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Adaptive Cognitive Training Enhances Executive Control and Visuospatial and Verbal Working Memory in Beginning Readers

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Abstract

In this study we examined whether children's working memory could be enhanced by adaptive cognitive training (ACT) and whether training outcomes would relate to behavioral self-regulation, a measure of executive control (EC) and certain pre-reading outcomes (phoneme awareness and letter knowledge). Children from economically disadvantaged communities were randomly assigned to an ACT (n = 23) or a wait-list control (n = 27) group. ACT consisted of an average of 20 minutes per day of adaptive visuospatial working memory training (Cogmed-JM) for up to 25 days at the beginning of the school year. ACT significantly improved performance in near-transfer (untrained visuospatial test) and far-transfer (tests of verbal working memory and behavioral self-regulation). However, ACT had no direct effects on either measure of pre-reading skill. Our findings suggest that ACT may indirectly help children at risk for later reading problems to benefit from instruction opportunities by developing self-regulation and memory skills.

Keywords: cognitive training, working memory, executive control, self-regulation, beginning reader

Abbreviations: Adaptive Cognitive Training (ACT); Executive Control (EC); Inhibitory Control (IC); Working Memory (WM)

1. Introduction

1.1 Introduction to the Problem

Children from economically disadvantaged communities in the United States are at increased risk for academic underachievement and school failure (Buckner, Mezzacappa, & Beardslee, 2009). Economic disadvantage may be associated with specific stressors of poverty that may exert influences on cognition (Blair, 2010; Evans & Schamberg, 2009). Reasons for this may include the fact that children living in poverty show heightened rates of impairments in executive functions (EF).). This collection of top-down processes, also known as executive control (EC), includes working memory (WM), inhibitory control (IC) and cognitive flexibility (Diamond, 2013). There are reports of impairments in working memory (WM) among children (Farah *et al.*, 2006; Mezzacappa, 2004; Noble, McCandliss, & Farah, 2007; Sarsour *et al.*, 2011) living in poverty.

Given these observations, children from typically underserved, economically-disadvantaged homes may enjoy special benefits from interventions that may improve their EC skills. One such intervention is the focus of our study.

1.2 Importance of the Problem

Until recently, efforts to improve WM skills have not been successful. New technological advances that permit individuals to work continuously at their own capacity (adaptive training) show promise in developing cognitive skills and may include direct effects on WM (e.g., Klingberg *et al.*, 2005; Klingberg, Forssberg, & Westerberg, 2002). There are many products on the market which aim to improve cognitive skills in children (e.g., BrainWare Safari, Cognifit, Cogmed, Earobics, FastForWord, JungleMemory, Lumosity). Especially promising in terms of training WM are intensive cognitive training programs with game-like features using adaptive technology (Holmes, Gathercole, & Dunning, 2009; Holmes *et al*., 2010; Jaeggi *et al*., 2010; Klingberg, 2010; Klingberg, *et al*., 2005; St. Clair-Thompson, Stevens, Hunt, & Bolder, 2010), referred to as adaptive cognitive training (ACT) programs. ACT programs have been successfully used to train WM in typically developing children (Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009) as well as in young children with behavior and learning difficulties (Beck, Hanson, Puffenberger, Benninger, & Benninger, 2010; Dahlin, 2011; Holmes *et al*., 2009; Söderqvist, Nutley, Ottersen, Grill, & Klingberg, 2012). Functional (Olesen, Westerberg, & Klingberg, 2004) and biochemical (McNab *et al.*, 2009) changes associated with training of WM make this an especially promising line of investigation.

Claims about what ACT programs are actually training have proved controversial (Melby-Lerväg & Hulme, 2013). ACT programs that claim to train WM may involve training of other cognitive skills that may be important for learning, in much the same way that early musical training may transfer to other domains, such as EC (Bialystok & DePape, 2009; Moreno *et al*., 2011). In their meta-analysis, Melby-Lerväg and Hulme suggest that ACT computer programs claiming to be improving WM may involve "task-specific strategy effects", presumably making it difficult to determine whether the WM enhancements associated with ACT are due to WM. However, young children trained to reduce inhibitory demands in an EC "opposites" task performed significantly better in the same task than children trained to reduce WM demands by chunking (Diamond, Kirkham, & Amso, 2002). Thus we would indeed expect that children who might develop strategies on their own to perform demanding tasks like ACT that include IC (e.g., learning to inhibit irrelevant stimuli) would significantly improve in performance on tasks that demand EC. We do not find it surprising then that ACT programs which, by virtue of their adaptive nature, provide demanding and intensive experiences, are linked with improvements in IC in attention measures (Dowsett & Livesey, 2000; Holmes *et al.*, 2009; Thorell *et al.*, 2009). Neural pathways for attention and WM overlap considerably, suggesting that tasks which train WM would reasonably be expected to also involve training of attention-related skills, especially those involving the ability to ignore irrelevant stimuli (Gazzaley & Nobre, 2012; Ikkai & Curtis, 2011).

Inhibitory control (IC) skills arguably underlie all EFs (Barkley, 1997; Miyake *et al.*, 2000) permitting "goal directed behavior in novel situations" (Bull & Scerif, 2001, p. 288), and are closely associated with academic skills (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; NICHD Early Child Care Research Network, 2005). IC skills, like WM skills, undergo significant development during the early school years (Reck & Hund, 2011; Romine & Reynolds, 2005) and are linked with reading skills (De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Foy & Mann, 2013; Locascio, Mahone, Eason, & Cutting, 2010). In a study contrasting training of WM and IC, there was greater generalization to nontrained attention tasks in WM training than in IC training (Thorell *et al.*, 2009), suggesting that computerized ACT programs which claim to train WM, and which appear to do so, also may show benefits in EC (Thorell *et al*., 2009). Thus, we propose that challenging and demanding ACT programs may indeed give children strategic practice with EC, most easily measured in young children with behavioral self-regulation.

