the academic curriculum; therefore it makes sense to offer them a chance to train their WM within their schools.

The present study

The purpose of this study is to explore the effectiveness of CCT in increasing the cognitive abilities of children with learning disabilities in a school setting over a period of 10 weeks. We expect different levels of gains depending on the initial levels of WM capacity of the school children, such that children with delayed WM would display greater gains for visual and verbal WM from CCT. We also expect gains for visual and verbal WM from those children with typical levels of WM, although we predict these gains will not be as strong as the delayed WM group. Finally, although we expect that both the delayed and typical groups will have quantitatively different WM capacities after exposure to the intervention, we predict that the gap between each group will decrease to the degree that the differences between the two would no longer be significant.

Hypotheses

(H1) Children with delayed WM capacity are expected to significantly improve in post-test verbal WM by a large magnitude compared to pre-test scores; (H2) Children with delayed WM capacity are also expected to significantly improve in post-test visual WM by a large magnitude compared to pre-test scores; (H3) Children with typical WM capacity are expected to improve by a small magnitude in post-test verbal WM compared to pre-test scores; (H4) Children with typical WM capacity are also expected to improve by a small magnitude in post-test visual WM compared to pre-test scores; (H5) Post-test improvement in verbal WM for both delayed and typical WM capacity are predicted to not be statistically different; (H6) Post-test improvement in visual WM for both delayed and typical WM capacity are also predicted to not be statistically different; (H7) Given the expected differences in training effects for both delayed and typical WM groups, it is hypothesized that there will be an interaction for pre and post-test verbal WM scores and group classification of WM; (H8) It is hypothesized that there will be an interaction for pre and post-test visual WM scores and group classification of WM.

Method

Participants

Participants consisted of 49 males and 32 females (N = 81), ranging from 11 to 18 years of age (*M* = 12.83). Recruitment of participants was conducted during 2010 - 2013 and took place at a private school in Southern California. This school specializes in providing education for students with learning disabilities and related disorders. Specifically, 51 of the 81 participants received one or more formal diagnosis(es); see Table 1 for the specific diagnoses. Participants in this study were parent-referred or referred by a teacher. All participants were treated in accordance to the Ethical Principles of Psychologists and Code of Conduct (American Psychological Association, 2002).

Table 1. Diagnoses of Participants

Type of Disorder	Instances
Autism	3
Emotional Disturbances	5
Other Health Impairment	9
ADHD (including ADD)	13
Specific Learning Disabilities	43

Note. A total of 19 children had multiple diagnoses. The number of students with each type of disorder (as identified in this table) does not sum to 51 because of the multiple diagnoses.

Measures

Wide Range Assessment of Memory and Learning Second Edition™ (WRAML2) was developed by Sheslow and Adams (2003) to provide an assessment of memory for individuals, ages 5 to 90. The WRAML2 consists of a battery of tests for general memory as well as optional subtests for working memory and recognition. Specifically, the general memory battery consists of tests to assess verbal memory, visual memory, and attention. These tests can be combined into an index of general memory. The WRAML2 has been demonstrated to have a high reliability for the general memory index (Sheslow & Adams, 2003).

The Working Memory assessment consists of two tasks, one for symbolic (or visual) working memory and the other for verbal working memory, which have been normed for children ages 9 and older. The scores of both subtests can be combined into a working memory index, which has been demonstrated to have high internal reliability (Strauss, Sherman, & Spreen, 2006). Only the verbal and symbolic working memory subtests (from the WRAML-2) were used during the pre and post-test phases of this project.

Assessment of verbal working memory was based on a task where participants were provided with a verbal sequence of animals and non-animals and then instructed to recall the sequence. An additional requirement for the participants, as they recalled the sequence, was to first report the animals and then the non-animals. Participants were awarded one point for recalling the animals correctly, another point for recalling the non-animals correctly, and a bonus point for recalling both groups correctly without the intrusion of an incorrect response. If the participants responded incorrectly across two consecutive items, then the test was discontinued and the participant would only earn the points up to the point of termination. The total number of points was used to create an aggregate verbal WM raw score. The raw score was then transformed into a standardized value.

The assessment of symbolic working memory was based on a task where participants were provided with a verbal sequence of numbers and/or letters and then instructed to point on a sheet to indicate the numbers and letters they heard. Two levels of this test were administered for participants ages 9 and older. Upon completion or discontinuation of the first level, the second level was conducted. In the first level, participants were only verbally provided sequences of numbers ranging from one to eight, and instructed to point on a sheet to indicate the numbers they heard in order from least to greatest. Points were summed in order to provide a total symbolic working memory raw score. The raw score was transformed into a standard score.

