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PREDICTORS OF CHANGE IN SHORT-TERM MEMORY SPAN FOLLOWING WORKING MEMORY TRAINING[1]

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SUMMARY

Background: Computer-based working memory training exercises produce improvements in performance on ability measures that are similar to the trained tasks (near-transfer), but results have been inconsistent regarding generalization of training outcomes to other abilities and behaviors, particularly those reflecting symptoms of attention-deficit/hyperactivity disorder (ADHD). In contrast to the growing body of efficacy research in this area, almost no studies have systematically investigated characteristics of subjects that predict response to working memory training. This study is an investigation of subject characteristics that predicted change in near-transfer immediate memory span performance following working memory training.

Material/ Methods: Children and adolescents aged 9-16 years (N=62) with a broad range of reported symptoms of attention-deficit/hyperactivity disorder (ADHD) completed working memory training for a 25-day period. Assessments of verbal and visual working memory span and ADHD symptoms were completed at the beginning and end of working memory training.

Results: Greater improvement in working memory span from baseline to post-training was predicted by poorer memory span, more hyperactivity-impulsivity symptoms, and fewer inattention symptoms at the baseline.

Conclusions: For baseline memory span and hyperactivity-impulsivity symptoms, study results are consistent with a remediation or rehabilitation model in which working memory training produces more near-transfer improvement for individuals who have more baseline delay or impairment. However, the opposite relationship was found for inattention, perhaps because poor attention skills interfere with the ability to actively engage in working memory training. Clinically, this information may be useful for identifying individuals who are more likely to benefit from working memory training.

Key words: working memory, ADHD, hyperactivity, impulsivity, attention problems

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PREDICTORS OF CHANGE IN SHORT-TERM MEMORY SPAN FOLLOWING WORKING MEMORY TRAINING

Working memory is the cognitive system used for the temporary storage and manipulation of information in immediate awareness during the performance of other mental processing activities (Baddeley, 2007; Klingberg, 2010). Deficits in working memory underlie difficulties in a variety of critical cognitive functions, including attention, concentration, reading, and language skills (Gathercole, Alloway, Willis, & Adams, 2006; Gathercole et al., 2008; Klingberg, 2010). Neuropsychological and imaging studies strongly implicate working memory deficits in attention-deficit/hyperactivity disorder (ADHD) symptoms (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Lipowska 2012), and human and animal research models demonstrate that working memory function relies on the prefrontal cortex and catecholamine modulation, two areas strongly implicated in the pathophysiology of ADHD symptomatology (Barkley, 2006). Recently, some novel working memory training (WMT) programs have been proposed as potential treatments for disorders involving working memory functioning and some language/learning disorders (Klingberg et al., 2005; Kronenberger, Pisoni, Henning, Colson, & Hazzard, 2011; Holmes, Gathercole, & Dunning, 2009).

Historically, working memory capacity has been thought to be static, but recent studies using novel WMT programs have suggested that working memory may be more plastic than previously thought (Buschkuehl & Jaeggi, 2010; Diamond & Lee, 2011; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Klingberg, 2010; Morrison & Chein, 2011; Shipstead, Redick, & Engle, 2012). These WMT programs present challenging memory exercises, using adaptive training algorithms in which items become more difficult as subjects master the tasks. Several studies examining WMT report improvement not only in the training-specific task and very similar tasks (near transfer), but also in untrained tasks (far transfer) such as tests of executive functioning and behavior ratings of attention and concentration (Morrison & Chein, 2011). Klingberg and colleagues, for example, demonstrated near and far transfer effects in both young, healthy adults (Olesen, Westerberg, & Klingberg, 2004) and children diagnosed with ADHD (Klingberg et al., 2005). Randomized clinical trials using Klingberg’s WMT program have demonstrated differences compared to placebo programs on a variety of near-transfer and far-transfer measures (Holmes et al., 2009; Klingberg et al., 2005; Green et al., 2012).

Holmes et al. (2009) studied children with low WM using an adaptive training program (Cogmed Working Memory Training) and a non-adaptive version of the program as a comparison. They found generalized and sustained improvement in working memory at post-training and at follow-up six months later in the adaptive training group for all aspects of WM tested, and these training gains were significantly greater in the adaptive training group than in the non-adaptive comparison group. Adaptive training appeared to have little benefit for academic ability immediately following post-training but showed a significant increase at the six-month follow up. Green et al. (2012), in a randomized, double-blind, placebo-controlled design, found significant reductions in ADHD-related behaviors in children following WMT with Cogmed compared to a placebo control group. Using a different type of WMT based on an N-back algorithm, Jaeggi et al. (2011) also found improvements compared to a placebo control condition in both WM skills and general fluid intelligence.