Our interest in behavioral self-regulation is motivated by the current view that WM is a component of the EC system (Diamond, 2013; Miyake *et al*., 2000), and that behavioral self-regulation provides another measure of that same system (McClelland *et al*., 2007b). To assess behavioral self-regulation we have used a behavioral task involving children's response to a challenging cognitive scenario. This brief behavioral task, the Head-Toes-Knees-Shoulders (HTKS) test (Ponitz, McClelland, Matthews, & Morrison, 2009), has emerged as a reliable and valid measure of behavioral EC, also known as behavioral self-regulation, namely, the ability to regulate and control thoughts and behaviors (Ponitz *et al*., 2008). The HTKS is a reliable and valid measure of behavioral self-regulation in children aged 4-6 years (McClelland *et al*., 2007a; McClelland *et al*., 2007b; Ponitz *et al*., 2008), the age group of interest in the present study. It requires children to perform the opposite of a response to oral commands, and scores are predictive of academic achievement in pre-kindergarteners and kindergarteners (Ponitz *et al*., 2008; Ponitz *et al*., 2009). Tasks which require a child to remember a currently relevant sequence and to inhibit a prepotent response (performing the sequence in the order it was given or to resist the impulse to perform the tasks as the experimenter performed them) pose special demands on young children (Diamond *et al*., 2002). Behavioral self-regulation at the transition to formal schooling has been shown to be more important in predicting final grades, school attendance and work habits than even IQ (Duckworth & Seligman, 2005). Improvement in behavioral self-regulation skills thus also constitutes a potential target for ACT. Normal development of WM skills facilitates development of self-regulation in children, which appears to be associated with changes in the hippocampus and frontal lobe (Blair & Diamond, 2008). Thus, interventions that improve WM may also be effective in improving self-regulatory behaviors in kindergarteners. To date, researchers have found transfer of training effects of ACT programs to EC in children with ADHD (Klingberg *et al*., 2005) and autism (Kouijzer, de Moor, Gerrits, Congedo, & van Schie, 2009), but to our knowledge ACT programs have not been examined for effects on behavioral self-regulation, one of our foci for outcomes in the present study.

In their recent meta-analysis, Melby-Lervåg and Hulme (2013) concluded that while it appears that ACT may transfer to skills similar to those that are trained (near-transfer), far-transfer effects appear more elusive. A hallmark of a successful cognitive training program is the transfer of improvements experienced in the program to untrained domains (Fernandez & Goldberg, 2009). 'Near-transfer effects' involve transfer of training benefits to tasks thought to directly tap the trained skills (as might occur when performance on the Corsi block tapping task improves for children who are trained on a computer task where they must use a mouse to click on targets in a visuospatial game). 'Far-transfer effects' involve transfer of benefits to untrained skills such as might occur when improvements are seen in behavioral self-regulation, classrooms behaviors, or academic skills as a result of computer training on a visuospatial game. In terms of near-transfer, it is important to validate claims of the ACT program by showing that near-transfer occurs. The program we will be using in the present study (Cogmed-JM) claims to train visuospatial WM; thus we expect to find near-transfer effects of the training to untrained visuospatial memory tasks. Our primary interest in the present study, however, is whether ACT further transfers to self-regulation, verbal WM and pre-reading skills, all of which can be regarded as far-transfer skills. The study with aims closest to ours is Dahlin (2011), which examined far-transfer of ACT on reading skills among special needs children aged 9-12 years. Using a pre-post within-subjects non-equivalent control design, Dahlin found significant effects of ACT on reading comprehension but not several other reading-related skills. No other studies to date have examined effects of cognitive training on either reading or on pre-reading skills, as is an aim of the present study.

The EC system has clear significance to learning in general (Bierman *et al.*, 2008; Davidse, de

Jong, Bus, Huibregts, & Swaab, 2011; NICHHD Early Child Care Research Network, 2003; Valiente, Lemery-Chalfant, & Swanson, 2010). Although the specific nature of the relationships between EC and WM is not yet fully understood, the EC system is clearly linked with WM, which involves maintaining and manipulating information without the presence of external cues (Baddeley, 2003), focusing attention and inhibitory control (Ponitz *et al*., 2008). Whereas it is well known that EFs are also linked specifically to reading (Adams & Snowling, 2001; Altemeier, Jones, Abbott, & Berninger, 2006; Booth, Boyle, & Kelly, 2010; Carroll, 2004; Conners, 2009; Hughes & Ensor, 2011; Sesma, Mahone, Levine, Eason, & Cutting, 2009; St. Clair-Thompson & Gathercole, 2006), relatively little is known about whether interventions aimed at improving WM and/or EF skills will also improve pre-reading skills, and addressing this fact is one of the aims of the present study.

Learning to read is a complex process that requires the coordination of many aspects of cognition, including visual perception, language skills, WM, and attention (Swanson & Beebe-Frankenberger, 2004). This coordination presumably involves an EC system responsible for focusing attention, inhibiting irrelevant responses, and shifting attention (Banich, 2009; Friedman *et al*., 2006; Miyake *et al*., 2000). Among the cognitive skills that are precursors of success in learning to read (i.e., pre-reading skills) are phoneme awareness and letter knowledge, both of which are important predictors of reading success (Adams, 1990; Cunningham, 2001; Mann & Foy, 2003). Reading interventions focused on these subskills are highly effective (Cavanaugh, Kim, Wanzek, & Vaugh, 2004; Denton, Vaughn, & Fletcher, 2003; Mody, 2003). Of particular importance to early reading success is the development of phoneme awareness (Anthony & Francis, 2005; Bus & van Ijzendoorn, 1999; Mody, 2003; Morais, 1991). The EF aspects of WM and response inhibition, which link strongly to early literacy (Bierman *et al*., 2008; NICHD Early Child Care Research Network, 2005), are all employed in making phoneme judgments (i.e., do 'cat' and 'cap' start with the same sound?) and manipulations ('cat' without the first phoneme is 'at') as well as in decoding and spelling. Thus, one benefit of improved EF skills could be improved pre-reading skills in beginning readers.

But WM itself is also directly related to reading skill. Good readers have superior WM while deficits in WM often accompany weak foundational reading skills (Gathercole, Alloway, Willis, & Adams, 2006; Mann, Liberman, & Shankweiler, 1980; St. Clair-Thompson & Gathercole, 2006). WM also presages reading ability (Liberman, Mann, Shankweiler, & Werfelman, 1982) and relates to reading comprehension (Hannon, 2012; Mann *et al*., 1980, Mann, Shankweiler & Smith, 1984) presumably because it acts as a buffer for retaining ordered strings of words as their corporate meaning is reconstituted. Furthermore, response to reading intervention is possibly mediated by WM (Howes, Bigler, Burlingame, & Lawson, 2003). The current absence of a WM training program for beginning readers that specifically trains verbal WM may have discouraged interventionists from examining ACT effects on pre-reading skills. If visuospatial WM training programs were found to also improve verbal WM, the possibility of which will be explicitly examined in this study, the efficacy of early reading interventions that include ACT might be significantly enhanced.