Captain's Log, a computerized cognitive training program, was used as the intervention for this study. Participants interacted with this training program primarily through the use of a computer mouse and keyboard. Captain's Log is designed to develop a wide range of cognitive skills through various brain training exercises and is organized into three training sets: attention skills training, problem solving skills training, and working memory training (Sandford, 2007; Sandford & Browne, 1988). Only two of the working memory training modules from the working memory set were used, specifically the working memory skills and the auditory working memory modules. Captain's

Log was programmed to run each module for 15 minutes, with the first session beginning at the simplest level and adjustments in difficulty were made based on the child's performance. Specifically, the adaptive nature of Captain's Log would adjust the difficulty of the modules to become easier if the participant made an error, or harder if the participant selected a correct response.

Procedure

Assessment of WM was achieved through the use of WRAML2 and was completed a week before the cognitive intervention. The WRAML2 is a norm-referenced measure of memory that is administered using a standardized format. Performance on the subtests of the WRAML-2 are reported in terms of a scaled score, which have a mean of 10 and a standard deviation of 3. In clinical settings, a criterion of one standard deviation below the mean is widely used to establish clinical significance (Kraemer et al., 2003). This same approach was used to establish a student's classification of WM (i.e., delayed or typical) in this sample. Therefore, participants who scored seven or greater on the WM measures were categorized into the typical WM group. Conversely, those students who scored six or below on the same measures were categorized into the delayed WM group.

Following pretesting, participants began the computerized cognitive training via the use of the Captain's Log (CL) program. Participants played CL games/activities 30 minutes per day, four days a week, for a total of 20 hours across 10 weeks. Students who were absent or late during sessions were given respective make-up sessions in order to assure that all participants completed the 20 hours of CL training. A week after CL training was completed, all participants were assessed on their WM through the WRAML2. Assessment and cognitive training both took place at the participants' school during the regular school-day hours.

Analysis of Data/Design

A mixed design was used for this study based on a 2 within-subjects (i.e., pre-test vs. post-test) by 2 between-subjects (i.e., delayed vs. typical) pre-experimental design. A paired samples t-test was used to assess differences across pre-test and post-test scores of working memory and an independent samples t-test was used to assess differences between delayed and typical students. Furthermore, a factorial analysis of variance (ANOVA) was used to determine the presence of any interaction effects on working memory performance as a result of testing period (i.e., pre-test vs. post-test) and WM ability (i.e., delayed vs. typical). Finally, the significance level criterion of $p < .05$ was used and practical significance was assessed through the use of a Cohen's D. (Ferguson, 2009).

Results

Summary descriptive statistics for delayed and typical WM scores are presented in Table 2. An observed trend was that each group (i.e., delayed and typical) showed improvement; however, each improvement was analyzed to discern the statistical difference and magnitude.

Table 2. Descriptive Statistics for Working Memory Measures

	Delayed WM							
	Pre-test		*Post-test*					
	Mean [95 % CI]	*SD*	Mean [95 % CI]	*SD*	*t*	*df*	*p*	*d*
Verbal	5.45 [4.89, 6.0]	0.82	7.27 [6.10, 8.43]	1.73	-3.03	10	$p < .05$	1.42
Visual	5.43 [4.38, 6.47]	1.13	8.14 [6.59, 9.68]	1.67	-2.8	6	$p < .05$	1.93

	Typical WM							
	Pre-test		*Post-test*					
	Mean [95 % CI]	*SD*	Mean [95 % CI]	*SD*	*t*	*df*	*p*	*d*
Verbal	10 [9.5, 10.49]	2.07	10.21[9.6, 10.81]	2.53	-0.86	69	$p = .39$	0.09
Visual	9.67 [9.17, 10.16]	2.13	9.94 [9.27, 10.60]	2.89	-1.1	73	$p = .27$	0.1

H1: A comparison of pre-test verbal WM scores and post-test verbal WM scores among children with delayed WM was conducted. The paired samples t-test indicated a significant difference between pre-test verbal WM scores (M = 5.45, SD = 0.82) and post-test verbal WM scores (M = 7.27, SD = 1.73), $t(10) = -3.03$, $p = .013$. The analysis of magnitude revealed that the difference was large, d = 1.42. The results of the analysis support hypothesis one, suggesting that children with delayed WM experience gains after exposure to CCT.