In contrast to results suggesting potential positive effects of WMT, other researchers have reported negative results and have expressed skepticism about the impact of WMT. Shipstead et al. (Shipstead, Hicks, & Engle, 2012; Shipstead, Redick, et al., 2012) question some weaknesses in the methodology of the current research, including the inconsistent use of working memory tasks, problems with placebo conditions, a lack of blinded, placebo-controlled studies, the questionable validity of outcome measures, and differences in the types of significant changes reported across studies. Questions also exist about the degree to which WMT generalizes and transfers to the target symptoms or problems of the disorders that it is intended to treat. Epstein and Tsal (Epstein & Tsal, 2010), for example, concluded that cognitive training more consistently improved trained (e.g., near-transfer) cognitive tasks with less evidence for improvement in non-trained (e.g., far-transfer) tasks, such as overall academic productivity and ADHD symptoms. Recently, one empirical study reported no difference between college-age adults who completed a WMT program and those who completed a placebo adaptive cognitive training program that did not target working memory (Redick et al., 2013).

Most empirical research on WMT to date has focused on questions of efficacy – whether WMT produces change in targeted abilities and behavior. However, equally important questions involve the mechanism by which WMT might produce change and whether certain individual characteristics predict who is more likely to demonstrate improvement after WMT. For example, Gibson et al. (2013) theorize that the effectiveness of WMT may be dependent on its ability to tax secondary memory, which is the component of working memory that has been lost from active maintenance (e.g., primary memory) but can still be accessed from long-term memory (Unsworth & Engle, 2007). According to this theory, programs that target secondary memory may be more effective in producing change in working memory and attention outcomes because secondary memory is more important than primary memory in the explanation of individual differences in symptoms of inattention (Gibson et al., 2012). Therefore, individuals who show more improvement in secondary memory following WMT would be expected to demonstrate more improvement in those far-transfer tasks related to attention and executive functioning.

There has also been very little attention paid to individual differences in responsiveness to WMT. Individual differences in response to WMT might illuminate the mechanism of the action of WMT and help with identifying target populations that could benefit most from WMT. Secondary analyses from WMT efficacy studies suggest that baseline WM or ADHD subtype are unrelated to change (Jaeggi et al., 2008; Klingberg et al., 2005; Redick et al., 2013). However, these studies were not designed or powered to evaluate moderators of WMT outcome. For example, in order to adequately evaluate the potential influence of a characteristic on WMT outcome, a study should sample individuals with a wide range of that characteristic.

The issue of individual differences in WMT efficacy is important not only for theoretical reasons but also for clinical reasons. If WMT is to be a viable treatment for conditions such as ADHD or low working memory, it must produce large improvement in individuals who have those conditions. Conversely, if individuals who show the greatest response to WMT are those that have the strongest working memory prior to treatment, the treatment value of WMT for conditions associated with poor working memory is limited. However, despite the importance of studying individual differences in response to WMT for theoretical and clinical purposes, there has been almost no systematic study of the relationship between WMT response and individual differences in the key symptoms targeted by WMT, such as low working memory capacity and the symptoms of ADHD. Clinically, this information would be helpful in matching individuals to appropriate WMT treatments for their symptoms, and theoretically, this information could enhance the understanding of specific cognitive abilities that improve with WMT.

In this study, we investigated characteristics predicting the magnitude of change in a near-transfer immediate memory span performance following WMT. Because low working memory capacity and ADHD have been two important clinical conditions evaluated in WMT efficacy studies, we focused on the individual differences in the symptoms of these conditions.