1.3 Hypotheses and Correspondence to Research Design

In summary, the aim of the present study is to examine the effects of ACT in a randomized between-subjects design. In order to achieve compliance by school principals, teachers and parents at the research sites, a wait-list control design, where all children would have access to the program at some point in the year, was required. The constraints of this design on the timing of assessments required that testing be conducted within 3 months of the training, which may limit our ability to detect effects of ACT on our academic measures. We will be looking at the outcomes of training on untrained aspects of cognition such as verbal memory skills, executive control, measured with behavioral self-regulation, and on phoneme awareness and letter knowledge, the primary pre-reading skills. ACT programs which explicitly aim to train verbal working memory are not yet available for children as young as the focus of the present study (kindergarten). For this reason, demonstrating transfer effects of a visuospatial WM ACT program, such as the one we employ in the present study (Cogmed-JM), to the verbal domain would be of particular importance to early reading interventionists. If ACT facilitates development not only of untrained visuospatial tasks but also of verbal WM and EC, then, using ACT, even if it is in the visuospatial rather than the verbal domain, in interventions targeting children at risk for later reading problems may help to further narrow the literacy achievement gap by facilitating the children's domain-general ability to benefit from instruction. Thus, it will be important to demonstrate that pre-reading measures are correlated with visuospatial and verbal working memory, as well as with self-regulation, as examined in our third hypothesis.

In a test of our final hypothesis, we will examine factors the predict ACT performance with an eye to identifying children who might most benefit from such training, if it appears to be effective. Prior research suggests that lower-scoring children at the beginning of training improve the most.

1.3.1 *Summary of Research Hypotheses*

We will examine the following hypotheses:

1. Adaptive cognitive training (ACT) will show near-transfer effects, improving performance in untrained visuospatial WM tasks.
2. ACT will show far-transfer effects in improving performance in verbal WM and executive control (EC) tasks.
3. Pre-reading skills (phoneme awareness and letter knowledge) will be significantly correlated with performance on visuospatial WM, verbal WM and EC tasks.
4. Lower-performing children at T1 will benefit more from ACT than children who are at lower risk for later reading problems.

2. Method

2.1 Participants

All data were collected during the kindergarten year, for two different cohorts of children, referred to as Cohorts 1 (n = 23) and 2 (n = 32). Participants (M_{age} = 62.21 months, SD = 3.50, range = 56.2 – 74.3 months) consisted of 55 kindergarten children from predominantly Hispanic and African American households who were recruited from schools with high proportions of low-income children (see Table 1). All of the children spoke English fluently; some were also fluent in Spanish according to parent-reports. Instruction was exclusively in English at all schools. Four children from the second cohort left the school prior to completion of the T2 assessments; their data are not included in this report. The final sample (n = 51; 26 girls) consisted of 23 children who received ACT (11 in Cohort 1 and 12 in Cohort 2) and 28 in the waitlist control condition (12 in Cohort 1 and 16 in Cohort 2).

The parents/caregivers of the child participants were contacted via the school/program administrator, telling parents and guardians about the purpose and procedures to be used in the study, and asking them to sign a consent form on behalf of their children if they wished to be included in the study. Informed written consent procedures by the parent/caregiver and child oral assent were consistent with the guidelines of the APA. Children were randomly assigned to a trained group (trained at the beginning of the school year, T1) or a wait-list control group (trained after T2 data collection, mid-year).

Eligibility criteria included that the children were not being considered for an Individualized Education Plan (IEP; for children with demonstrated special needs) nor did they have an IEP at the time of testing. Children with vision problems were included if the parents reported that their correction procedures were effective and that the children were using these devices (glasses) at the time of testing. Children with hearing problems according to parent report would not have been eligible for the study, had such children appeared in our sample, which they did not.

Demographic information regarding each of the following was obtained from the parents and are reported by group, and in the entire sample, in Table 1: age, gender, ethnicity, maternal and preschool education, bilingualism history, family history of reading and attention problems.

Table 1. Summary of demographic variables
(Means and Standard Deviations, and sample size) by group

Variable	ACT Group (*n* = 23)	Wait-list Control Group (*n* = 28)
Age (months)	62.40 (2.89)	61.90 (3.99)
Percent female	43.5%	57.1%
Ethnicity (% Hispanic, African-American, mixed race)	65.2%, 13.0%, 4.3%	60.7%, 17.9%, 0%
Maternal education (% not completed College)	74%	93%
Parent-reported family history of reading problems (*n*)	2	2
Parent-reported family history of attention problems (*n*)	2	0
Spanish-English bilingual (% fluent, according to parent report)	48%	39%
Child attended preschool	72.7%	75%

2.2 Cognitive Training

The JM version of Cogmed, published by Pearson Education (www.cogmed.com) was given to the children at the beginning of the school year in a series of 20-25 training sessions for 4-5 days a week after school (Cohort 1) or during school (Cohort 2). All training was supported by undergraduate student training aides who were trained according to the protocols established for the program. In each session the children completed 115 trials split across three different tasks selected from a bank of 7 visuospatial tasks. The tasks were administered according to a pre-determined (non-randomized) plan that cycled periodically through each game, so that in a 25-day period, the children played each game an equal number of times. According to Cogmed (www.cogmed.com) the training was designed to adapt so as to keep the user training at WM capacity, and the number of trials was designed to dynamically adapt so as to keep the user training for at least 15 minutes each day (on average, we observed that children trained for 20 minutes each day). The tasks all consisted of animated animal or animal-like figures represented in a various settings (e.g., swimming in a pool, riding on a rollercoaster, riding in bumper cars). Starting with two figures, some of the figures made a sound and changed color during a short time period. It was the children's task to indicate their recall of which figures had changed color and in what sequence by clicking on the figures in the right sequence on the screen.

With three exceptions (all girls), all the trained children completed a minimum of 60 tasks during the 25 day period, which, given 3 tasks per day, on average, results in an equivalent minimum of 20 days of training, following the stipulated training criteria. Thus all but three children were compliant with Cogmed protocol. The children who failed to achieve criterion each completed at least 45 tasks within the 25 days of training. Failure to achieve criterion for these children was due to missed school days and motivational factors during training. Separate analyses were conducted with and without the inclusion of data from these noncompliant children. No differences were noted in any of the results for the samples including or excluding noncompliant trainers, although there were significant correlations between training days and some outcome measures, as will be reported in the results section.