H2: An accompanying comparison of pre-test and post-test of visual (i.e., symbolic) WM scores among children with delayed WM was also conducted. The paired samples t-test was significant, $t(6) = -2.80$, $p = .031$. The analysis of magnitude revealed that the difference was large, d = 1.93. The results of this analysis indicated that children with delayed visual WM demonstrated gains after exposure to CCT.

H3: In order to assess differences among children with typical verbal WM a comparison of pre-test and post-test scores was conducted. The paired samples t-test for pre-test verbal WM scores (M = 10.00, SD = 2.07) and post-test verbal WM scores (M = 10.21, SD = 2.53) yielded no significant differences $t(69) = -0.86$, $p = .394$, d = 0.09. Children with typical verbal WM did not make significant improvements as a result of exposure to CCT therefore hypothesis three was not supported.

H4: An assessment of the differences among children with typical visual WM was also conducted to examine the differences between pre-test and post-test scores. The paired samples t-test for pre-test visual WM scores (M = 9.67, SD = 2.13) and post-test visual WM scores (M = 9.94, SD = 2.89) were not significant,

$t(73) = -1.10$, $p = .274$, $d = 0.10$. Children with typical visual WM did not exhibit a significant improvement as a result of exposure to CCT therefore hypothesis four was not supported.

H5: In order to assess the expected similarity of post-test verbal WM scores between children with delayed WM and children with typical WM, an independent samples t-test was conducted. Results of the analysis indicated a significant difference between the post-test scores of verbal WM of children with delayed WM ($M = 7.27$, $SD = 1.73$) and children with typical WM ($M = 10.21$, $SD = 2.53$), $t(79) = -3.70$, $p = .001$. Contrary to what was expected, children with delayed verbal WM did not approach the verbal WM abilities of their typical peers in terms of post-test scores, therefore hypothesis five was not supported.

H6: Similar to hypothesis five, the difference in post-test symbolic WM scores between children with delayed WM and children with typical WM was evaluated via an independent samples t-test. The analysis demonstrated that there was no significant difference between post-test scores of symbolic WM of children with delayed WM ($M = 8.14$, $SD = 1.67$) and children with typical WM ($M = 9.94$, $SD = 2.89$), $t(79) = -1.62$, $p = .109$. As was expected, children with delayed visual WM were able to approximate the post-test levels of their typical peers as a result of exposure to CCT, therefore hypothesis six was supported.

H7: To assess the possibility of an interaction on verbal WM abilities, a mixed-design 2x2 analysis of variance (ANOVA) with time of assessment (pre-test, posttest) as the within-subjects factor and verbal WM classification (delayed, typical) as the between-subjects factor was conducted. The resulting analysis revealed a significant main effect for verbal WM classification $F(1, 158) = 9.58$, p = .002, $\eta p^2 = .057$, but no significant main effect for time of assessment $F(1, 158) = 1.12$, p = .290, $\eta p^2 = .007$ (see Table 3 for descriptive data). Similarly, the predicted interaction of time of assessment and WM classification was not significant, $F(1, 158) = .087$, p = .769, $\eta p^2 = .001$. As a result, hypothesis seven was not supported. Both classifications of WM ability experienced similar rates of gains in verbal WM as a result of exposure to CCT.

Table 3. Main Effects for Verbal Working Memory

Variable	df	*F*	eta	*p*
Classification	1	9.57	0.057	0.01*
Time of Assessment	1	1.12	0.007	0.29
Interaction	1	0.08	0.001	0.77

Note: * p < .05

H8: Finally, one last mixed-design 2x2 ANOVA of visual WM was conducted with time of assessment (pre-test, posttest) as the within-subjects factor and visual WM classification (delayed, typical) as the between-subjects factor. This analysis demonstrated a significant main effect for time of assessment $F(1, 158) = 4.65$, p = .032, $\eta p^2 = .029$, and a significant main effect for visual WM classification $F(1, 158) = 19.13$, p = .001, $\eta p^2 = .108$ (see Table 4 for descriptive data). These main effects were not qualified by an interaction between time of assessment and visual WM classification $F(1, 158) = 3.12$, p = .079, $\eta p^2 = .019$. Although the predicted interaction was not significant, it did approach significance. As a result, although hypothesis eight was not supported there appears to be a trend in support of the prediction. Therefore, its possible children with different levels of WM may experience varying rates of gains in visual WM as a result of exposure to CCT.

