School Mental Health
DOI 10.1007/s12310-010-9030-9

ORIGINAL PAPER

Working Memory Training for Children with Attention Problems or Hyperactivity: A School-Based Pilot Study

Enrico Mezzacappa · John C. Buckner

Abstract We piloted a computer program to train working memory for children with attention problems or hyperactivity who attended an urban public school serving economically disadvantaged neighborhoods. Training was conducted daily for 5 weeks during school hours. Teachers rated children's behaviors before and after the intervention, and standardized assessments of verbal and visuo-spatial working memory were also conducted. No attrition occurred due to an inability or unwillingness on the part of children to complete the training. Overall, children's behavior and working memory improved following training, compared to baseline. Our findings suggest that school-based working memory training may be a viable means for treating children with attention problems or hyperactivity that warrants further investigation. This approach may also overcome barriers to care delivery for economically disadvantaged children who are known to be at higher risk for poor school outcomes.

Keywords ADHD · Attention problems · Computer-assisted learning · Hyperactivity · School-based interventions · Working memory training

Parts of this paper were presented in a poster at the annual meeting of the American Academy of Child and Adolescent Psychiatry, October 23–28, 2007, Boston, MA.

E. Mezzacappa (✉) · J. C. Buckner
Department of Psychiatry, Children's Hospital, HU-121, 300 Longwood Avenue, Boston, MA 02115, USA
e-mail: Enrico.Mezzacappa@childrens.harvard.edu

Introduction

Problems of inattention, hyperactivity, and impulsivity of the sort typically seen in children who suffer from attention-deficit hyperactivity disorder (ADHD), when left unattended, have been associated with school failure, social isolation, depression, substance abuse, delinquency, and suicide (Biederman et al., 2004, 2006; Drabick, Gadow, & Sprafkin, 2006). As a result, investigators have assiduously sought to identify core deficits underlying the observable symptoms of ADHD in an effort to devise effective treatments. Impairments in executive function have shown promise in this regard.

For example, Barkley (1997) proposed a conceptual model that involves the interplay of different components of executive function in order to explain the symptoms seen in ADHD. In this model, behavioral inhibition is purported to be necessary for other processes such as working memory to inform the subsequent planning and regulation of goal-directed behaviors. In fact, working memory, the focus of this study, is the ability to keep information accessible for as long as it is necessary to guide and carry out goal-directed behaviors. For everyday purposes, one needs working memory to remember what to focus on, what to do next, and how to do it.

Conceptually and heuristically, working memory is often separated into verbal and visuo-spatial domains. Each domain is further subdivided into recall and manipulation. Recall involves an exact reproduction of information; for example, repeating a sequence of objects or numbers in the same order they were given. Manipulation involves recall of information in some alternative manner, for example, repeating a sequence of numbers backward, or grouping objects by supra-ordinate rules (e.g., animals, fruits, etc.), and reflects the capacity to recall and utilize information in

Published online: 23 February 2010

more flexible ways. Like other executive functions, the proficiency of working memory matures considerably with development from preschool through adolescence (Conklin, Luciana, Hooper, & Yarger, 2007; Luciana, Conklin, Hooper, & Yarger, 2005). This maturation in proficiency corresponds to changes in fronto-parietal gray matter structures and their white matter inter-connections (Klingberg, 2006).

Empirical research by other investigators, while never actually testing the model originally proposed by Barkley (1997), has nonetheless supported the potential explanatory value of working memory deficits among the underlying problems encountered in ADHD. A meta-analysis of working memory performance indicated that verbal and visuo-spatial working memory are both compromised in children with ADHD, with greater impairments noted for the manipulation of visuo-spatial information (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005). Neuroimaging studies of normal development of working memory capacity on the one hand, and the neural correlates of ADHD on the other, suggest commonalities in the brain substrates underlying the two. Maturation of fronto-parietal gray matter structures and their white matter inter-connections was associated with increases in working memory capacity between early childhood and mid-adolescence (Klingberg, 2006), as well as with symptoms of ADHD when these structures appeared to be less functionally active (Dickstein, Bannon, Castellanos, & Milham, 2006).

