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Do programs designed to train working memory, other executive functions, and attention benefit children with ADHD? A meta-analytic review of cognitive, academic, and behavioral outcomes

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HIGHLIGHTS

- Executive function and attention training for ADHD show limited efficacy.
- Training short-term memory improves short-term memory moderately.
- Training does not improve academic, behavioral, or cognitive functioning in ADHD.
- Significant illusory rater effects are evident following cognitive training.

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ABSTRACT

Children with ADHD are characterized frequently as possessing underdeveloped executive functions and sustained attentional abilities, and recent commercial claims suggest that computer-based cognitive training can remediate these impairments and provide significant and lasting improvement in their attention, impulse control, social functioning, academic performance, and complex reasoning skills. The present review critically evaluates these claims through meta-analysis of 25 studies of facilitative intervention training (i.e., cognitive training) for children with ADHD. Random effects models corrected for publication bias and sampling error revealed that studies training short-term memory alone resulted in moderate magnitude improvements in short-term memory ($d = 0.63$), whereas training attention did not significantly improve attention and training mixed executive functions did not significantly improve the targeted executive functions (both nonsignificant: 95% confidence intervals include 0.0). Far transfer effects of cognitive training on academic functioning, blinded ratings of behavior (both nonsignificant), and cognitive tests ($d = 0.14$) were nonsignificant or negligible. Unblinded raters ($d = 0.48$) reported significantly larger benefits relative to blinded raters and objective tests (both $p < .05$), indicating the likelihood of Hawthorne effects. Critical examination of training targets revealed incongruence with empirical evidence regarding the specific executive functions that are (a) most impaired in ADHD, and (b) functionally related to the behavioral and academic outcomes these training programs are intended to ameliorate. Collectively, meta-analytic results indicate that claims regarding the academic, behavioral, and cognitive benefits associated with extant cognitive training programs are unsupported in ADHD. The methodological limitations of the current evidence base, however, leave open the possibility that cognitive training techniques designed to improve empirically documented executive function deficits may benefit children with ADHD.

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1. Introduction

The mounting number of commercial claims[1] that computer-based cognitive training will provide significant and lasting improvement in attention, impulse control, social functioning, academic performance, and complex reasoning skills for children with ADHD could not have arrived at a better time—if these claims are veridical. Children with ADHD are in dire need of innovative and effective treatments in light of the disheartening MTA study results documenting significant and continued impairment across a wide range of clinical, educational, and interpersonal outcomes after 3–8 years despite receiving the most effective treatments available for the disorder for an extended time period (Jensen et al., 2007; Molina et al., 2009). The failure of these treatments (individually titrated psychostimulant medication alone, intensive parent training and classroom contingency management alone, or their combination) to significantly improve the long-term functioning of children with ADHD is not altogether unexpected. Neither treatment was derived based on a theoretical framework of the disorder. Psychostimulants were discovered serendipitously by an astute physician noting improved concentration and reduced motor activity in children administered Benzedrine who suffered postpneumoencephalography[2] headaches. Contemporary parent and classroom contingency management (behavioral) therapies, in contrast, were appropriated from the widespread application of operant conditioning principles for individuals with developmental/intellectual disabilities beginning in the 1960s (for a historical review, see Bijou, 1966).

The prevalent use of the two treatments for children with ADHD reflects the reality that these children are referred primarily because of their significant and pervasive behavioral and interpersonal problems at home and at school (Pelham, Fabiano, & Massetti, 2005), not their cognitive deficits. When administered in their most potent forms and monitored carefully, psychostimulant medication alone and combined with behavioral treatment is associated with large magnitude reductions in inattention and hyperactivity/impulsivity symptoms (ES range = 1.53 to 1.89) for up to 24 months (Van der Oord, Prins, Oosterlaan, & Emmelkamp, 2008), whereas psychosocial intervention used alone is associated with more moderate reductions in core symptoms and comparatively larger reductions in ratings of impairment (ES range = .31 to .87) (Fabiano et al., 2009; Van der Oord et al., 2008). These impressive reductions in core behavioral symptoms and impairment ratings, however, are unaccompanied by significant or sustained improvements in ecologically valid academic and learning outcomes such as quiz and test grades, overall grade point averages, grade retentions, high school graduation rates, and standardized achievement test scores (Molina et al., 2009; Van der Oord et al., 2008). In addition, no study has demonstrated sustained maintenance of medication or psychosocial treatment-related behavioral changes beyond 24 months (Jensen et al., 2007; Molina et al., 2009), although the role of treatment adherence in long-term outcomes remains poorly understood.

The relative impotence of psychostimulant and intensive behavioral treatment to improve academic and learning outcomes in children with

[1] www.braintrain.com/cognitive-training-research; www.cogmed.com; http://junglememory.com.

[2] Pneumoencephalography, a now obsolete medical procedure, was used during the early 20th century and involved draining most of the cerebrospinal fluid from around the brain and replacing it with air, oxygen, or helium to enhance x-ray imaging.

ADHD warrants consideration if the field is to progress in designing innovative therapies for the disorder. Psychostimulants such as methylphenidate act primarily as dopamine and norepinephrine reuptake inhibitors, and to a lesser extent, as direct agonists that stimulate the release of dopamine and norepinephrine into the synapse. The well-documented finding that both processes promote the availability of these neurotransmitters in cortical-subcortical pathways involving the frontal/pre-frontal cortex, temporal lobe, and basal ganglia is of particular relevance for the treatment of ADHD (cf. Dickstein, Bannon, Castellanos, & Milham, 2006, for a meta-analytic review). These anatomical structures play a critical role in supporting executive functions (EF), an umbrella term for higher-order cognitive processes such as working memory, set shifting, and inhibitory control that enable goal directed behavior and novel problem solving (Garon, Bryson, & Smith, 2008; Miyake et al., 2000). EF deficits are implicated in most contemporary models of ADHD (Barkley, 1997; Rapport et al., 2008; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) and associated with adverse educational (Jensen et al., 2007), interpersonal (Diamantopoulou, Rydell, Thorell, & Bohlin, 2007; Kofler et al., 2011), and occupational outcomes (Barkley & Murphy, 2010).