Table 4. Main Effects and Interaction for Visual Working Memory

Variable	df	*F*	eta	*p*
Classification	1	19.13	0.108	0.01*
Time of Assessment	1	4.65	0.029	0.03
Interaction	1	3.12	0.019	0.07

Note: *p < .05, †p approached significance

Discussion

Overall the results highlight a trend consistent with the hypotheses. Specifically, students with delayed WM were observed to make greater significant gains as a result of CCT in comparison to students with typical WM. Because of this pattern of findings the results will be combined when discussing their implications.

The first and second hypotheses were related to expected gains for children with delayed WM as a result of exposure to CCT. Overall, both hypotheses were supported, and demonstrated large effect sizes. Thus, it appears that CCT improved this group of children's WM, despite their previous classification as delayed WM. In fact, the magnitude of change was significantly large that the post-test scores of this group would have enabled them to be re-classified as typical WM, in terms of decision making for group classification. This finding is similar to previous studies that have investigated gains made by special education children after exposure to CCT (Alloway, Bibile, Lau, 2013; Dahlin, 2011; Klingberg, Forssberg, & Westerberg, 2002; Klingberg et al., 2005). This practical gain is important when considering the academic consequences associated with WM deficits, including difficulty with arithmetic (Passolunghi, 2006) and reading (Melby-Lervag, Lyster, & Hume, 2012; Swanson, 2006).

The third and fourth hypotheses predicted gains for children with typical WM as a result of exposure to CCT. These hypotheses were not supported. Although children with typical levels of visual and verbal WM were able to make a small degree of improvement as a result of CCT, these gains were not statistically significant. Thus, it appears that children with typical WM abilities, in both visual and verbal, did not noticeably benefit from exposure to CCT. A possible explanation could be that levels of WM for this group may already be near their peak performance leaving little room for improvement. Such a conceptualization would be consistent with researchers who argue that working memory has limited capacity (see Cowan, 2001).

The fifth and sixth hypothesis were related to expected similarities between children with delayed and typical WM abilities at the conclusion of computer training. The fifth hypothesis, related to verbal WM, was not supported; however, the sixth hypothesis, related to visual WM, was supported. Although the children with delayed WM were able to make increases in their post-test verbal WM abilities to the extent that they would no longer be classified as delayed WM, these gains were not great enough to be comparable with their typical peers. However, the children with initial WM deficits were able to increase their visual WM to the point that they would no longer be classified as delayed and were able to approximate their typical peers' post-test level performance of WM. These findings suggests that children with delayed WM may benefit more from training in terms of visual WM rather than verbal WM. Consistent with these findings, a 2008 study by Abikoff and colleagues, which examined a group of 7-12 year old children diagnosed with ADHD, found that children who attended a six week summer intervention program that utilized CCT demonstrated significant increases in their post visual-spatial WM, but no increases with verbal WM. Possible reasons for this particular pattern of differences between visual and verbal WM functioning may have cognitive and developmental underpinnings.

Several researchers have suggested that there are increased cognitive demands related to visual WM rather than verbal WM (Bayliss et al., 2003; Dahlin, 2011; Gathercole et al., 2004). The taxing cognitive demands creates a situation where children with visual WM deficits may have a lower initial ability and consequently more room for improvement once these deficits are overcome compared to their typically functioning peers. Studies that investigated differences in the development of verbal and visual WM among children have demonstrated that the earlier of the two systems to develop is visual WM (Alloway, Gathercole, & Pickering, 2006; Koppenol-Gonzalez, Bouwmeester, & Vermunt, 2012; Pickering, 2004). A developmental history demonstrating an earlier relationship with visual WM, combined with opportunities for enhancement from CCT, and overcoming cognitive burdens may explain the large gains observed for visual WM.