Barkley's views (1997) concerning possible mechanisms underlying the symptoms of ADHD are actually embedded within a broader theoretical model addressing the regulation of goal-directed behavior. This model is consistent with the perspectives of others, in that the observable inattention and hyperactivity–impulsivity encountered in children with ADHD can be conceptualized as relative failures of behavioral regulation, often referred to as self-regulation, that have equally important implications for interference with adaptive functioning as they do for the production of symptoms (Blair & Diamond, 2008; Buckner, Mezzacappa, & Beardslee, 2009; Posner & Rothbart, 2000). This conceptualization permits psychopathology and any related impairments to be studied from the perspective of the components and skills that support self-regulation and to design interventions targeting symptoms and adaptive functioning through these fundamental self-regulatory skills.

There is mounting evidence for the plasticity of self-regulatory skills, as well as emerging data suggesting that both typically developing children and children with impairments may benefit from interventions designed to improve these skills. For example, a universal, preventive, classroom-based preschool curriculum designed to enhance a range of executive functions, including working memory, led to greater improvements in school-readiness skills compared to a standard preschool preparatory curriculum that focused solely on content-based skills (Diamond, Barnett, Thomas, & Munro, 2007). In a similar vein, typically developing preschool children showed improvements in working memory following cognitive training, along with improvements in non-trained attentional skills, suggesting that training of one skill may transfer to related skills (Thorell, Lindqvist, Nutley, Gunilla, & Klingberg, 2009).

Interventions designed to strengthen self-regulatory skills may be particularly relevant for children whose skills are lagging or impaired, since these abilities are crucial to successful adaptation both in and out of school. For example, Holmes et al. (2009) reported that cognitive training for children with working memory deficits led to sustained enhancement of this skill and was associated with improvement in mathematical skills assessed 6 months following the intervention, indicative of enduring transfer of trained skills to meaningful school function.

A handful of studies to date have adopted cognitive training interventions for children who suffer from ADHD. Klingberg et al. (2005) tested a computer program designed to improve working memory in children struggling with ADHD. After 5 weeks of training, they observed positive effects on visuo-spatial working memory, verbal working memory, complex reasoning, and parent-reported symptoms of inattention and hyperactivity–impulsivity. Once again, there was evidence for transfer of training effects to non-trained skills and to observable behavior, which was still present when children were re-assessed 3 months following the intervention.

Using the program developed by Klingberg et al. (2005), Holmes et al. (2010) compared the effects of cognitive training to stimulant medication on working memory deficits in children with ADHD. With Baddeley's (2000) model of working memory as the underpinning for the assessments used in this study, they found that cognitive training improved verbal, visuo-spatial, and executive aspects of working memory alike. Furthermore, the beneficial effects on executive working memory were apparent 6 months after the intervention was completed, while stimulant medication was associated with non-enduring improvements in visuo-spatial working memory. Finally, Shalev et al. (2007) studied computerized training for sustained, selective, orienting, and executive attention in children struggling with ADHD. They focused on the transfer of training effects to behavioral and school performance indices and found significant improvements in reading comprehension and passage copying, and in parent reports of inattentiveness.

Compounding the problems encountered with attention problems, hyperactivity and impulsivity per se, children living in poverty are at heightened risk for developing mental health problems, for academic underachievement, and for school failure (Buckner et al., 2009). Poverty may exert its influences through complex effects on the development of meta-cognitive skills that are critical to good self-regulation. These deleterious influences may occur very early in development, and their repercussions can be enduring. For example, children exposed to poverty as infants have shown impairments in attention and executive function when they reached the ages of 4–6 (Mezzacappa, 2004). Poverty in childhood has been found to be related to concurrent impairments across a range of executive functions (Farah et al., 2006; Nobles, McCandliss, & Farah, 2007) and is predictive of working memory impairments in adults (Evans & Schamberg, 2009).