Although psychostimulant treatment usually results in moderate-to-large magnitude improvements on laboratory-based cognitive tasks such as the CPT (Losier, McGrath, & Klein, 1996; Van der Oord et al., 2008), its association with improved performance on measures of executive function is considerably more limited. For example, placebo controlled psychostimulant studies generally report significant improvement on several aspects of non-executive functioning involving regulation of attention and response speed, but small-to-moderate magnitude changes or no effects on tasks with a prominent executive component (Bedard, Jain, Hogg-Johnson, & Tannock, 2007; Epstein et al., 2006; Kobel et al., 2009; Rhodes, Coghill, & Matthews, 2006). These results suggest that actuating the anatomical structures underlying executive functions improves important aspects of the attentional component and motor response elements related to task performance, but not to a degree that translates into meaningful improvement in cognitive functioning and learning outcomes for children with ADHD.

Empirically supported behavioral treatments, in contrast, are hypothesized to achieve their effects by means of operant conditioning processes (Barkley, 2000). When applied in a therapeutic context for children with ADHD, the underlying assumption is that ADHD-related impairment in school performance/learning and interpersonal relationships reflects inadequate learning histories and/or underlying volitional control deficits that can be managed through the contingent application of learning principles such as reinforcement and response cost.[3] Treatment contingencies focus conventionally on increasing attention, compliance, and academic productivity, and decreasing excessive gross motor activity and impulsive behavior. These targets are selected based on the expectation that strengthening and weakening desirable and undesirable behaviors, respectively, will result in enduring behavioral change. Extensive evidence supports the efficacy of operant techniques for improving a wide range of behaviors in children with ADHD while contingencies are actively implemented (for a review, see Pelham & Fabiano, 2008). No study to date, however, has demonstrated sustained maintenance of conditioned behavioral changes over an extended time frame (Jensen et al., 2007; Molina et al., 2009) or the transfer of effects to EF-related cognitive performance outcomes, even when accompanied by inordinate incentives (Dovis, Van der Oord, Wiers, & Prins, 2012).

Collectively, our current and most potent evidence-based therapies provide effective, short-term relief of externalizing symptoms and some functional impairments but minimally affect the executive functioning deficits and adverse learning outcomes common to ADHD. Accumulating evidence from neuroimaging studies provides important insights regarding this enigma. Widely distributed hypoactivity in frontal/prefrontal cortical regions implicated in executive functioning is well documented in children with ADHD (cf. Dickstein et al., 2006, for a meta-analytic review), and the relations among CNS arousal, increased activity level, and task performance are well established (for reviews, see Barry, Clarke, McCarthy, Selikowitz, & Rushby, 2005; Rapport et al., 2008). The near-normalization of attention and gross motor activity observed with psychostimulants and incentivized behavioral interventions likely reflects the impact of these treatments on arousal-regulating mechanisms needed to activate EF-supporting structures within these brain regions (Cortese et al., 2012). Repeated resonance scans acquired prospectively from 5 to 15 years of age, however, reveal a nearly three year delay in attaining peak cortical thickness in these same prefrontal/frontal regions in children with ADHD relative to typically developing children (Shaw et al., 2007). Activating these regions is thus unlikely to translate into large magnitude cognitive improvements or learning outcomes due to the ontogenetically underdeveloped structures themselves and executive functions these structures support.

The emerging neuroimaging evidence, coupled with Barkley's (1997) seminal paper that re-conceptualized ADHD as a disorder of underdeveloped or deficient executive functions, stimulated considerable research in the field and provided important insights for the design of innovative treatments for the disorder. Longitudinal developmental research reveals three primary executive functions – working memory, inhibition, and set shifting (Garon et al., 2008; Miyake et al., 2000) – which are identified consistently in meta-analytic (Dickstein et al., 2006; Willcutt et al., 2005) and factor analytic reviews (Miyake et al., 2000), supported by a strong genetic basis (Friedman et al., 2008), and shown to be developmentally contiguous (Huizinga, Dolan, & van der Molen, 2006). All three have also been the target of recent cognitive training studies attempting to improve executive functions and/or attention in children with ADHD.

The clinical model of psychopathology posits that interventions aimed at improving suspected underlying neurological substrate(s) and core psychological/cognitive features of ADHD should produce the greatest level and breadth of therapeutic change (National Advisory Mental Health Council's Workgroup, 2010; Rapport, Chung, Shore, & Isaacs, 2001). Conversely, those aimed at peripheral behaviors should show limited generalization upward to core features, and minimally affect other peripheral symptoms. Novel interventions are thus more likely to be successful if they target aspects of executive functioning that are not only deficient in ADHD, but also related to the primary behavioral and learning functional impairments associated with the disorder. In the ensuing sections, we summarize the empirical basis for designing novel treatments targeting each of these three higher-order executive functions (EF) and related attentional components, evidence for and against ADHD-related deficits in each EF, and research examining the role of each EF in ADHD-related behavioral symptoms and functional impairments (i.e., academic, peer, and family; Pelham et al., 2005).

1.1. Working memory

Of the 25 cognitive training studies to date (Table 1), 68% describe working memory as a primary target for remediation; a skewness mirroring the evidence supporting working memory relative to inhibition and set shifting in ADHD-related behavioral and functional impairments. Working memory is a limited capacity system responsible for the temporary storage, rehearsal, processing, updating, and manipulation of internally-held information. The multicomponent system serves a critical role in guiding everyday behavior and underlies the capacity to perform complex tasks such as learning, comprehension, reasoning, and planning (Baddeley, 2007). The *working* component of working memory involves mental processing of internally held information for use in guiding behavior, and is reified across neurocognitive models as the

[3] Specific neurological mechanisms, such as abnormal extinction processes that interfere with and diminish the ability to develop normal behavior–consequence relationships, have been proposed to underlie the deficient learning gradients in ADHD (Sagvolden, Johansen, Aase, & Russell, 2005).