The seventh and eight hypotheses were intended to reveal more information about the differences in rates of benefits that children obtain from CCT. Findings from our study suggest that rates of benefits for verbal WM were not observed to vary significantly as a result of initial classification of WM ability, as a result hypothesis seven was not supported. Additionally, a similar assessment on the rates of benefits for visual WM was not observed to vary significantly either as a result of initial classification of WM ability and thus hypothesis eight was also not supported. However, it is important to note that the interaction tested by hypothesis eight was observed to approach the level of significance. This may provide tentative evidence that rates of gains in WM, as a result of CCT, are different between both verbal and visual WM depending on initial levels of WM. The results related to hypotheses seven and eight are similar to the pattern of findings observed for hypotheses five and six, such that it appears that a positive trend is stronger for visual WM rather than verbal WM as a result of CCT. As previously discussed, differences in development of WM may play a role on the observed differences. For example, Jarvis and Gathercole (2003) found a dissociation between verbal and visual WM among children, suggesting that even into late adolescence these subtypes of WM develop at differing rates. Additionally, Koppenol-Gonzalez and colleagues (2012) observed better performance in visual processing tasks rather than verbal processing in children, ages 4 to 15, supporting differences between theses two subtypes of WM. Specifically, among the older participants it was observed that children were able to supplement their performance on visual processing tasks by recoding visual information phonologically, which allowed them to outperform younger children who lack this ability. Similar to the younger children, it may be the case that children with delayed WM in the current study were not able to supplement different domains of WM tasks by utilizing additional WM skills to the same extent as their peers with typical WM.

Overall, the patterns of findings from this project support CCT as a potential intervention for children with deficits in WM, particularly in the area of visual WM. Given the relationship between working memory impairments and poor academic outcomes, it appears that CCT has a strong potential to be used in interventions for children at high risk for educational underachievement. It would be expected that the gains experienced by the children with delayed WM would translate into improved academic performance, although further research is required to confirm this.

A possible limitation of this study may have been the unequal gender distribution across groups. Two thirds of the participants were young males, and one third of the participants were young females. Previous studies have mentioned a lack of gender differences on WM assessments (Alloway et al., 2006; Klingberg et al., 2005), whereas others shared similar distributions of gender (Dahlin, 2011; Holmes et al., 2010; Klingberg et al., 2002; Mezzacappa & Buckner, 2010; Prins et al., 2011; Shavlev et al., 2007). Despite expected differences in occurrences of WM deficits between males and females (e.g., males are twice as likely to be diagnosed with ADHD than females; Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007), gender would not be expected to function as a confounding variable.

Another possible limitation is that the number of children in the study with delayed WM was relatively small compared to typical WM. This could potentially affect the data analysis, however all distributions were found to not violate homogeneity. Therefore, similar patterns would still be expected given a larger number of delayed participants.

One final consideration involves a potential regression towards the mean effect, specifically for the delayed group since their mean scores shifted towards the overall mean during the post-test measurement. However, it is thought to be unlikely that such regression towards the mean has occurred, due to the utilization of a highly standardized and normed measured of WM (i.e., the WRAML2). Moreover, the pretest and posttest means for verbal and visual working memory among students in the delayed group were not at the extreme end of scaled scores (which have a range of 1-19); this reality reduces the likelihood of a regression to the mean effect.

Future Directions and Recommendations

These results indicate that CCT is a potential strategy for students with deficits in WM, specifically in the area of visual WM. Given the relationship between WM, literacy, and mathematics, as well as the potential for CCT to improve these academic skills, it would appear that CCT could be a valuable intervention for children identified as having problems with WM within the Response-to-Intervention (RTI) model. The RTI model is a widely used academic intervention in American educational settings, which enables educators to identify different strengths and weaknesses of children (Fuchs et al., 2003). It involves an initial school-wide screening period followed by placement into different tiers of instruction that vary in terms of intensity. The intensity of the instruction is related to the deficits experienced by the students. Future studies may examine the effectiveness of CCT as an intervention within the RTI model to improve a student's academic performance by targeting core cognitive deficits.

Given the possibility for CCT to be incorporated within the RTI model, it would also be of interest for future researchers to investigate how CCT could lead to increases in various measures of academic performance. Previous research has identified that CCT leads to improved performance in mathematical reasoning abilities (Holmes, Gathercol, & Dunning, 2009) and reduction of off-task behaviors during academic tasks (Green et al., 2012). However, a more practical measure of academic benefits such as grades, teacher/parent ratings, and scores on national assessments would help demonstrate that CCT provides benefits beyond training WM.

Although not all hypotheses were supported, the general trends observed among individuals with deficits in WM are particularly powerful. The benefits of CCT still warrant additional research, the current findings regarding CCT are largely in agreement with previous literature. As a whole, parents and educators may find this information particularly useful when considering how to remedy issues associated with working memory.

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