MATERIAL AND METHOD

Participants

Participants for the study were 62 children and adolescents aged 9-16 years, who were recruited from the local community and clinics using print advertisements and word-of-mouth. Two sites participated in data collection, an urban child psychiatry clinic (N=32) and a university-based psychology department (N=30). Inclusion criteria for the study were broad (age 9-16 years and able to complete the WMT exercises) in order to capture a sample with diverse functioning. Most subjects (N=46) had no prior mental health treatment or diagnosis, by parent-report; 13 subjects had a current or prior parent-reported diagnosis of Attention-Deficit/Hyperactivity Disorder (ADHD), and 3 subjects had another parent-reported diagnosis (other diagnoses in the sample were Learning Disorders, N=5; Depressive Disorders, N=2; and Anxiety Disorders, N=7; numbers add to more than 62 due to comorbidities). Of the 13 subjects with ADHD, 9 were currently taking medication for their condition. See Table 1 for additional characteristics of the study participants.

Table 1. Sample Characteristics

Variable	N	Mean	SD	Range
Age (Years)	62	13.1	2.0	9-16
Grade	62	7.9	2.0	3-12
Sex				
Male	28			
Female	34			
Race/Ethnicity				
White Non-Hispanic	56			
Black/African-American	2			
Hispanic	1			
Multiple race	3			
Rater				
Mother	55			
Father	6			
Stepmother	1			
ADHD Diagnosis				
Yes	13			
No	49			
Receiving Special Educational Services				
Yes	8			
No	54			

Procedure

Study visits. All study procedures were reviewed and approved by the university institutional review board, and the parents of participants provided informed consent prior to initiation of any study procedures. Participants were seen for three study visits. At Visit 1, participants received baseline assessments and were trained in the use of the Cogmed WMT program. Participants then completed the 5-week Cogmed WMT program at home, with weekly calls from research personnel to discuss and coach on progress in the program. Within one week of completion of the WMT program, participants returned to the sites for post-training assessments. All assessments were administered by experienced personnel supervised by doctoral-level psychologists.

Working memory training. Participants were randomly assigned within each site to one of two versions of Cogmed WMT. In the standard WMT condition (N=32), participants completed 20-25 days (the goal was 25 days, but participants were retained if they completed at least 20 days of training) of game-like, computer-based exercises over a 5 week period. Five types of verbal exercises required subjects to remember the forward serial order of letters and digits, while five types of spatial exercises involved memory for the forward serial order of locations on a grid. Eight of these 10 types of exercises were completed at home on the computer each day, for approximately 30 minutes. In the modified WMT condition (N=30), four of the 8 exercises presented each day were modified to require completion of a mental operation (basic mathematical operation for the verbal tasks or judgments of symmetry of a dot pattern for the visuospatial tasks) between the presentation of the stimulus and the subject’s response. Hence, for all 8 types of exercises presented each day, standard WMT required only memory recall without intervening processing, whereas modified WMT required completion of a mental operation between presentation and recall for half of the exercises each day (see Gibson et al. (2012) for additional information about these conditions).

For both types of WMT, an adaptive training algorithm was used in which participants were presented with memory tasks of increasing difficulty (span length and complexity) following correct completion of the items; difficulty was reduced when the items were answered incorrectly. The WMT programs were introduced and demonstrated at the first study visit, and subsequently completed by participants on their home computers via the internet. Parents were encouraged to closely monitor the child during the completion of the WMT exercises, and families received a weekly call from a coach to review progress and encourage adherence.

Measures

Short-term and working memory skills. The *Digit Span* and *Spatial Span* subtests of the Wechsler Intelligence Scale for Children, Fourth Edition – Integrated (WISC-IV-I) (Wechsler et al., 2004) require subjects to reproduce a series of spoken digits or sequential locations, respectively, in forward order or backward order. Digit Span Forward (DSF) and Spatial Span Forward (SSF) require reproduction of the stimulus elements in forward order immediately after presentation of the stimuli (without any intervening operations), whereas Digit Span Backward (DSB) and Spatial Span Backward (SSB) require that stimuli be reproduced in the reverse order of their presentation. Hence, DSF and SSF reflect short-term rote memory with fewer demands on central executive control, while DSB and SSB require concurrent mental operations (reversal) during short-term memory retention and therefore place more demands on the central executive control of concurrent cognitive processes (short-term memory and reversal of stimuli). DSF, DSB, SSF, and SSB tests have been extensively used and validated as measures of verbal short-term memory, verbal working memory, visuospatial short-term memory, and visuospatial working memory, respectively (Pickering & Gathercole, 2001; Wechsler et al., 2004).