Poor children are also less likely to receive assessment and treatment for their problems (Buckner & Bassuk, 1997; Leaf et al., 1996; Armbruster, Gerstein, & Fallon, 1997). In the case of ADHD for example, estimates from the National Health and Nutrition Examination Survey (Froehlich et al., 2007) indicate that 'Poor children are most likely to meet criteria for ADHD yet are least likely to receive consistent pharmacotherapy.' Fewer than 16% of children in the lowest SES quintile who met criteria for ADHD received consistent pharmacotherapy in the year prior to the survey. These very low treatment rates among poor children are particularly striking in light of the prevalence estimate for ADHD of 11% in this subgroup, the highest of any subgroup studied. These observations emphatically point to the need for alternative treatment approaches and service delivery models that overcome barriers to the provision of care to poor children. School-based screening and mental health treatment can provide viable, much needed portals and service delivery to children who may not otherwise have easy access to providers (Armbruster & Lichtman, 1999; Burns et al., 1995; Farmer, Burns, Phillips, Angold, & Costello, 2003; Watts & Buckner, 2007).

Encouraged by the potential of cognitive training to enhance self-regulatory skills in an enduring fashion and by our interest in interventions that would lend themselves readily to dissemination, our goals for this pilot study were (1) to examine the viability of conducting working memory training during school hours with economically disadvantaged children suffering from attention problems and hyperactivity and (2) to generate preliminary effect sizes for the impact of this intervention on those symptom domains, as well as on standardized performance indices of working memory, in order to plan for a larger clinical trial.

Method

The Children's Hospital Boston Institutional Review Board and the Boston Public Schools Committee on Research and Evaluation approved the study. Given the small, pilot nature of the study, it was conceived from the outset as a single-group design with pre–post comparisons.

Participants

Nine students were enrolled in the study. Three were girls. Children ranged in age from 8 to 10.5 and attended the second through fourth grades in the same public school located in an economically disadvantaged neighborhood of Boston. All study participants were children with ethnic minority backgrounds. At the time of the study, the ethnic-racial composition of the school as a whole was black: 34.1%, Hispanic: 63.2%, other 1.6%, and white: 1.1%. Children attending the school all qualified for free breakfast and lunch programs, indicative of the overall low SES status of the neighborhood served by the school.

None of the participating children had ever received clinical assessments or treatments, medical or otherwise, for any psychiatric conditions prior to this study; and none received any assessments or treatments for mental health–related issues during the course of working memory training. Of the nine students enrolled in the study, eight completed the training. One student relocated to another school district during the fourth week of training and was lost to follow-up.

Assessments

Parents and teachers completed the Home and School Versions of the ADHD Rating Scale-IV (ADHD-RS-IV), respectively, before and after the intervention (DuPaul, Power, Anastopoulos, & Reid, 1998). The ADHD-RS-IV is a verbatim questionnaire of the 18 symptoms, 9 for inattention and 9 for hyperactivity–impulsivity that comprise Criterion A for each of the two subtypes of ADHD in DSM-IV (APA, 2000). Ordinarily, in order to reach diagnostic criteria for a particular ADHD subtype according to DSM-IV, children must display six or more symptoms from the respective subscale, and these must be present in more than one setting; e.g., home and school. For reasons we discuss below, we focused our assessments of children's behavior on teacher reports.

With the ADHD-RS-IV, symptoms are evaluated on a 4-point Likert scale: Never or Rarely (0), Sometimes (1), Often (2), and Very Often (3). We considered item responses of 2 (Often) or 3 (Very Often) to represent endorsement of a given symptom. Furthermore, by summing the individual symptom scores, we examined changes in overall symptom levels in relation to our intervention.

Normative data for this instrument were derived from a sample of 2,000 children between the ages of 4 and 19 chosen to be representative of the geographic, gender, and ethnic-racial proportions reflected in the 1990 US census. Psychometric properties of teacher reports indicate good internal consistency (total score = .94, inattention = .96, hyperactivity/impulsivity = .88) and test–retest reliability (total score = .90, inattention = .89, H/I = .88). Our primary outcome measure was the change in raw total ADHD score from pre-treatment baseline to post-intervention score.