All training was performed on the school premises using PC computers in the school's computer lab or in a designated room using laptops. Coaches were trained-undergraduate students responsible for no more than 2 children during a session. Training sessions, including pause times, lasted about 30-40 minutes per day. Motivational features in the program included a distinct audible cue for incorrect responses, positive visual feedback (acquisition of a starfish which is added to a visual array at the bottom of the screen) for correct responses, and a meter located on the left-side of the training screen which "fills" up as training levels improve, trial by trial. At the end of each session, sea creatures are added to an aquarium. In addition, the trainers provided positive verbal feedback during the training sessions and encouraged the children to take breaks if there were more than 3 errors in a row, as recommend by Cogmed. Finally, each successful game completion was rewarded with a happy face placed on a reward calendar for the day. Successful completion of 3 or more tasks in each session earned the children a sticker. Four successful training days in one week resulted in the child being able to select a small toy from a treasure chest.

2.2.1 *Cognitive Training Measures*

Indicators of cognitive training were obtained with

(1) Start Index: average performance based on results from days 2 and 3 of training.

(2) Max Index: average performance based on the two best days during the training period.

(3) Index improvement (CI): difference between the maximum and start indices.

(4) Training intensity: number of tasks completed within 25 days divided by 3 (equivalent to number of training days).

2.3 Materials

2.3.1 *Working Memory Measures*

2.3.1.1 *Visuospatial Working Memory*

The Corsi Block-Tapping test was used to examine near-transfer to nontrained visuospatial memory skills. In this task, the child is asked to point to blocks, which are fixed in a random array on a board placed in front of the child in the same order as the examiner (forward) and in the opposite order as the examiner (backward). Arrays start at two items, with a maximum of nine in the span for the forwards task, and 6 in the backwards task, and increase in complexity by one item at a time. The child is given at least two opportunities to complete each span protocol for the 'Tools of the Mind Kit'. Results are scored in terms of the highest span children are able to complete on each task, according to the (https://my.vanderbilt.edu/toolsofthemindevaluation/files/2012/01/Corsi.pdf). The composite score (Visuospatial WM) consists of summed z scores for the forwards and backwards subtests. This task is reliable and valid (Farrell Pagulayan, Busch, Medina, Bartok, & Krikorian, 2006) and due to constraints beyond the control of the researchers, was used in Cohort 2 only, at both times T1 and T2.

2.3.1.2 *Verbal Working Memory*

The digit span subtest of the Wechsler Intelligence Scale for Children (Wechsler, 1992) was used to assess verbal memory at T1 and T2 (far-transfer). In this standardized, reliable and valid test, the examiner says single digits at the rate of one per second, and asks the participants to repeat them forwards (Digits-F) and backwards (Digits-B). Digits-B is considered a reliable measure of WM and reliably predicts reading performance (Gathercole & Pickering, 2001). The composite score (Verbal WM) consisted of summed z-scores for the forwards and backwards subtests.

2.3.2 *Emergent Reading Measures*

Several tests were used to measure emergent reading skills at the two different testing times (beginning and middle of the year: T1 and T2, respectively). The tests given at each testing time, and how composite scores were derived, are described in detail below and are summarized in Table 2. Composite scores were derived by converting raw scores to z-scores, and summing the z-scores.

Table 2. Summary of composite measures at T1 and T2 (summed z-scores)

	Measure				
Assessment	Letter Knowledge	Phoneme Awareness	Reading	Verbal Memory	Visuospatial Memory
T1	DibelsNext-LNF	DibelsNext-FSF + Rosner/Elision	WJ-Words + Nonwords	DF + DB + Non-word Repetition	Corsi-F + Corsi-B
T2	DibelsNext-LNF + DibelsNext-CLS	DibelsNext-FSF + DibelsNext-PSF + Elision	WJ-Words + WJ-Nonwords	DF + DB + Non-word Repetition	Corsi-F + Corsi-B

2.3.2.1 *Letter Knowledge*

Scores on the Letter Naming Fluency (LNF) subtest of the Dynamic Indicators of Basic Early Literacy Skills (DIBELSNext) assessment tool (University of Oregon, Center on Teaching and Learning, 2012) served as a measure of letter knowledge at each testing period. Alternate-form reliability is .86 (http://www.soprislearning.com/docs/librariesprovider3/assessment-files/technical_adequacy_report.pdf).

In the LNF task the children are asked to name letters arranged in random sequence; the number correctly identified in one minute yields the score. Children were not penalized for articulation errors on this task. Due to floor effects, DIBELSNext protocols recommend against assessing letter sound knowledge at T1. So, at T2 only, the DIBELSNext Nonword Fluency subtest, which measures the children's ability to provide letter sounds for letters arranged in random sequences within one minute, was also included in the composite Letter Knowledge score (summed *z*-scores).

2.3.2.2 *Phoneme Awareness*

As summarized in Table 2, phoneme awareness skills were measured with the First Sounds Fluency (FSF) subtest of the DIBELSNext test (alternate forms reliability = .82; http://www.soprislearning.com/docs/librariesprovider3/assessment-files/technical_adequacy_report.pdf) and the Rosner (Cohort 1) or CTOPP Elision test (Cohort 2) at T1. At T2, Phoneme awareness was measured with the DIBELSNext Phoneme Segmenting (PSF) task (DIBELSNext also recommends that this task only be administered at T2, given the likely floor effects at T1), and the CTOPP Elision subtest (Wagner, Torgesen, & Rashotte, 1999). In the FSF task, children are asked to provide the first sounds they hear in familiar words spoken to them by the examiner. The score reflects the number of sounds correctly identified in one minute. In both the Rosner and the CTOPP Elision test the children are asked to remove syllables, singleton phonemes (e.g. syllable onsets), and phoneme in blends from familiar words by making a verbal response as to what a word would sound like if they removed one of these units from the word. In these tasks, each item is scored as correct or incorrect in relation to its target using specified guidelines. The children's responses were transcribed and digitally recorded for later off-line analysis. Complete (100%) agreement between transcriptions and off-line analyses was noted on a subset of samples (*n* = 10). In the DIBELSNext Phoneme Segmenting Fluency (PSF) task (Compton, 2006; Kaminski & Good III, 1996) the child is asked to identify the phonemes in target words within one minute. Alternate-forms reliability = .44 (http://www.soprislearning.com/docs/librariesprovider3/assessment-files/technical_adequacy_report.pdf). Composite scores for Phoneme Awareness for each testing time, T1 and T2 were computed by summing the Z-scores for the tests as follows: T1 = FSF + Rosner/CTOPP Elision and T2 = FSF + PSF + CTOPP Elision, as shown in Table 2.