There is not universal agreement on definitions, components, and uses of the terms “short-term memory,” “working memory,” and “immediate memory.” For the sake of parsimony, in this paper, we subsume tests of immediate memory with relatively little additional concurrent cognitive processing (e.g., digit span forward) and tests of immediate memory with more additional concurrent cognitive processing (e.g., digit span backward) under the broad umbrella of “working memory.” This is consistent with conceptualizations of working memory that include components of the memory store and the managing central executive (Baddeley, 2007; Engle, Tuholski, Laughlin, & Conway, 1999).

ADHD Rating Scale – IV. The ADHD Rating Scale-IV (DuPaul, Power, Anastopoulos, & Reid, 1998) is a parent-completed behavior checklist consisting of the

18 symptoms of Attention-Deficit/Hyperactivity Disorder (ADHD), worded for completion as a questionnaire. Parents rate each item on a 0 (never or rarely) to 3 (very often) scale of frequency. The Inattentive score of the ADHD-RS is the sum of ratings for the 9 ADHD Predominantly Inattentive Type items, and the Hyperactive-Impulsive score of the ADHD-RS is the sum of ratings for the 9 ADHD Predominantly Hyperactive-Impulsive Type items. In the present study, raw scores on the Inattentive and Hyperactive-Impulsive subscales were used as measures of parent-rated ADHD symptoms.

Statistical Approach and Analysis

Initial analyses investigated change in each WMT condition over time using a series of repeated measures 2 (baseline vs. post-training) x 2 (standard vs. modified WMT) ANOVAs, with working memory (DSF, DSB, SSF, SSB) and ADHD rating (ADHD-RS-Inattentive, ADHD-RS-Hyperactive-Impulsive) scores as the dependent variables. The subsequent (primary) study analyses consisted of a series of hierarchical regression equations predicting change (calculated by subtracting the baseline from the post-training scores) in short-term/working memory span (DSF, DSB, SSF, and SSB) scores following WMT. Predictor variables were entered in three blocks: Block 1 consisted of demographic variables (age, sex, grade, receiving special education services, repeating a grade [coded as yes/no], caregiver years of education, performance site, and type of WMT), which were entered using a stepwise method (in order to minimize the variable:subject ratio) as control variables with the retention of variables significantly predicting working memory change at a $p<0.05$ level. Block 2 consisted of pre-training working memory span (pre-training score on the working memory span change measure used in that regression equation), in order to investigate whether pre-training working memory capacity predicted change following WMT. Block 3 consisted of parent-rated pre-WMT symptoms of ADHD (baseline ADHD-RS-Inattentive and ADHD-RS-Hyperactive-Impulsive scores). This hierarchical regression analysis investigated whether change in working memory measures was predicted by pretraining working memory scores or pretraining ADHD-RS symptom scores after accounting for differences in demographic variables.

RESULTS

Change in Working Memory and ADHD Symptom Scores By Time and WMT Type

None of the interaction effects terms for time (baseline vs. post-training) x WMT type (standard vs. modified WMT) were statistically significant (all $p>0.09$; Table 2), indicating that the type of WMT was not related to a greater or lesser improvement in DSF, DSB, SSF, SSB, or ADHD-RS scores.

The main effect of the WMT type on working memory and ADHD rating scores was significant only for ADHD-RS Inattentive scores, with subjects in the modified

Table 2. Change in Working Memory and ADHD Symptom Scores by Time and Working Memory Training Type

Variable	Standard WMT		Modified WMT		Type	Time	Type x Time
	Pre	Post	Pre	Post			
ADHD-RS IN	5.6 (7.2)	3.2 (5.3)	8.9 (7.2)	6.7 (5.7)	**5.06** **(0.03)**	**15.43** **(0.001)**	0.05 (0.82)
ADHD-RS HI	3.2 (5.5)	1.7 (3.1)	4.6 (5.2)	3.2 (4.3)	1.77 (0.19)	**10.36** **(0.002)**	0.04 (0.94)
Digit Span For	10.0 (2.1)	11.6 (2.0)	10.8 (2.7)	11.6 (2.3)	0.44 (0.51)	**27.78** **(0.001)**	2.89 (0.10)
Digit Span Back	8.1 (2.2)	8.6 (2.5)	7.9 (2.3)	8.7 (2.6)	0.00 (0.98)	**7.45** **(0.008)**	0.37 (0.55)
Spatial Span For	8.3 (1.9)	10.4 (2.0)	8.6 (2.2)	10.1 (1.7)	0.00 (0.99)	**39.92** **(0.001)**	0.95 (0.33)
Spatial Span Back	7.5 (1.9)	9.5 (1.9)	7.5 (2.2)	8.9 (2.2)	0.47 (0.50)	**38.15** **(0.001)**	1.09 (0.31)