Table 1
Executive functions and attention processes targeted for facilitative intervention training (FIT).

Study	Training target	Working memory[a]			Short-term memory[b]		Behavioral Inhibition		Set-shifting	Attention			
Author (year)		Updating	Manipulation/dual-task	Serial reordering	PH	VS	Motor	Cognitive		Orienting alertness	Vigilance sustained	Selective	Divided
Beck et al. (2010)	STM				X	X							
Dahlin (2011)	STM				X	X							
Gibson et al. (2011)	STM				X	X							
Gray (2011)	STM				X	X							
Green et al. (2012)	STM				X	X							
Holmes et al. (2010)	STM				X	X							
Klingberg et al. (2005)	STM				X	X							
Mezzacappa and Buckner (2010)	STM				X	X							
Prins et al. (2011)	STM					X							
Kerns, Eso, and Thomson (1999)	Attention										X	X	X
Lange et al. (2012)	Attention									X	X	X	X
Semrud-Clikeman et al. (1999)	Attention										X	X	
Tamm, Nakonezny, and Hughes (in press)	Attention										X	X	X
Tamm et al. (2010)	Attention										X	X	X
Tucha et al. (2011)	Attention									X	X	X	X
Halperin et al. (in press)	Mixed EF				X	X	X					X	
Hoekzema et al. (2010)	Mixed EF				X						X		
Johnstone et al. (2012)	Mixed EF					X	X						
Johnstone, Roodenrys, Phillips, Watt, and Mantz, (2010)	Mixed EF					X	X						
Klingberg et al. (2002)	Mixed EF				X	X	X						
Rabiner, Murray, Skinner, and Malone, (2010)	Mixed EF					X					X		
Shalev, Tsal, and Mevorach (2007)	Mixed EF							X		X	X	X	
Steiner, Sheldrick, Gotthelf, and Perrin (2011)	Mixed EF				X	X				X	X	X	X
van der Oord et al. (2012)	Mixed EF			X		X	X		X				
Kray et al. (2012)	Set Shifting								X				

Note: Studies are grouped by training target and alphabetized within grouping to permit direct comparisons of study characteristics and effect sizes in subsequent tables. PH = phonological; VS = visual spatial; STM = short-term memory; EF = executive function.

[a] All tasks require at least minimal working memory/central executive resources (e.g., maintaining task instructions). Tasks are coded as targeting WM processes if these processes were targeted explicitly through adaptive training components designed specifically to increase abilities in one or more working memory central executive subprocesses (updating, manipulation/dual processing, and serial reordering) by a majority of training components. All studies using CogMed were coded as targeting short-term memory given empirical evidence indicating that this training paradigm improves short-term but not working memory processes (Gibson et al., 2011).

[b] Short-term memory refers to the storage/rehearsal components of the working memory system (i.e., the *memory* components of working memory).

central executive, internal focus of attention, or secondary memory, among other terms (Baddeley, 2007; Cowan, 2011; Unsworth & Engle, 2007). Meta-analytic and neuroimaging data (cf. Wager & Smith, 2003) indicate three interrelated subcomponents: *continuous updating* (active addition and deletion of items from working memory), *manipulation/dual processing* (diverse processes that involve operating on information while storing the same or other information in WM), and *serial reordering* (mental manipulation of temporal order). No memory/storage functions are ascribed to the *working* components of working memory; instead, these prefrontally-mediated executive functions serve to process or manipulate the information currently held within the two, anatomically distinct, short-term storage/rehearsal components: the *phonological* and *visuospatial* subsystems, which handle verbal and non-verbal visual and spatial information, respectively.

Distinguishing between *working* (central executive) and *memory* (storage/rehearsal) deficits is critical for treatment development, given the differential relationship of each system with ADHD-related impairments. Specifically, children with ADHD demonstrate large magnitude impairments in the central executive (*working*) component of working memory (Kasper, Alderson, & Hudec, 2012), and these impairments are related functionally to inattention (Burgess et al., 2010; Kofler, Rapport, Bolden, Sarver, & Raiker, 2010), hyperactivity (Rapport et al., 2009), impulsivity (Raiker, Rapport, Kofler, & Sarver, 2012), and social problems (Kofler et al., 2011). In contrast, the smaller magnitude ADHD-related impairments in phonological and visuospatial storage/rehearsal (*memory*) processes appear to be unrelated to or minimally involved in these key areas of functioning (Alderson, Rapport, Hudec, Sarver, & Kofler, 2010; Raiker et al., 2012; Rapport et al., 2009). The *working* (central executive) components of working memory are also intricately involved in a wide range of academic and intellectual abilities, ranging from math, reading, and listening comprehension and achievement, to complex learning and fluid reasoning (Swanson & Kim, 2007), whereas the *memory* components of working memory are associated with more limited yet important roles in learning outcomes (cf. Sarver et al., 2012, for a review).

Collectively, ADHD-related central executive deficits appear to be a particularly promising target for intervention given (a) large magnitude effect size estimates (ES = 2.01 to 2.05; Kasper et al., 2012) indicating that at least 81% of children with ADHD have deficits in the *working* component of working memory,[4] and (b) the strong association between central executive deficits and ADHD-related impairments in core behavioral symptoms and learning/educational outcomes (Burgess et al., 2010; Rapport et al., 2008, 2009).