2.3.3 *Executive Control Measure*

2.3.3.1 *Behavioral Self-Regulation*

The executive control measure, also used as a measure of far-transfer, consisted of the Head-Toes-Knees-Shoulders test (Ponitz *et al*., 2008; Ponitz *et al*., 2009), a reliable and valid measure of executive control (behavioral self-regulation) in children aged 4-6 years (McClelland *et al*., 2007a; McClelland *et al*., 2007b; Ponitz *et al*., 2008). Due to time constraints beyond the control of the researchers, it was administered at T2 only for Cohort 1, and at T1 and T2 for Cohort 2. The HTKS consists of a structured observation involving four behavioral rules involving touching four body parts (head, toes, should, knees), and requiring children to perform the opposite of a response to four different oral commands. If children pass the head/toes part of the task, they complete advanced trials where the knees and shoulders commands are added. The HTKS task was conceptualized as a measure of IC (a child must inhibit the dominant response of imitating the examiner), WM (a child must remember the rules of the task) and attention focusing (the child must focus attention to the directions being presented by the examiner). The HTKS has been shown to be predictive of academic achievement in prekindergarteners and kindergarteners (McClelland *et al*., 2007a; McClelland *et al*., 2007b). Examiners were trained according to a video and written protocol developed by the authors of the HTKS. The scores on each of the 3 subtests at T2 were summed to create a composite measure of Executive Control. Parallel forms (A and B) of the HTKS were administered at the two testing times.

2.3.4 *Control Measures*

2.3.4.1 *Age*

Age was measured as the child's age in months on the first day of testing at the beginning of the kindergarten year.

2.3.4.2 *Expressive Vocabulary*

Children were tested using the Expressive One Word Picture Vocabulary Test (EOWPVT; Brownell, 2001). Split-half reliability ranges from .84 (KR) at age 2 to .92 at age 9, with a median reliability coefficient of .90. The concurrent validity measures range yielded low to moderate correlations (ranging from .19 to .59).

2.4 Procedure

Children were randomly assigned to the trained or wait-list groups. At T1 and T2, all examiners were blind as to whether the children were in the treated or the control group. All the children completed two sessions of assessments within the same time intervals: (1) T1: baseline at the beginning of the school year and (2) T2: post-training, 3 months later. Testing at both times period was conducted individually in a quiet room in two sessions at each time period lasting about 20-30 mins each. The tests were administered in random order. The waitlist control children received training mid-year, after the assessments had been completed.

In order to examine the effects of ACT, a randomized between-subjects design was used. Multivariate analysis of variance was used to evaluate training effects on visuospatial WM (near-transfer), verbal WM (far-transfer), emergent literacy (letter knowledge and phoneme awareness), and executive control (behavioral self-regulation). Cohen's *d*, partial eta squared (and eta squared) were used to calculate effect size. In addition, we conducted correlation analyses (Pearson) to examine how WM, emergent literacy and executive control were associated. Multiple regression analyses were used to examine independence of contributions of WM and executive control to emergent literacy skills.

3. Results

3.1 Overview of Data Analysis

Before analysis, the data were examined for missing values, fit between their distributions, and the assumptions of multivariate analysis (Tabachnick & Fidell, 2001). Using a range of -1 to 1 as cutoffs for both skewness and kurtosis, a stringent test for the skew and kurtosis indices, according to Kline (1998), we found that none of the measures were abnormally distributed. All statistical analyses were two-tailed with alpha set to .05. One-way multivariate analyses of variance were conducted to evaluate baseline and training effects. A-priori tests using *t*-tests were conducted following significant MANOVAs. Partial eta squared (η_p^2) (and eta squared: η^2) were used for calculating effect sizes for the MANOVAs, and Cohen's *d* was used as an estimate of effect size forthe individual *t*-tests. For the *t*-tests, degrees of freedom were adjusted when violations of the assumption of heterogeneity of variance were revealed by significant Levene's tests for Equality of Variances. Furthermore, we conducted Pearson correlation analyses to examine relationships between variables. Regression analyses were used to examine whether contributions of variables to reading-related measures were dependent or independent of major predictor variables.

3.2 Compliance

For Cohorts 1 and 2, 82% and 92% of the participants respectively completed at least 20 sessions, the minimum according to Cogmed protocols. By comparison, 80% of children in experimental trials (Bennett, Holmes, & Buckley, 2013; Holmes *et al*., 2009) and 91% in a school-based setting achieved baseline (Holmes & Gathercole, 2013). The Cogmed Improvement (CI) Indices were 18.64 and 20.92 respectively for Cohorts 1 and 2 ($p > .05$). An average CI of 24 has been reported for the RM version of Cogmed (Bennett *et al*., 2013; Holmes & Gathercole, 2013; Holmes *et al*., 2009; Holmes *et al*., 2010). There was no significant difference for the Cogmed Indices for the two cohorts (i.e., Cohorts 1 and 2) thus the scores for Cohorts 1 and 2 were combined. A paired-samples *t*-test showed that Improvement, as measured by the difference between the Start and Max Indices, was statistically different, $t(22) = 13.38$, $p = .0001$, $d = 2.49$

There were statistically significant correlations between number of completed training days and performance on various outcome measures as will be described below, as well as significant differences on the CI for non-compliant ($M = 14.67$, $SD = 2.52$) and training-compliant ($M = 20.6$, $SD = 7.27$) children, $t(8.71) = 2.72$, $p = .024$, $d = 1.09$, although their Start ($M = 44.33$, $SD = 1.53$ vs. $M = 44.5$, $SD = 7.29$, respectively) and Max Indices ($M = 59.00$, $SD = 3.46$ vs. $M = 65.05$, $SD =$ 6.53) did not different significantly ($p > .05$, *d*s = .03 and 1.16 respectively). Thus all analyses were conducted using data from the entire sample and then rerun again excluding the data from the noncompliant children ($n = 3$). Where differences were obtained with their data removed these additional analyses were then also reported.

3.3 Baseline Analyses

Before examining the effects of training at T2, we first examined whether there were differences between the groups prior to training, at baseline (T1). A multivariate ANOVA including the major variables prior to training in this study (Visuospatial and Verbal Memory, Phoneme Awareness, Letter Knowledge, and Executive Control), as well as age and vocabulary (e.g. our control measures), revealed no significant group differences, *F*s(1, 43) < 2.50, *MSE*s = 2.98, 3.02, .23, 1.29, and 331.75, respectively, $p > .05$. Table 3 shows the performance for the ACT group and the Waitlist Control groups before training, as well as the results of the individual *t*-tests conducted on each measure.