Note: Values for Standard WMT and Modified WMT are mean (standard deviation). ADHD-RS IN=ADHD Rating Scale Inattentive Raw Score; ADHD-RS HI=ADHD Rating Scale Hyperactive-Impulsive Raw Score; WMT=working memory training; For=Forward; Back=Backward; Type = WMT Type (Standard vs. Modified); Time = Score Prior to WMT (Pre) vs. Score Following WMT (Post). Values in columns with headings of Type, Time, and Type x Time are F-tests with df=(1,60); values in parentheses in those columns are p-values. Values in bold font are statistically significant (p<0.05).

WMT program scoring higher than subjects in the standard WMT program at both baseline and post-training. However, the lack of a significant time x WMT type interaction effect on ADHD-RS Inattentive scores shows that the change from the baseline to post-training in those scores was not different for the different types of WMT. Changes in working memory and ADHD rating scores from the baseline to post-treatment were significant for all measures (Table 2), indicating significant improvement in working memory and significant declines in ADHD symptoms from the baseline to post-treatment, regardless of the type of training.

Factors Related to Change in Working Memory Following WMT

None of the demographic variables were significantly related to change in the working memory measures (DSF, DSB, SSF, SSB; all p>0.05) in stepwise analyses, so demographic variables were dropped from further analyses in the regression equations. Baseline pretraining working memory span scores (Block 2), on the other hand, were consistently related to change in the span score, with lower span scores related to greater change for all span variables (Table 3). For the third block of predictor variables (baseline ADHD-RS scores), subjects with higher inattentive scores at the baseline showed less improvement in DSB, SSF, and SSB scores, whereas subjects with higher hyperactive-impulsive scores at the baseline showed greater improvement in DSB and SSF scores. The regression equations with baseline working memory span and baseline ADHD-RS scores as predictors accounted for 25% (DSB) to 52% (SSF) of the change in working memory span scores (Table 3).

Table 3. Regression Equation Predicting Change in Working Memory Span Scores after WMT

Block	Working Memory Span Change Score			
	DSF	DSB	SSF	SSB
1. (Demographics)	---[a]	---[a]	---[a]	---[a]
Age				
Sex				
Grade				
Special Education Services (Y/N)				
Repeated a Grade (Y/N)				
Caregiver Education				
Performance Site				
Type of Training (Standard WMT vs. Modified WMT)				
2. (Pretraining Span)				
Span Score	-0.55***	-0.27*	-0.66***	-0.53***
R^2	0.30***	0.07*	0.44***	0.28***
3. (Pretraining ADHD-RS Scores)				
ADHD-RS-IN	-0.23	-0.60***	-0.40**	-0.32*
ADHD-RS-HI	0.21	0.40*	0.28*	0.19
R^2	0.33***	0.25***	0.52***	0.33***

Note: Dependent variables in regression equations are Working Memory Span Change Score: Change in Digit Span Forward (DSF), Digit Span Backward (DSB), Spatial Span Forward (SSF), or Spatial Span Backward (SSB), expressed as posttraining score minus baseline (pretraining) score. Pretraining span score is for the same test used to provide the span change score (e.g., Pretraining Digit Span Forward score for the equation predicting change in Digit Span Forward scores). ADHD-RS IN=ADHD Rating Scale Inattentive Raw Score; ADHD-RS HI=ADHD Rating Scale Hyperactive-Impulsive Raw Score; WMT=working memory training; R^2 values for Block 2 are for Pretraining Span predicting span change variables; R^2 values for Block 3 are for Pretraining Span, Pretraining ADHD Rating Scale Inattentive Score, and Pretraining ADHD Rating Scale Hyperactive-Impulsive Score predicting span change variables.

[a] Demographic variables were entered using a Stepwise method; no demographic variable met criterion for entry into the regression equation.