1.2. Inhibition

Behavioral inhibition (BI) is hypothesized as a cognitive process that sub-serves behavioral regulation and executive function and underlies the ability to withhold (*action restraint*) or stop (*action cancellation*) an on-going response. Deficits in behavioral inhibition are frequently cited as a core, underlying deficit responsible for ADHD following Barkley's (1997) seminal theory, and children with ADHD often underperform on behavioral inhibition tasks relative to typically developing (TD) children (e.g., Oosterlaan, Logan, & Sergeant, 1998). The results of recent meta-analytic reviews, however, challenge the veracity of BI deficits in ADHD, and indicate that ADHD-related impaired performance on behavioral inhibition tasks is more parsimoniously explained by basic attentional, performance variability, and/or working memory process deficits (Alderson, Rapport, & Kofler, 2007; Lijffijt, Kenemans, Verbaten, & van Engeland, 2005)

Evidence supporting a link between behavioral inhibition and ADHD symptoms is similarly modest. For example, Brocki, Eninger, Thorell, and Bohlin (2010) reported a moderate association ($r = .30$) between parent/teacher behavioral ratings and children's BI performance in a community sample, whereas ADHD clinical studies have reported non-significant relations between BI indices and parent and teacher ratings of hyperactivity/impulsivity (Kuntsi, Oosterlaan, & Stevenson, 2001; Nigg, 1999) or classroom observations of attention and gross motor movement (Solanto et al., 2001). Experimentally manipulating BI demands has also been shown to exert no discernible effect on objectively measured motor activity in children with ADHD (Alderson, Rapport, Kasper, Sarver, & Kofler, 2012). Collectively, these studies suggest that behavioral inhibition processes may be intact in ADHD, and appear to be weakly or unrelated to ADHD-related behavioral symptoms.

1.3. Set shifting

Set shifting, or cognitive flexibility, refers to the ability to flexibly switch back and forth between tasks or mental sets. Tasks commonly used to assess set shifting require participants to mentally hold two response sets simultaneously and switch between these response sets according to pre-specified criteria (e.g., every other trial), or to monitor performance and change response sets based on performance feedback. Meta-analytic reviews reveal moderate magnitude set shifting deficits in children with ADHD (Frazier, Demaree, & Youngstrom, 2004; Willcutt et al., 2005), and indicate that approximately 25% to 35% of children with ADHD have deficits in this aspect of executive functioning. Extant evidence that set shifting deficits are related to ADHD symptoms, however, is limited. Only two studies have examined this relation. One reported a moderate ($r = .61$; Chhabildas, Pennington, & Willcutt, 2001), and the other, a more modest ($r = .17$; Willcutt et al., 2001) relation between set shifting performance and ADHD symptoms. Collectively, few studies have examined set shifting in children with ADHD, and the limited evidence available indicates that set shifting performance deficits are weakly to moderately related to ADHD symptoms.

1.4. Attention

Several nascent cognitive training paradigms for children with ADHD directly target one or more components of attention predicated on strong evidence of attention deficits derived from parent and teacher reports (Power et al., 1998; Tripp, Schaughency, & Clarke, 2006), as well as evidence of large magnitude impairments in objectively observed classroom attention (Kofler, Rapport, & Alderson, 2008; Rapport, Denney, DuPaul, & Gardner, 1994). Attention is also considered an integral component of all executive functions (Baddeley, 2007; Cowan, 2011; Unsworth & Engle, 2007), and attentional resource limitations are often assumed to reflect working memory and other executive functioning deficits (Melby-Lervåg & Hulme, 2013). These perspectives suggest that targeting attentional processes in children with ADHD could result in generalized performance improvements across executive functions.

In contrast to the large magnitude attention deficits required for an ADHD diagnosis and documented reliably by parents, teachers, and objective observers, identifying the specific cognitive components of attention that are impaired in ADHD has been considerably more challenging. Among the diverse models of attention (Baddeley, 2007; Cowan, 2011; Miyake & Shah, 1999; Posner, 2011), studies of childhood ADHD frequently focus on four components of attention: *Orienting/alertness* (the ability to enhance one's activation level following a stimulus of high priority; Tucha et al., 2006), *selective/focused attention* (the ability to facilitate the processing of one source of environmental information while attenuating the processing of others; Huang-Pollock, Nigg, & Carr, 2005), *divided attention* (the ability to simultaneously attend and respond to multiple tasks or multiple task demands; Odegaard, Wozny, & Shams, 2012), and *vigilance/sustained attention* (the ability to maintain a tonic state of alertness during prolonged and sustained mental activity; Denney, Rapport, & Chung, 2005).

[4] Estimates reflect the percent overlap between ADHD and non-ADHD groups. Approximately 19% of children with ADHD score within the typically developing range (Zakzanis, 2001).

Converging evidence indicates that *orienting/alertness* processes may be intact in ADHD (Huang-Pollock, Nigg, & Halperin, 2006), whereas moderate-to-large magnitude *vigilance/sustained attention* deficits are typically reported (ES = 0.62 to 1.34; Frazier et al., 2004; Huang-Pollock, Karalunas, Tam, & Moore, 2012; Losier et al., 1996; Willcutt et al., 2005). These effect sizes suggest that approximately 33% to 55% of children with ADHD evince sustained attention deficits (Zakzanis, 2001). In contrast, the evidence is mixed with regards to focused/selective and divided attention. Children with ADHD have been reported to perform better (Lajoie et al., 2005), similar to (Huang-Pollock et al., 2005), and worse (Tarnowski, Prinz, & Nay, 1986; Tucha et al., 2006) than typically developing children on these attentional components. A similar pattern of results has accrued for studies examining *divided attention*, wherein children with ADHD have performed better (Koschack, Kunert, Derichs, Weniger, & Irle, 2003), similar to (Lajoie et al., 2005) and worse than typically developing children (Savage, Cornish, Manly, & Hollis, 2006; Tucha et al., 2006).

The relationship between *vigilance/sustained attention* and ADHD behavioral and functional impairments is similarly complex. Performance on vigilance/sustained attention tasks is correlated weakly to moderately with parent and teacher ratings of attention (Epstein et al., 2003; Klee & Garfinkel, 1983) and hyperactivity/impulsivity (Brocki, Tillman, & Bohlin, 2010), as well as with objectively observed classroom attention (Barkley, 1991; Rapport et al., 1987). In addition, deficient sustained attention is associated with overall poorer academic performance (Rapport et al., 1994), lower grades and standardized test scores (Molina et al., 2009), and higher rates of special education placement and comorbid learning disabilities (Faraone et al., 1993).