Six of nine parents completed the ADHD-RS-IV prior to the intervention, while only four parents of the eight students who completed the training returned the post-treatment assessment. Questionnaire data were complete for teacher reports pre- and post-intervention. For this reason, we focused our analyses on the teacher ADHD-RS-IV. Based on teacher reports at baseline, seven of the nine students enrolled in the study showed combined—inattentive and hyperactive-impulsive—symptomatology, while the remaining two students showed primarily inattentive symptomatology.

Standardized assessments of children's working memory were also obtained before and after the intervention. Verbal working memory was assessed using the Digit Span subtest of the WISC-IV (Wechsler, 2003). This test requires a child to repeat increasingly long sequences of numbers, forward or backward. The responses we scored were the longest backward sequences successfully reproduced before and after the intervention. The outcome measure was the raw change in sequence length. Visuo-spatial working memory was assessed using the Finger-Windows subtest of the Wide Range Assessment of Memory and Leaning—WRAML (Adams & Sheslow, 1990). This test requires a child to replicate a spatial pattern indicated by the examiner who points through holes on a grid. The responses we scored were the longest visual patterns successfully reproduced before and after the intervention. The outcome measure was once again the raw change in sequence length.

Working Memory Training

The computer program used to train working memory, 'RoboMemo' (a Registered Trademark of CogMed Cognitive Medical Systems AB, Stockholm, Sweden), is designed to suit children 7–12 years of age (Klingberg et al., 2005). The program comprised eleven different exercises, five that trained visuo-spatial working memory, five that trained verbal working memory, and one that trained both domains of working memory. These exercises varied in their inherent complexity, and the program adjusted the level of difficulty for each exercise to the child's evolving ability, so that the child's working memory capacity was always challenged.

Children performed the exercises by interacting with an on-screen robot that provided them with verbal and visual feedback after each trial. An example exercise for verbal working memory included the child selecting the syllable that differed between two multi-syllabic 'pretend' words simultaneously presented aurally and visually. An example exercise for visuospatial working memory included the child replicating a sequence of lights on a panel that had been rotated 90° after the visual sequence was presented. The on-screen robot provided encouragement when children erred and positive feedback whenever they were successful. As an added incentive, when children performed successfully, they accumulated 'energy' that was transferred to a built-in game called 'RoboRacing' played after they completed the daily exercises.

Procedure

Teachers from the second through fourth grades participated in educational groups about ADHD and the nature of the intervention. Teachers then informed the parents of children, who in their estimation were struggling with symptoms of ADHD, about the study. Parents who indicated interest in having their child participate attended a meeting at school with one of the investigators and their child's teacher. The rationale for the study and the nature of the intervention were explained, and consent was obtained at that meeting. Children were then invited to the meeting, the rationale and nature of the intervention were explained again in developmentally appropriate language, and the child's assent was obtained.

Children received working memory training during school hours for 40–45 min each day for 5 weeks. The time of day that a child was removed from class was varied so that no class was missed more than once each week. The training itself was conducted in a pre-designated, quiet room. Feedback from teachers was solicited weekly to ensure that there were no perceived adverse effects related to removing children from class, such as difficulties with transitions to and from the classroom, or falling behind with class work. Since removing children from class would invariably draw attention to the participants, we suggested that any questions emanating from peers about removal from class be addressed by stating that participants had been chosen to help doctors test a new educational computer program for children.

During working memory training, children wore headphones in order to receive the audio input of the program, as well as to reduce any outside distractions. A research assistant attended to the child at all times while the training was being conducted. At the end of each day of exercises, children were allowed to choose a small tangible reinforcement from among items such as sports or action figure cards, colored pencils, or costume jewelry.

Results

All parents invited to participate in the study agreed to meet with one of the study investigators to have the study explained, including the need to remove the child from class on a regular basis during the course of the intervention. All parents consented for their children to participate in working memory training. All nine children assented to participate as well. There was no attrition due to an inability or unwillingness on the part of children to complete the training. Feedback from teachers revealed no perceived harmful effects related to removing children from class.