Table 3. Means and standard deviations for major variables at T1 (Prior to training)

Measure	ACT Group	Waitlist Control	Range	*t*	*p*	*Effect size (d)*
Age	62.40 (2.89)	61.90 (4.05)	56.3-67.9	.44	.66	.14
Vocabulary	43.73 (11.21)	36.00 (12.74)	22-67	1.54	.14	.64
Phoneme Awareness measures						
DIBELSNext FSF	5.13 (6.93)	3.79 (6.95)	0-32	.69	.49	.19
Rosner (Year 1 only)	6.00 (4.92)	4.42 (3.96)	0-15	.85	.40	.35
Elision (Year 2 only)	1.67 (3.08)	1.94 (3.91)	0-13	.20	.84	.08
Letter Knowledge						
DIBELSNext LNF	16.22 (14.88)	20.54 (14.50)	0-47	1.05	.30	.29
Verbal memory measures						
Digits						
Forward	5.61 (2.82)	4.29 (2.45)	0-9	1.79	.08	.50
Back	1.00 (1.31)	.68 (1.22)	0-12	.91	.37	.25
Nonword repetition	7.04 (2.85)	6.08 (1.98)	2-8	1.04	.31	.39
Visuospatial Memory Measures						
Corsi-Blocks (Year 2 only)						
Forward	4.00 (.95)	3.87 (.89)	0-15	.36	.72	.14
Backward	2.68 (1.15)	2.50 (1.10)	1-14	.39	.70	.16
Self-Regulation (Year 2 only)						
HTKS Total	37.17 (16.72)	28.81 (20.29)	0-58	1.19	.26	.45

3.4 Adaptive Cognitive Training Effects

A multivariate analysis of variance including the major variables in this study (Visuospatial and Verbal Memory, Phoneme Awareness, Letter Knowledge, and Executive Control) revealed an overall significant effect of ACT, $F(1, 29) = 2.78$, $p = .042$, MSEs = 2.03, 3.30, 7.88, 318.75, respectively , $\eta_p^2 = .38$ ($\eta^2 = .34$, .23, .07, and .19, respectively). In order to further examine which of these variables showed significant effects at T2 we conducted *t*-tests on the composite scores. Composite score analyses revealed significantly higher scores for trained than for untrained children in Visuospatial WM, $t(27) = 3.72$, $p = .001$, $d = 1.44$,[1] Verbal WM, $t(50) = 2.71$, $p = .009$, $d = .74$, and Executive Control, $t(50) = 3.34$, $p = .002$, $d = .95$. Results for the individual test scores are summarized in Table 4. There were no statistically significant effects of training on the emergent literacy measures.

Table 4. Means and standard deviations for major variables at T2 (3 months after training)

Measure	ACT Group	Waitlist Control	Range	*t*	*p*	*Effect size (d)*
Phoneme Awareness measures						
DIBELSNext FSF	35.74 (13.58)	29.44 (10.98)	12-60	1.82	.08	.51
DIBELSNext PSF	36.64 (18.61)	35.93 (25.38)	0-78	.12	.91	.03
CTOPP Elision	5.00 (3.07)	4.18 (3.47)	0-13	.87	.39	.25
Letter Knowledge Measures						
DIBELSNext-LNF	42.86 (13.29)	40.29 (17.14)	10-83	.58	.56	.17
DIBELSNext-CLS	21.18 (14.86)	21.75 (12.96)	0-134	.11	.92	.04
Verbal memory measures						
Digits						
Forward	7.04 (2.55)	5.96 (1.82)	3-12	1.75	.09	.49
Back	2.05 (1.17)	1.29 (1.22)	0-6	2.23	.03	.64
Nonword repetition	10.41 (3.58)	9.68 (2.99)	0-16	.79	.44	.22
Visuospatial Memory Measures (span)						
Corsi-Blocks (Year 2 only)						
Forward	4.64 (.50)	3.93 (.80)	4-16	2.56	.017	1.06
Backward	3.18 (1.17)	2.47 (1.19)	0-10	1.53	.14	.60
Self-Regulation						
HTKS-Total	42.90 (11.97)	29.04 (17.68)	0-56	3.34	.002	.95

3.5 Correlations between Major Variables

For this analysis, we used Pearson correlations to examine the relationships between our major measures at T1 and T2: Visuospatial WM, Verbal WM, Phoneme Awareness, Letter Knowledge, and Executive Control. The results are summarized in Table 5. At T1, results were unchanged in terms of significant results and direction of relationships when age and vocabulary were controlled. At T2, as shown in Table 5, when age was controlled, significant results and direction were

[1] Note that Visuospatial Memory was only included in the test battery at T1 and at T2 in Cohort 2 and Executive Control was only included at T1 in Cohort 2, hence the lower df associated with the analyses involving Visuospatial Memory at T1 and T2, and for Executive Control at T1.

unchanged. However, when vocabulary was controlled, at T2 neither of the WM or Executive Control measures was significantly correlated with either of the academic measures.

Table 5. Zero-order Pearson (r) and partial Pearson correlations (age and vocabulary controlled) between working memory (WM) and executive control, and academic measures before and after training

	Visuospatial WM	Verbal WM	Executive Control
T1 (Before Training)			
Letter Knowledge	.50**	.56**	.52**
Age controlled	.58**	.67***	.58**
Vocabulary controlled	.35*	.46*	.31*
Phoneme Awareness	.57**	.38**	.59**
Age controlled	.62**	.63**	.58**
Vocabulary controlled	.54**	.67***	.37*
T2 (After Training)			
Letter Knowledge	.22	.32*	.32*
Age controlled	.24	.38*	.39*
Vocabulary controlled	.08	.26	.25
Phoneme Awareness	.53**	.55***	.58***
Age controlled	.53**	.59***	.69***
Vocabulary controlled	.28	.42*	.51**

*: $p < .05$. **: $p < .01$. ***: $p <.001$

3.5.1 *T1 Intercorrelations between Major Variables.*

As shown in Table 5, at T1, Visuospatial WM was significantly correlated with Verbal WM, $r(28) = .65$, $p = .0001$, and Executive Control, $r(28) = .54$, $p = .003$ and Verbal Memory was also significantly correlated with Executive Control, $r(28) = .74$, $p = .0001$. Both Letter knowledge and Phoneme Awareness were significantly correlated with Visuospatial $r(28) = .50$, $p = .006$, and $r(28) = .57$, $p = .002$, respectively, and Verbal WM, $r(51) = .56$, $p = .\ 0001$, and $r(51) = .38$, $p = .006$, respectively as well as with Executive Control, $r(28) = .52$, $p = .004$, and $r(28) = .59$, $p = .001$, respectively. A multiple regression analysis revealed that at T1, none of the major variables (Visuospatial WM, Verbal WM and Executive Control) was an independent predictor (βs < .28, $p > .05$) of Letter Knowledge, $R^2 = .37$, $p = .01$. The major variables also were not independent predictors (βs < .34, $p > .05$) of Phoneme Awareness at T1, ($R^2 = .51$, $p = .001$).