Collectively, meta-analytic and empirical studies indicate specific rather than generalized attention deficits in children with ADHD, with moderate-to-large magnitude *vigilance/sustained attention* deficits but potentially intact orienting, focused, selective, and divided attention abilities. These vigilance deficits are modestly associated with observed classroom inattentive behavior and impaired academic performance (Barkley, 1991; Rapport et al., 1987).

1.5. Treatment of executive functions and attention

The substantial literature validating significant working memory (WM) central executive and vigilance/sustained attention deficits in children with ADHD, coupled with their unique predictions of myriad behavior and cognitive outcomes, renders these cognitive functions highly creditable targets for innovative treatments. The evidence supporting inhibition, set shifting, WM storage/rehearsal, and other cognitive components of attention, in contrast, is more limited.

Two types of non-pharmacological treatment approaches may hold the most promise and warrant consideration. The first approach involves the design of *compensatory* strategies that have assumed one of two formats in past years: traditional cognitive behavioral therapy (CBT), and environmental/curricula restructuring. Variations of CBT were introduced in the early to middle 1980s to address the myriad self-regulatory and cognitive deficits associated with ADHD. These interventions focused on teaching children problem-solving and specific strategies such as self-monitoring, modeling, role playing, self-instruction, self-reinforcement, and generating alternatives in decision-making situations (e.g., Abikoff & Gittelman, 1985; Hinshaw, Henker, & Whalen, 1984). A comprehensive review of CBT outcome studies, however, concluded that “there is little empirical support for its clinical utility with children with hyperactivity” (Abikoff, 1991, p. 205); a conclusion reaffirmed in a recent meta-analysis of CBT outcome studies for children with ADHD (adjusted ES = 0.01; Washington State Institute for Public Policy, 2012).

The second type of compensatory intervention developed for children with low working memory capacity entails *environmental/curricula restructuring*. This approach focuses on identifying instructions and activities that are likely to exceed children's working memory capacity within a classroom setting, and minimizing these demands. To date, only one outcome study has examined the effectiveness of this strategy in a classroom setting, and found no significant benefits relative to two cohort control groups on a comprehensive academic and working memory outcome battery (Elliot, Gathercole, Alloway, Holmes, & Kirkwood, 2010).

A second potentially promising treatment approach entails *facilitative* training. This approach was introduced in the early 2000s and designed to foster the development of attention and/or executive functions rather than compensate for identified executive functioning weaknesses. A common element of this approach is the use of computer-based (or automated) training exercises to strengthen the hypothesized deficient EFs and/or EF-related processes. A central tenet of these programs is that lasting, quantitative improvement in the development and/or efficiency of the EF-related neural substrates can be accomplished by means of extensive training involving repetition, practice, and feedback,[5] and by doing so, improvement will generalize or transfer to other tasks, activities, and abilities that rely on these same neural networks (Klingberg, 2010). This is a critical assumption of EF *facilitative intervention training* (FIT) programs and differs in important ways from traditional CBT strategies that rely on teaching regulatory and problem solving strategies as change agents.

A total of 25 outcome studies were identified that examined the efficacy of FIT for children with ADHD, and these studies are the focus of the current meta-analytic review. Several of the studies included in the meta-analysis have been the subject of narrative reviews (Apter, 2012; Epstein & Tsal, 2010; Redick et al., 2013; Rutledge, van den Bos, McClure, & Schweitzer, 2012; Takeuchi, Taki, & Kawashima, 2010) and commentaries (Gathercole, Dunning, & Holmes, 2012; Morrison & Chein, 2011; Shah, Buschkuehl, Jaeggi, & Jonides, 2012), nearly all of which highlight the lack of methodological rigor characteristic of the FIT literature. The commentaries and reviews differ, however, in their assessments concerning the potential of FIT to strengthen targeted neural substrate mechanisms and processes to an extent that generalizes to improved cognitive, behavioral, and functional outcomes for children with ADHD. None of the reviews included a majority of the ADHD FIT studies that are available currently, and only two adopted a quantitative (meta-analytic) approach for estimating the potential value of FIT for improving executive functioning-related outcomes. The first review reported limited to medium magnitude short-term training effects for visuospatial and verbal memory, respectively, but no evidence of far transfer[6] or maintenance effects (Melby-Lervåg & Hulme, 2013). The results, however, were based on composite indices of 23 diverse studies involving children, adolescents, and adults with and without diagnosed psychopathology, and a small number of studies involving children with ADHD ($k = 4$). The second meta-analysis examined 6 of the 25 cognitive training studies (Sonuga-Barke et al., 2013). They found no significant benefits on ADHD symptoms based on blind ratings, but included only a small percentage of the studies' reported outcome measures and were unable to assess potential moderators of treatment efficacy across studies.

The current meta-analytic review synthesizes the effects reported across 25 studies of FIT programs intended to improve executive functions and/or attention in children with ADHD, quantifies the extent to which training results in near and far transfer effects, and evaluates whether targeted executive functions reflect the most deficient processes identified in previous meta-analytic reviews involving children with ADHD (Frazier et al., 2004; Kasper et al., 2012; Martinussen, Hayden,

[5] The term *neuroplasticity* is used to refer to this process and signifies the brain's ability to create new pathways and rearrange existing ones for purposes of neural communication.

[6] Thorndike and Woodworth (1901) used the term *transfer effects* initially to describe the transfer of learning that occurs when common stimulus–response elements are shared between the original learning source and the learning target. Contemporary use of the terms, *near transfer* and *far transfer* effects, refers to an increase in performance on tasks that are highly similar and dissimilar to those used during training, respectively, as discussed below (see ‘Methodological criteria’).

Hogg-Johnson, & Tannock, 2005; Willcutt et al., 2005). This latter point is critical because the potential for FIT to improve the wide range of behavioral and cognitive difficulties evidenced by children with ADHD depends on the extent to which these difficulties are related to particular EF deficits and whether these EFs are modifiable at the neuronal level.