Despite the small sample size, our outcome variables met assumptions for normality of distribution. Data were analyzed using match-paired *t* tests comparing pre- and post intervention scores. All contrasts were two-tailed to account for the possibility that removing children from class could lead to worsening rather than improvements in ADHD symptoms and working memory. Effect sizes (d') were calculated for correlated outcomes according to Kraemer and Thiemann (1987), where $d = (\text{Time 2} - \text{Time 1 Score})/\text{SD Time 1 Score} \times [2 \times (1 - r)]^{1/2}$, subsequently adjusted for small sample sizes (Hedges & Olkin, 1985), where $d' = d \times 1 - [3/(4 \times df - 1)] = d \times .88$.

Our findings are presented in Table 1. All outcome measures changed in the expected direction. Our primary outcome, teacher ratings of total ADHD symptoms, improved on average by 26% [$t(7) = -2.9$; $p = .023$]. Supporting this result were comparable improvements in the WISC Digit Span Backward of 36% [$t(7) = 2.8$; $p = .026$] and WRAML Finger-Windows of 33% [$t(7) = 3.5$; $p = .01$], which are the scores for verbal and visuo-spatial working memory, respectively.

A closer examination of individual student's performance indicated that teachers' ratings of total ADHD symptoms improved in seven students and worsened for one. For the WISC Digit Span Backward, scores improved in six children, worsened for one student, and showed no change in the remaining child. For the Finger-Windows Test, scores improved in seven students and worsened for one. Declines in performance across the three measures were not unique to one child.

Discussion

The results of this small, open-label pilot study suggest that training working memory in school settings may be a viable way to help children who struggle with attention problems or hyperactivity in the classroom. Hence, this approach warrants further investigation, especially since the skill-building nature of this approach presents some appealing characteristics that may render it more acceptable to parents who are reticent to expose their children to stimulants or other pharmacological interventions for attention problems and hyperactivity. Furthermore, the school setting provides a natural means to reach many children in need, including those who might otherwise not receive assessment or treatment, and to ensure that treatment is administered with fidelity and taken to completion with minimal attrition. In this regard, it also bears mentioning that teachers, aides, and other educational specialists could be trained to administer the intervention, further contributing to improved access to care.

Beyond our descriptive outcomes, the conclusions we can draw from this pilot study are obviously limited by the small sample size, the lack of a control group, the use of teachers as the sole means for recruitment and final evaluation of participants, and the fact that teachers were not blind to the intervention status of participants. Teachers' expectancies, and the fact that children spent some time out of class each day to receive the intervention, could have also favorably impacted their ratings. Nevertheless, our standardized measures of working memory, which were not subject to observer bias, indicated positive changes following the intervention that were comparable in magnitude to the improvements in the teachers' ratings and were consistent with changes in working memory following cognitive training reported by other investigators.

Table 1 Summary of results

Outcome	Time 1	Time 2	Raw change	Percent change	d'
Teacher ADHD RS Total score	30.4	22.6	−7.75	−26	1.02
WISC digits Backward	5.1	7.0	+1.87	+36	.93
WRAML Finger-Windows	10.9	14.5	+3.62	+33	.73

Given the small sample and the absence of longer-term follow-up, we could not address whether changes in working memory mediated observed changes in symptoms of ADHD. Evidence for mediation, either partial or total, would lend support to the premise that working memory deficits contribute to the pathogenesis of ADHD. Longer-term follow-up would also permit the assessment of eventual improvements in academic achievement and social skills that might also be attributable to enduring improvements in both working memory skills and in the symptoms of ADHD. Such observations would support the premise that training specific meta-cognitive skills may generalize to related skills and transfer to meaningful functional skills needed in every day life as well.