3.5.2 *T2 Intercorrelations between Major Variables.*

As shown also in Table 5, the major variables (Visuospatial WM, Verbal WM and Executive Control) were also significantly intercorrelated at T2, as they had been at T1: Visuospatial WM correlated significantly with Verbal WM, $r(27) = .56$, $p = .002$, and with Executive Control, $r(27) = .50$, $p = .008$. Verbal WM also correlated significantly with Executive Control, $r(52) = .57$, $p =$

.0001.

We were especially interested in how the measures that had showed significant effects of ACT (Visuospatial and Verbal WM, and Executive Control) would associate with reading-related skills (Phoneme Awareness and Letter Knowledge) after training, given that each of these major predictor variables had been significantly correlated with early reading skills prior to training at T1, as we reported above. By mid-year in kindergarten, according to DIBELSNext, children are expected to have had specific instruction in letter sounds, and not only have they gained awareness of phonemes, but they should also have had some instruction in phoneme sequencing. Thus, at T2, shown in Table 2, Letter Knowledge and Phoneme Awareness were measured with different subtests than they had been measured at T1, reflecting developmentally appropriate expectations for early reading subskills at the beginning compared to the middle of the kindergarten year. At T2, Visuospatial WM, which was correlated with Executive Control and Verbal WM, also associated with Phoneme Awareness, $r(50) = .56$, $p = .002$, but not with Letter Knowledge, $r(27) = .22$, $p = .27$. In addition to being correlated with Executive Control and Visuospatial WM as reported above, Verbal WM was also significantly correlated with Letter Knowledge, $r(50) = .32$, $p = .023$ and with Phoneme Awareness, $r(50) = .55$, $p = .0001$. In addition to being associated with Visuospatial and Verbal WM, as we reported above, Executive Control was also significantly correlated with Letter Knowledge, $r(50) = .32$, $p = .026$. Phoneme Awareness, $r(50) = .58$, $p = .0001$.

In order to examine how WM (visuospatial and verbal) and executive control contributed to the significant relationships with phoneme awareness and letter knowledge, we conducted regression analyses. Executive Control and Verbal Memory contributed to Letter Knowledge, $R^2 = .183$, $p = .007$, but only Verbal WM emerged as a significant independent predictor of Letter Knowledge, $\beta = .32$, $p = .05$ (Executive Control: $\beta = .16$, *ns*). The Regression analysis including Executive Control, Verbal WM and Visuospatial WM as predictors of Phoneme Awareness ($R^2 = .54$, $p = .0001$), revealed that only Executive Control was an independent predictor of Phoneme Awareness, $\beta = .441$, $p = .018$ (Verbal Memory $\beta = .24$, *ns*, and Visuospatial Memory $\beta = .18$, *ns*).

3.5.3 *T1 Predictors of ACT performance.*

The ACT Improvement Index was significantly negatively correlated with the Start Index, $r(35) = -.58$, $p = .0001$, which was positively correlated with vocabulary, $r = .28$, $p = .049$. These correlations showed that children performing at the lowest levels at the beginning of training tended to be children with the lowest vocabularies, and that they improved the most during training. The consequence of this would be to make the lowest-performers act more like the higher performers; pushing all of the children towards the same levels of performance could explain some of the reduced significance of the correlations and regressions at T2 in Table 5, though not the increased association between EC on phoneme awareness.

4. Discussion

In this study we examined whether ACT in the visuospatial domain, using an evidence-based ACT program, would improve performance on near-transfer visuospatial tasks and also such far-transfer tasks as verbal WM, executive control and pre-reading skills. First it was important to examine whether this training would generalize to tasks in the same domain (near-transfer) as the training. It is vital in studies of ACT that near-transfer be established before any possible far-transfer effects can be interpreted (Melby-Lervåg & Hulme, 2013). We found that ACT substantially improved visuospatial WM in untrained tasks and the effect size was very large ($d = 1.44$), comparable to the effect size for transfer to untrained visuospatial tasks in a prior study (effect size = .95) with older children (Holmes & Gathercole, 2013).

Next, in the first of several explorations of far-transfer effects, we found that ACT resulted in significant improvements in verbal WM compared to the untrained group, with a more moderate effect size (d = .75), identical to the effect size reported by Holmes and her colleagues in their recent study with older children for transfer to verbal WM (Holmes & Gathercole, 2013). This finding adds to the literature that WM may involve some domain-general aspects, possibly involving controlled attention or executive attention mechanisms (Chein, Moore, & Conway, 2011). Thus, training one aspect of working memory (e.g., visuospatial) may either generalize to other aspects (e.g., verbal) due to improved EF skills or such training may tap a domain-general aspect of WM. Also consistent with the notion of domain-general aspects is our finding that visuospatial WM correlated with phoneme awareness and letter knowledge at T1. During the late kindergarten and first grade period, when stronger demands are made of decoding abilities, verbal WM skills gain in predictive strength for reading ability relative to visuospatial skills (Mann & Liberman, 1984). The younger age of our participants, none of whom were able to decode any words or nonwords at T1, and the use of pre-reading skills rather than actual decoding skills may be responsible for this divergence.

An additional test of far-transfer was a test of self-regulation, and here we again found that ACT significantly improved EC skills, as measured by self-regulation behaviors on the HTKS. Indeed, the effect size was quite large (d = .95). This finding is consistent with several other studies showing that cognitively demanding training improves EC (for review see Diamond & Lee, 2011). However, it is the first to examine, and to show that ACT that was aimed at improving WM also improves children's ability to self-regulate in an untrained task. This finding also confirms the informal observations of our coaches that the children became increasingly tolerant of inevitable errors and error-related feedback during the course of the training. Errors in an ACT program are inevitable because the training is adapted to the child's current level of performance. At the beginning of training, most of the children were visibly and audibly bothered by errors/error feedback. Such behaviors included crying and aggressive outbursts for some children. By the end of training, these behaviors had either diminished in frequency or intensity, or had disappeared, not because the tasks had become easier, but rather in spite of the tasks becoming harder. Thus, our impression is that the ACT program used here (Cogmed-JM), in addition to training WM, also provides extensive experience in EC, as reflected in the significantly higher self-regulation skills in the trained children. Perhaps, too, as Zelazo and colleagues ((Zelazo, Reznick, & Pinon, 1995) have suggested, intrinsic motivation or sensitivity to social demands may have increased during the course of the training, both of which would conceivably be associated with improved performance on the EC task. Holmes and colleagues also observed that increased self-awareness and compensatory strategy use may have accounted for improvements in cognitive skills during the training they used (Holmes *et al*., 2009). Our observations about EC during the course of the training, combined with the empirical finding that ACT improved EC, do not diminish our finding that ACT improves WM. Improved EC or intrinsic motivation may have enhanced tolerance for error-making and or/dealing with error-feedback, or it may have increased sensitivity to social rewards or use of compensatory strategies. This, when combined with improved WM capacity, may help children to develop strong pre-reading skills, the primary academic objective of this early intervention effort, and ultimately help them to learn to read successfully. Demands placed on WM, such as occurs during ACT, however, may be especially important for developing WM and generalizing to far-transfer tasks, as Conway and Getz have suggested (Conway & Getz, 2010).