The numerous advantages associated with meta-analysis relative to narrative literature reviews have been recapitulated in several commentaries and textbooks devoted exclusively to the topic (e.g., Hunter & Schmidt, 2004; Lipsey & Wilson, 2001). The approach is particularly useful for evaluating FIT efficacy in children with ADHD due to the numerous between-study differences in (a) EF and/or attentional components targeted, (b) training tasks employed, (c) length and number of training sessions, (d) measures used to evaluate near- and far transfer effects, and (e) the use of objective and subjective outcome measures among the 25 outcome studies available for review. Quantifying the different outcome measures in comparable metrics (effect sizes), and providing overall estimates of the impact of FIT on cognitive, behavioral, and functional outcomes also provides a more powerful estimate of the true effects associated with FIT for children with ADHD (Hunter & Schmidt, 2004). Study characteristics (see Table 2) were coded and analyzed as potential moderators when results revealed that effect sizes across studies differed by more than would be expected based on study-level sampling error.

2. Method

2.1. Literature searches

A three-tier literature search was conducted using Medline, PubMed, PsycInfo, PsycArticles, PsycBooks, ERIC, Dissertation Abstracts International, and Social Science Citation Index. Search terms included permutations of the ADHD diagnostic label as words (e.g., attention-deficit/hyperactivity disorder, attention deficit disorder, attention deficit, attention problems, hyperactivity), and permutations of lettered acronyms (e.g., ADD, ADHD, ADD-I, ADHD-I, ADHD-C). Each search term was coupled with additional search terms to identify studies that incorporated a facilitative intervention training (FIT) approach (defined below) to improve any aspect of executive functions in children and/or adolescents. Additional search terms included *executive function training*, *working memory training*, *cognitive training*, *neurocognitive training*, *attention(al) training*, *phonological working* (or *short-term*) *memory training*, *visuospatial working* (or *short-term*) *memory training*, and the term *intervention* and *treatment* substituted for the word 'training' in subsequent searches. No search delimiters were selected to avoid missing studies due to database misclassification; studies from all publication years, geographical locations, and cultural groups were eligible for inclusion. Searches were conducted independently by two of the authors (SAO, LMF) and repeated until no new studies were located. Following the initial search, studies cited by articles using a facilitative intervention training approach with children or adolescents with ADHD were examined (Tier II backward search), and a forward search (Tier III) was conducted using the Social Science Citation Index to locate studies citing these articles. E-mails were sent to authors of six studies located using the above search parameters that met study inclusion criteria (described below) but reported insufficient data for effect size calculation, four of whom provided the requested data. These procedures generated 165 peer-reviewed studies, 24 books/book chapters, 18 dissertations, 2 theses, and 8 unpublished reports. All search processes were completed and study recruitment was closed on December 1, 2012.

2.2. Inclusion and exclusion criteria

Studies were included in the meta-analytic review if they met the participant, facilitative intervention training (FIT), and methodological criteria described below, and were published or available in English.

Studies identified by the multi-step literature search were screened initially by two of the authors (SAO, LMF) and independently by the senior author (MDR) to determine eligibility. Titles, abstracts, and full texts were considered sequentially when determining eligibility. Disagreements (N = 3) were resolved by consensus among all 4 study authors based on comparison between our FIT definition and the studies' text. Classification of variables within the five moderator categories described below was coded independently by the two senior authors (MDR and MJK). Agreement was 100% for all moderators with

Table 2
Facilitative intervention training (FIT) study characteristics.

First author (year)	T (*n*)	C (*n*)	Program	Control group	Adaptive	Computerized	Total minutes	Total sessions	Total weeks	Minutes/session
Beck et al. (2010)	27	24	CogMed	Waitlist	Y	Y	750	25	6	30
Dahlin (2011)	41	15	CogMed	Waitlist	Y	Y	600	20	5	30
Gibson et al. (2011)	38	–	CogMed	None	Y	Y	600	20	6	30
Gray (2011)	36	24	CogMed	Adaptive	Y	Y	900	20	5	45
Green et al. (2012)	12	14	CogMed	Non-adaptive	Y	Y	625	25	–	25
Holmes et al. (2010)	25	–	CogMed	None	Y	Y	600	20	6	30
Klingberg et al. (2005)	20	24	CogMed	Non-adaptive	Y	Y	1000	25	5	40
Mezzacappa and Buckner (2010)	8	–	CogMed	None	Y	Y	1000	25	5	40
Prins et al. (2011)	27	24	Study developed	Adaptive	Y	Y	105	3	3	35
Kerns et al. (1999)	7	7	Pay attention!	Non-adaptive	Y	N	480	16	8	30
Lange et al. (2012)	16	16	AixTent	Adaptive	Y	Y	480	8	4	60
Semrud-Clikeman et al. (1999)	21	12	APT	Waitlist	Y	N	2160	36	18	60
Tamm et al. (in press)	54	51	Pay attention!	Waitlist	Y	N	480	16	8	30
Tamm et al. (2010)	19	–	Pay attention!	None	Y	N	480	16	8	30
Tucha et al. (2011)	16	16	AixTent	Adaptive	Y	Y	360	8	4	45
Halperin et al. (in press)	29	–	TEAMS	None	Y	N	177.5	5	5	35.5
Hoekzema et al. (2010)	10	9	Study developed	Non-adaptive	Y	N	450	10	–	45
Johnstone et al. (2012)	40	20	Study developed	Adaptive & waitlist	Y	Y	375	25	5	15
Johnstone et al. (2010)	15	14	Study developed	Non-adaptive	Y	Y	500	25	5	20
Klingberg et al. (2002)	7	7	CogMed	Non-adaptive	Y	Y	607.5	24.3	5	25
Rabiner et al. (2010)	25	27	Captain's log	Adaptive & waitlist	Y	Y	1400	28	14	50
Shalev et al. (2007)	20	16	CPAT	Adaptive	Y	Y	960	16	8	60
Steiner et al. (2011)	11	9	Captain's log	Adaptive & waitlist	Y	Y	960	32	16	30
van der Oord et al. (2012)	18	22	Study developed	Waitlist	Y	Y	1000	25	5	40
Kray et al. (2012)	10	10	Study developed	Non-adaptive	N	Y	120	4	4	30

Notes: T = treatment group; C = control group; *n* = number of participants within each group; APT = attention process training; TEAMS = training executive, attention, and motor skills; CPAT = computerized progressive attention training. Training time data represent lower value of range reported by authors.