* $p<0.05$

** $p<0.01$

*** $p<0.001$

DISCUSSION

This study is one of the first attempts to systematically examine factors predicting change in near-transfer working memory performance following WMT. Demographic variables were unrelated to change following WMT, but children with lower baseline digit or spatial spans showed more improvement on near-transfer measures of the same type of span measure following WMT. Even after accounting for this influence of pre-training span, children with fewer inattention symptoms and more hyperactivity-impulsivity symptoms showed greater improvement in working memory skills as measured by digit span backward and spatial span forward tests. The present findings are important because they provide evidence that pretraining measures related to working memory and executive functioning predict improvement following WMT. Such findings are clinically significant because they suggest the characteristics of individuals most likely to benefit from WMT. The ability to match evidence-based treatments to appropriate patients can provide both individual and systems benefits: cutting medical costs, saving time and energy, and providing the most potentially effective treatment first (Morrison & Chein, 2011).

Prior to the current study, little if any research had examined the possible relationship of working memory skills, executive functions, or ADHD symptoms with improvement in working memory training. Most investigations of WMT have examined efficacy in near-transfer WM or far-transfer executive functioning and behavior outcomes across entire samples, with less attention to potential moderators of WMT outcome. Although some results of those efficacy studies have been inconsistent, there is largely agreement that WMT produces improvement on the trained tasks and on near-transfer tasks. There is less consistent agreement on whether WMT produces far-transfer effects (Epstein & Tsal, 2010; Holmes et al., 2009; Kronenberger & Pisoni, in press; Melby-Lervåg & Hulme, 2013; Morrison & Chein, 2011; Shipstead, Redick, et al., 2012).

Much less attention has been given to factors that influence the effects of WMT. In contrast to our findings, some studies report secondary analyses suggesting that baseline WM is unrelated to WMT efficacy (Jaeggi et al., 2008; Redick et al., 2013). Other research (Klingberg et al., 2005) has found no significant effect of the ADHD subtype (Predominantly Inattentive vs. Combined) on the outcome measures of digit span or symptom ratings. However, the samples studied in those projects differed from our sample on key parameters. Specifically, we studied children with a wide range of symptoms and behaviors, ranging from some with ADHD to many with no diagnosis, whereas other studies focused on adults (Jaeggi et al., 2008; Redick et al., 2013) or on children with ADHD (Klingberg et al., 2005). It may be that the influence of ADHD symptoms and baseline WM on near-transfer WMT outcome is more evident in a child-aged sample with a broader range of functioning.

Baseline working memory skills predicted improvement on near-transfer measures of short-term and working memory. Specifically, children with lower baseline digit or spatial spans showed more improvement on near-transfer measures of the same type of span measure following WMT. This result is consistent with the near-universal finding that children who complete WMT improve on the trained tasks. Children who enter training with a poorer performance on working memory tasks have more room for improvement on those tasks and likely require less significant change in order to demonstrate such improvement. Alternatively, it is possible that results reflect regression to the mean, in which children with more extreme scores are more likely to score in the direction of the mean on a retesting, even with no intervention. Future research should address this possible effect by using randomized, placebo-controlled methods and by investigating predictors of improvement in far-transfer skills following WMT.

Baseline levels of hyperactivity-impulsivity also were related to improvement in some measures of near-transfer working memory skills following WMT, after baseline working memory skills were accounted for in regression equations. Children with more hyperactive-impulsive symptoms showed greater improvement in backward digit span and forward spatial span following WMT. This finding suggests that children with poorer executive functioning (reflected in greater levels of impulsivity and hyperactivity) are more likely to show improvement following

WMT, consistent with some prior studies reporting improvement in ADHD symptoms after WMT. It may be that the benefits of WMT for improvement in some areas of executive functioning are greatest (or most apparent) for children with poorer executive functioning (in the form of more impulsivity and hyperactivity) prior to treatment. On the other hand, families of children with more hyperactive-impulsive symptoms may have been more motivated to follow through with WMT or to implement other changes during WMT that were reflected in an improved working memory performance following WMT.

Surprisingly, attention problems were inversely related to improvement in near-transfer working memory skills following WMT: Children with more attention problems at baseline showed less improvement on measures of digit span backward, spatial span forward, and spatial span backward following WMT. This finding is in the opposite direction to our other findings, which indicated that children with poorer baseline functioning showed more post-WMT improvement. It may be that significant attention problems reduce the child's ability to focus and engage during WMT, resulting in less improvement as a result of less opportunity to learn and practice the WMT tasks. Another possibility is that the residual variance in attention problems after baseline hyperactivity-impulsivity and working memory scores accounted for in the regression equation reflects a different type of construct than attention problems in isolation. For example, this residual of attention problems (with shared variance due to hyperactivity-impulsivity and working memory removed) may reflect oppositionality, resistance, lack of motivation, or learning problems more than an executive functioning deficit per se.