It will be important to replicate the findings we reported here in larger, randomized, controlled trials, both to ensure the efficacy and generalizability of such an approach, as well as to account for the expectancy of parent and teacher reporters. It will also be important to examine whether training differentially affects inattention or hyperactivity–impulsivity and whether age, baseline severity, co-morbidity, gender, SES, or the concomitant use of medication functions as modifiers of treatment effects; all critical questions to explore as this intervention, and others like it, are tested with more children.

In summary, the developing child is an integral part of open, dynamic systems and is highly receptive to the influences of experience. While additional research is needed, the intervention we piloted, and others like it, offer the possibility of stimulating the maturation of fundamental meta-cognitive skills in a naturalistic setting during a period in human development when the plasticity of brain regions critical to self-regulation is high, with the prospect of creating enduring positive effects on the development of key components of self-regulation that are critical to good mental health and to successful academic achievement and social adaptation (Blair & Diamond, 2008; Buckner et al., 2009). Furthermore, the nature of this intervention and its delivery through schools are such that it may circumvent some barriers to the provision of care to children who are most in need of it; particularly those living in economically disadvantaged neighborhoods.

Acknowledgments The authors would like to acknowledge Delvina Miremadi, B.A., for her work in carrying out the intervention and Jennifer Turek-Queally, Ph.D., for her advice concerning the measurement of working memory.

Disclosures The authors have no financial interests in CogMed Cognitive Medical Systems nor any other financial conflicts of interest to disclose.

References

Adams, W., & Sheslow, D. (1990). *Wide range assessment of memory and learning (WRAML)*. Wilmington, Delaware: Wide Rang.

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders, text revision* (4th ed.). Washington D.C.: APA Press.

Armbruster, P., Gerstein, S. H., & Fallon, T. (1997). Bridging the gap between service need and utilization: A school-based mental health program. *Community Mental Health Journal, 33*, 199–211.

Armbruster, P., & Lichtman, J. (1999). Are school based mental health services effective? Evidence from 36 inner city schools. *Community Mental Health Journal, 35*, 493–504.

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*, 417–423.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin, 121*, 65–94.

Biederman, J., Monuteaux, M. C., Doyle, A. E., Seidman, L. J., Wilens, T. E., Ferrero, F., et al. (2004). Impact of executive function deficits and attention-deficit/hyperactivity disorder (ADHD) on academic outcomes in children. *Journal of Consulting and Clinical Psychology, 72*, 757–766.

Biederman, J., Monuteaux, M. C., Mick, E., Spencer, T., Wilens, T. E., Silva, J. M., et al. (2006). Young adult outcome of ADHD: A controlled 10-year follow-up study. *Psychological Medicine, 36*, 167–179.

Blair, C., & Diamond, A. (2008). Biological processes in prevention and intervention: The promotion of self-regulation as a means of preventing school failure. *Development and Psychopathology, 20*, 899–911.

Buckner, J. C., & Bassuk, E. (1997). Mental disorders and service utilization among youths from homeless and low-income housed families. *Journal of the American Academy Child and Adolescent Psychiatry, 36*, 890–900.

Buckner, J. C., Mezzacappa, E., & Beardslee, W. R. (2009). Self-regulation and its relations to adaptive functioning in low-income youths. *American Journal of Orthopsychiatry, 79*, 19–30.

Burns, B. J., Costello, E. J., Angold, A., Tweed, D., Stangl, D., Farmer, E. M. Z., et al. (1995). Children's mental health service use across service sectors. *Health Affairs, 14*, 147–159.

Conklin, H. M., Luciana, M., Hooper, C. J., & Yarger, R. S. (2007). Working memory performance in typically developing children and adolescents: Behavioral evidence of protracted frontal lobe development. *Developmental Neuropsychology, 31*, 103–128.

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science, 318*, 1387–1388.

Dickstein, S. G., Bannon, K., Castellanos, F. X., & Milham, M. P. (2006). The neural correlates of attention deficit hyperactivity disorder: An ALE meta-analysis. *Journal of Child Psychology and Psychiatry, 47*, 1051–1062.

Drabick, D. A. G., Gadow, K. D., & Sprafkin, J. (2006). Co-occurrence of conduct disorder and depression in a clinic-based sample of boys with ADHD. *Journal of Child Psychology and Psychiatry, 47*, 766–774.