Table 3
Facilitative intervention training (FIT) program near and far transfer effects.

Author (year)	Program	Training target	Control group	Effect sizes					
				Near objective		Far objective		Far subjective	
				COG	ACH	COG	ACH	Blinded	Unblinded
Beck et al. (2010)	CogMed	STM	Waitlist	–	–	–	–	0.23	0.64
Dahlin (2011)	CogMed	STM	Waitlist	0.85	–	–	0.41	–	–
Gibson et al. (2011)	CogMed	STM	None	0.45	–	–	–	0.27 PH 0.09 VS	0.62 PH 0.18 VS
Gray (2011)	CogMed	STM	Adaptive	0.28	–	0.49	0.03	–	0.03
Green et al. (2012)	CogMed	STM	Non-adaptive	0.70	–	–	–	0.16	–
Holmes et al. (2010)	CogMed	STM	None	0.84	–	0.11	–	–	–
Klingberg et al. (2005)	CogMed	STM	Non-adaptive	0.62	–	0.42	–	0.32	–
Mezzacappa and Buckner (2010)	CogMed	STM	None	0.99	–	–	–	–	0.91
Prins et al. (2011)	Study-developed	STM	Adaptive	0.64	–	–	–	–	–
Kerns et al. (1999)	Pay attention!	Attention	Non-adaptive	0.0[a]	–	0.31	–	0.0	–
Lange et al. (2012)	AixTent	Attention	Adaptive	0.55	–	–	–	–	–
Semrud-Clikeman et al. (1999)	APT	Attention	Waitlist	0.90	–	–	–	–	–
Tamm et al. (in press)	Pay attention!	Attention	Waitlist	−0.03	–	0.25	–	–	0.42
Tamm et al. (2010)	Pay attention!	Attention	None	–	–	0.18	–	–	0.40
Tucha et al. (2011)	AixTent	Attention	Adaptive	0.38	–	–	–	–	–
Halperin et al. (in press)	TEAMS	Mixed EF	None	–	–	–	–	–	0.51
Hoekzema et al. (2010)	Study-developed	Mixed EF	Non-adaptive	–	–	0.0[c]	–	–	–
Johnstone et al. (2012)	Study-developed	Mixed EF	Waitlist[d]	0.00	–	0.10	–	–	0.37
Johnstone et al. (2010)	Study-developed	Mixed EF	Non-adaptive	0.04	–	–	–	–	0.67[b]
Klingberg et al. (2002)	CogMed	Mixed EF	Non-adaptive	0.86	–	1.05	–	–	–
Rabiner et al. (2010)	Captain's log	Mixed EF	Adaptive[e]	–	–	–	0.11	–	0.25
Shalev et al. (2007)	CPAT	Mixed EF	Adaptive	–	–	–	–	.41	–
Steiner et al. (2011)	Captain's log	Mixed EF	Adaptive[e]	–	–	−0.07	–	0.11	0.21
van der Oord et al. (2012)	Study-developed	Mixed EF	Waitlist	–	–	–	–	–	0.46
Kray et al. (2012)	Study-developed	Set shifting	Non-adaptive	0.70	–	0.44	–	–	–

Note: COG = cognitive performance; ACH = standardized achievement; STM = short-term memory; APT = attention process training; TEAMS = training executive, attention, and motor skills; CPAT = computerized progressive attentional training; PH = phonological; VS = visual spatial; EF = executive function. Effect sizes are Cohen's *d* corrected for sample size.
[a] Reflects a non-significant change on a continuous performance test; a measure of sustained auditory attention was considered an outlier ($d = 3.02$) and excluded from this analysis.
[b] Reflects within (adaptive treatment) group pre-post differences-insufficient data was available for the non-adaptive control group.
[c] Authors reported no significant group differences in performance on three cognitive tasks, and did not respond to email requests for unreported data for two additional measures.
[d] Two active treatment groups receiving identical treatment with the exception of one component were collapsed and compared to a waitlist group by the authors.
[e] The more rigorous control group was compared against the treatment group.

one exception: disagreements regarding study blinding (N = 2) were resolved by contacting each study's primary author for clarification.

2.2.1. Participant criteria

Participant criteria for the meta-analysis included the following: studies including children and/or adolescents with a primary diagnosis of ADHD (any of the three subtypes) and/or studies including children and/or adolescents documented as experiencing significant attention and/or hyperactivity/impulsivity problems by teacher and/or parent rating scale report (47).[7] Only studies whose participants were of low average or higher estimated intelligence were included in the review (0). Studies in which participants were described as exhibiting hyperactivity secondary to traumatic brain injury were excluded from the review (4).

2.2.2. Facilitative intervention training (FIT) criteria

Facilitative intervention training was defined as an intervention designed to strengthen one or more executive functions (e.g., set-shifting, inhibitory control, and working memory) and/or attentional processes related to their execution (e.g., orienting/alertness, selective/focused attention, divided attention, vigilance/sustained attention). Studies were included in the review if they were designed to achieve permanent, quantitative improvement in the targeted EF(s) and/or attentional processes related to their execution by means of computer-based, automated, or manual training exercises involving extensive repetition, practice, and feedback within and across weeks. Studies in which training focused exclusively on teaching children problem solving and self-regulatory techniques (CBT; 26), modifying/restructuring the curricula and environment demands (1), neurofeedback (8), academic (1), parent behavioral management (1), and visual imagery (1) trainings were excluded from the review.

2.2.3. Methodological criteria

Methodological inclusion criteria required that the study author(s) report pre- and post-treatment metrics for dependent measures from which an effect size could be estimated. Exclusion criteria included repeat data (2), single subject designs (4), non-empirical/review articles (64), and non-English articles (0). Articles located during our initial Tier I search that were unrelated to cognitive/executive function training in children with ADHD (31) were also excluded. One unpublished thesis was excluded from our review after attempts to correspond with the author by email were unsuccessful. A second unpublished thesis was excluded due to excessive attrition (dropout rate > 73%) that resulted in marginal ($n = 1$) or empty ($n = 0$) data cells.