Our results should be interpreted in light of certain methodological characteristics and limitations of the study. One limitation of the current study is that all participants received the intervention in an unblinded format, with no placebo control. Therefore, effort and expectancy effects could account for real or perceived improvements in parent-rated ADHD symptoms following training. For example, a placebo effect on parent-rated ADHD symptoms might occur as the result of the requirement of parents to adhere to a more structured routine in order to implement WMT. This structure could have a positive impact on the externalizing symptoms of hyperactivity and impulsivity in their children. Furthermore, expectancy effects could motivate parents to invest more time and effort in the treatment plan in anticipation of treatment gains. Although expectancy or effort effects should have less impact on performance-based tests such as the span measures used in this study (e.g., compared to parent-rated behaviors), gains in span scores could potentially reflect practice effects. It is important to remember, however, that the primary aim of this study was not to demonstrate improvement following WMT but to identify characteristics predicting near-transfer improvement in working memory skills following training. Effort, placebo effects, structure, and practice effects would be less likely to account for the relations found between predictor characteristics and near-transfer gains in working memory following training than to produce global gains on outcome measures.

Another limitation to the study is the focus on near-transfer measures of span-based memory as outcome variables. Although span measures are commonly used to evaluate short-term and working memory (Wechsler et al., 2004), they are only one specific method for measuring working memory. Other methods of measuring working memory emphasize the importance of concurrent mental operations during memory activity (Engle et al., 1999), or assess different subtypes of working memory (Gibson et al., 2013). Furthermore, our study did not investigate predictors of change in the far-transfer outcomes of WMT such as attention, concentration, and learning. The potential impact (or lack thereof) of WMT on those far-transfer outcomes is the subject of ongoing research and divergent opinions in the scientific community (Klingberg, 2010; Shipstead, Redick, et al., 2012). Future research should address relations between pre-treatment characteristics and a broader set of near-transfer and far-transfer outcome measures.

Finally, our sample was heterogeneous in terms of age, background, geographic location, and WMT characteristics (two versions of WMT were used). Because the type of WMT was unrelated to short-term memory span change, both types of WMT were combined in all study analyses. Although this method did not allow for the investigation of findings specific to each type of WMT, it provided a more robust test of the primary questions in this study by demonstrating that baseline working memory span, hyperactivity-impulsivity, and attention problems predicted memory span change in a sample that received two types of WMT. An additional source of sample heterogeneity was psychiatric diagnosis; about 21% of the sample (13/62) had a diagnosis of ADHD, whereas 5% had a different DSM diagnosis, and about 74% had no diagnosis. This reflects a far higher rate of ADHD than is present in the population (Association, 2013). The oversampling of children with ADHD, while helpful in creating variability in ADHD symptom ratings for the purpose of the statistical analyses of this paper, was likely a by-product of recruitment flyers posted around an academic health center as well as interest within the ADHD community about Cogmed and other WMT programs.

Despite these limitations, the current study adds to the growing body of evidence that WMT may produce change in some types of near-transfer outcomes, particularly for individuals with certain characteristics. Pre-training deficits in memory span, coupled with more hyperactive-impulsive symptoms and fewer attention problems may be predictors of beneficial near-transfer outcomes following WMT. Future research in the field of WMT should broaden the investigation of outcome predictors and outcome measures, particularly for far-transfer outcomes. The greatest scientific and clinical yield at this point may come from explanatory studies that go beyond basic questions about the efficacy of WMT and focus on the characteristics of WMT that enhance generalization and transfer as well as the characteristics of those who benefit from WMT.

CONCLUSIONS

For baseline memory span and hyperactivity-impulsivity symptoms, study results are consistent with a remediation or rehabilitation model in which working memory training produces more near-transfer improvement for individuals who have more baseline delay or impairment. However, the opposite relationship was found for inattention, perhaps because poor attention skills interfere with the ability to actively engage in working memory training. Clinically, this information may be useful for identifying individuals who are more likely to benefit from working memory training.

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