ACT programs are not the only way to provide children with extensive EC experience (Diamond & Lee, 2011). Preschool programs incorporating training of self-regulatory skills into the curricula are associated with improvements in attentive behaviors and in early academic skills (Barnett *et al*., 2008; Diamond, Barnett, Thomas, & Munro, 2007). Repeated exposure to tasks that could improve IC (like go-no-go tasks) have been shown to improve performance, even in 3-year olds (Dowsett & Livesey, 2000). Even teacher-led games (like the Good Behavior Game) that reinforce attentive behaviors and that are built into learning activities lead to improvement in attentional behaviors (Dion *et al*., 2011). Future research should aim to both understand cognitive and psychosocial factors related to EC and also to determine whether or how these factors are affected by different types of EC experiences.

Most studies of EF skills (specifically WM and IC) show that these are important predictors, in preschool, of later academic performance in early reading and math (McClelland *et al*., 2007b; Welsh, Nix, Blair, Bierman, & Nelson, 2010). Our failure to find direct effects of ACT on pre-reading skills three months after training adds to the literature suggesting that direct effects of ACT on academics may take some time (more than 3 months) (Holmes *et al*., 2009), to become apparent, if there are such effects. For example, effects of WM improvements from ACT were only found for math skills when testing was done six months after training in 10 year olds with low WM (Holmes *et al*., 2009). Recently, Holmes and her colleagues (Holmes & Gathercole, 2013) found significant effects of ACT using Cogmed-RM over the course of the academic year for speaking, listening, reading and writing skills in 8 to 9 year-old children, and for low-achieving children in math. ACT may "benefit the ability to learn", as Holmes and Gathercole (2013) have concluded, but within the three-month period of time our study fails to find that these effects are yet reflected in enhanced academic skills. Further research is warranted in order to determine how long after training direct academic benefits of ACT are observed, if they are found, which we would expect, and what factors might enhance this process. Our study suggests that testing for academic effects of an ACT include assessment at least 6 months later.

Our zero-order correlation and regression analyses showed that WM and behavioral self-regulation skills (EC) were closely related both before (T1) and after training (T2) and that these skills are correlated with pre-reading skills. Of special importance, we believe, is the finding that phoneme awareness was independently linked with self-regulation. This finding now adds to the growing body of literature showing that phoneme awareness in young children is associated with EC abilities (Matthews, Ponitz, & Morrison, 2009) and specifically with IC (Blair & Razza, 2007; Foy & Mann, 2013). WM and IC skills may have distinct and separate roles in early reading acquisition, with WM having an independent effect on letter knowledge and IC having an independent effect on phoneme awareness. Our findings are consistent with the suggested role of WM in EC (Best & Miller, 2010; St. Clair-Thompson & Gathercole, 2006), as well as the interrelatedness of different types of WM measured in different domains.

Finally we found that children with the lowest scores on the visuospatial ACT game at the beginning of training improved the most with training, a finding which has been previously noted with programs targeting WM (Dahlin, 2011; Holmes & Gathercole, 2013), EF interventions (Diamond & Lee, 2011), with school-wide interventions (O'Shaugnessy, Lane, Gresham, & Beebe-Frankenberger, 2003) and with go-no-go tasks (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). In contrast, such findings have not been found among children with intellectual disabilities (Söderqvist *et al*., 2012), suggesting that the gains seen in low-scoring normal children are more than simply the result of a regression to the mean, else the same result should have obtained in the intellectually disabled children. We suggest that there may be a minimal level of memory ability required for training in order to maximize improvements with ACT and that those with intellectual disabilities may not possess this level of skill. Our study also found that children with the lowest English vocabulary scores improved the most in the ACT tasks. Furthermore, our partial correlation analyses showed that vocabulary was a significant factor in the relationships between the academic measures and our WM and EC measures at T2, but not T1. This suggests that abilities that affect improvement in the ACT tasks become more important as the kindergarten year progresses, and that one predictor of which children might benefit most from ACT would be those children who enter kindergarten with low oral language skills, as measured by vocabulary in the language of instruction (English, in this case).

4.1 Limitations

Our use of a passive control (waitlist) design, while required by the schools involved in the study, was not ideal for ruling out placebo effects of ACT. The use of testers who were blind to the children's group was thus a critical but not sufficient control aspect of the study. As more age-appropriate ACT programs become available, as they surely will in the coming years, a design with random assignment to equally effective ACT programs varying in theoretically and practically important ways (e.g., visuospatial vs. verbal memory training) will be practically and ethically reasonable.

4.2 Conclusions

Our findings add to the literature showing that ACT transfers to both trained and nontrained domains, specifically in terms of a near-transfer task due to practice on the training items (visuospatial) as well as in far-transfer tasks to verbal working memory and executive control. To our knowledge, our study of ACT in young children is the first study to show the direct effects of such training on executive function skills. It is also the first to separately explore the effects of ACT on the two most important prerequisite skills for reading acquisition, namely verbal working memory and the emergent reading skills of phoneme awareness and letter knowledge. Though there was a direct effect on working memory, there were no direct effects of ACT on the two emergent measures within the 3-month span from training to testing, consistent with other studies of ACT effects on academics prior to 6 months after training. Apparently the effects of ACT may take time to reach fruition. In light of this lack of an immediate effect on emergent reading but an effect on other skills that presage reading ability, we propose that ACT programs may act indirectly to improve chances for children from economically disadvantaged communities to benefit from early reading instruction. Rather than acting directly on literacy skills, our study appears to show that ACT's effects accrue over time and are most likely mediated through effects on working memory as well as through executive control. Both of these skills were profited by ACT and both are both highly correlated with pre-reading performance by mid-year in the kindergarten year. Future research should explore direct effects of ACT on pre-reading academic measures using a design well suited to detect such effects (i.e., longer than 3 months after training).

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