DuPaul, G. J., Power, T. J., Anastopoulos, A. D., & Reid, R. (1998). *ADHD rating scale—IV. Checklists, norms and interpretation*. New York: Guilford Press.

Evans, G. W., & Schamberg, M. A. (2009). Childhood poverty, chronic stress, and adult working memory. *Proceedings of the National Academy of Sciences, 106*, 6545–6549.

Farah, M. J., Shera, D. M., Savage, J. H., Betancourt, L., Giannetta, J. M., Brodsky, N. L., et al. (2006). Childhood poverty: Specific associations with neurocognitive development. *Brain Research, 1110*, 166–174.

Farmer, E. M. Z., Burns, B. J., Phillips, S. D., Angold, A., & Costello, E. J. (2003). Pathways into and through mental health service for children and adolescents. *Psychiatric Services, 54*, 60–66.

Froehlich, T. E., Lanphear, B. P., Epstein, J. N., Barbaresi, W. J., Katusic, S. K., & Kahn, R. S. (2007). Prevalence, recognition, and treatment of attention-deficit/hyperactivity disorder in a national sample of US children. *Archives of Pediatrics and Adolescent Medicine, 161*, 857–864.

Hedges, L., & Olkin, I. (1985). *Statistical models for meta-analysis*. New York: Academic Press.

Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science, 12*, F9–F15.

Holmes, J., Gathercole, S. E., Place, M., Dunning, D. L., Hilton, K. A., Elliott, J. G. (2010). Working memory deficits can be overcome: Impacts of training and medication on working memory in children with ADHD. *Applied Cognitive Psychology* (in press).

Klingberg, T. (2006). Development of a superior frontal-intraparietal network for visuo-spatial working memory. *Neuropsychologia, 44*, 2172–2177.

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlstrom, K., et al. (2005). Computerized training of working memory in children with ADHD—A randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry, 44*, 177–186.

Kraemer, H. C., & Thiemann, S. (1987). *How many subjects? Statistical power analysis in research*. Newbury Park, CA: Sage.

Leaf, P., Alegria, M., Cohen, P., Goodman, S. H., Horwitz, S. M., Hoven, C. W., et al. (1996). Mental health service use in the community and schools: Results from the four-community MECA study. *Journal of the American Academy of Child and Adolescent Psychiatry, 35*, 889–897.

Luciana, M., Conklin, H. M., Hooper, C. J., & Yarger, R. S. (2005). The development of nonverbal working memory and executive control processes in adolescents. *Child Development, 76*, 697–712.

Martinussen, R., Hayden, J., Hogg-Johnson, S., & Tannock, R. (2005). A meta-analysis of working memory impairments in children with attention deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry, 44*, 377–384.

Mezzacappa, E. (2004). Alerting, orienting and executive attention: Developmental properties and socio-demographic correlates in an epidemiological sample of young, urban children. *Child Development, 75*, 1373–1386.

Noble, K. G., McCandliss, B. D., & Farah, M. J. (2007). Socioeconomic gradients predict individual differences in neurocognitive abilities. *Developmental Science, 10*, 464–480.

Posner, M. I., & Rothbart, M. K. (2000). Developing mechanisms of self-regulation. *Development and Psychopathology, 12*, 427–441.

Shalev, L., Tsal, Y., & Mevorach, C. (2007). Computerized progressive attentional training (CPAT) program: Effective direct intervention for children with ADHD. *Child Neuropsychology, 13*, 382–388.

Thorell, L. B., Lindqvist, S., Nutley, S. B., Gunilla, B., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science, 12*, 106–113.

Watts, C., & Buckner, J. C. (2007). Children's hospital neighborhood partnerships: A model for service delivery and systems change through school-community-university collaboration. *The Community Psychologist, 40*(3), 26–29.

Wechsler, D. (2003). *Wechsler intelligence scale for children* (4th ed.). New York: Psychological Corporation.