2.2.4. Included studies

A total of 25 studies published or conducted (for unpublished studies) between 1999 and 2012 met study criteria and were included in one or more sets of analyses (see Appendix A). These studies incorporated either an adaptive ($k = 24$) or non-adaptive ($k = 1$) training methodology. Adaptive training conventionally involves the within-session adjustment of task difficulty based on each child's performance to ensure that they are engaged in training activities that are at or slightly above their current capabilities. Non-adaptive training exercises involve a predetermined number of trials that do not adjust for the child's performance during the task. The 25 studies (24 published studies, 0 dissertations, and 1 thesis) provided 436 effect sizes. Study characteristics and their corresponding effect sizes appear in Tables 2 and 3.

[7] Numbers in parentheses indicate the number of studies not meeting the specific inclusion/exclusion criteria and omitted from the meta-analysis.

Study data were categorized to address the following principal questions:

i. *Near transfer effects*. To what extent do facilitative intervention training (FIT) programs improve the cognitive functions they target? That is, to what extent do FIT programs result in improvements on untrained tasks measuring the same EFs targeted in training? Are these improvements observable at the conclusion of training (*near transfer, immediate outcomes*) and maintained over an extended time interval (*near transfer, long-term outcomes*)? Using different tasks that rely on the identical EF(s) being trained is necessary to demonstrate that the underlying EF improved, given that improvements on the trained tasks may merely reflect task-specific practice effects (Shipstead, Redick, & Engle, 2012). For example, training children's short-term verbal memory using an adaptive digit span task, then demonstrating that training transfers to improved performance on word list memory tasks, would represent a near transfer effect.
ii. *Far transfer effects*. To what extent do FIT programs result in improvements in behavioral, cognitive, and functional outcomes that were not directly trained but that are (at least partially) dependent on the trained cognitive processes? Are these far transfer effects apparent at the conclusion of training (*far transfer, immediate outcomes*), and maintained over an extended time interval (*far transfer, long-term outcomes*)? *Far transfer effects* represent improved performance and/or behavior on post-treatment measures that are highly dissimilar to and qualitatively different from those used during training, but that involve overlapping brain regions and depend to a considerable extent on the same cognitive abilities targeted during training (Unsworth & Engle, 2007). Training children's working memory and demonstrating that training transfers to improved academic achievement and/or behavioral functioning that relies to some extent on working memory processes represent examples of far transfer effects (Shipstead et al., 2012).
iii. If facilitative intervention training results in near or far transfer effects, are these effects moderated by the EF(s) targeted for training, or by other study characteristics described below and listed in Tables 2 and 3?

2.3. Coding of moderators

2.3.1. Outcome measurement interval

Study data were categorized based on the time interval reported between the conclusion of training and the collection of outcome measures (immediate or long-term). *Immediate* outcomes were defined as the first instance during which outcomes were assessed following the completion of FIT, and were collected between 1 day and 4 weeks following the final FIT session. *Long-term* outcomes were defined as outcomes assessed for a second time following the completion of FIT to examine treatment maintenance effects; duration ranged from greater than 4 weeks to 9 months.

2.3.2. Measurement characteristics

Outcome measurement type was coded as a categorical variable with four mutually exclusive categories; many studies reported outcomes across multiple categories: Subjective measures reflect an adult's perception of children's behavior, performance, or abilities, and were subdivided into (1) *blinded* and (2) *unblinded* ratings. Blinded ratings ($k = 8$) were defined as ratings completed by adults who were unaware of the child's treatment group status; unblinded ratings ($k = 13$) were defined as ratings completed by adults who were aware of the child's treatment status (including unintentionally as reported by the author) or if an effect size that included the control group used to control for expectancy effects could not be calculated due to inadequate data reported. Objective measures were subdivided into (3) laboratory tests of *cognitive performance* ($k = 11$) and (4) performance on standardized *academic achievement* subtests ($k = 3$). FIT near and far transfer outcome measures reported in each of the 25 studies are detailed in Appendix B.

2.3.3. Training target

Training Target was coded as a categorical variable based on the EF/attention systems targeted during training sessions. As shown in Table 1, many FIT programs targeted multiple cognitive systems. Training Target was classified into four types: 0 = *short-term memory training* ($k = 9$), which focused primarily on training short-term memory storage and rehearsal abilities with minimal focus on central executive (i.e., working memory) abilities[8]; 1 = *mixed executive functioning training* ($k = 9$), which focused on improving a combination of executive functions (e.g., short-term memory and behavioral inhibition) within and across sessions; 2 = *attention training* ($k = 6$), which focused exclusively on improving one or more specific attention-related abilities (e.g., sustained, selective, and divided attention); and 3 = *set shifting training* ($k = 1$), which focused on training and improving the ability to minimize interference while switching between two mental sets.

2.3.4. Control group

The type of control group(s) employed in each study was coded as an ordered categorical variable to index the quality of experimental control based on recommendations for gold standard experimental methodology (Shipstead et al., 2012). Studies were classified into ordinal groups, wherein higher values reflect more rigorous control methods: 0 = no control group ($k = 5$); 1 = waitlist control ($k = 5$); 2 = active/non-adaptive control ($k = 7$); 3 = active/adaptive control ($k = 8$). An active control group was defined as a group receiving a form of placebo or alternative treatment concurrently with the facilitative intervention training group. This approach is superior to waitlist-only designs, but does not control for potential expectation biases or contact intervention hours.[9] An adaptive control group was defined as a control group that received non-EF training that adjusts in difficulty based on individual performance throughout the training sessions, controls for expectation of change, and involves a similar level of contact intervention hours within and across sessions (cf. Shipstead et al., 2012, for a review of recommended methodological considerations).

2.3.5. Treatment intensity

Each study was coded using four continuous variables: total minutes trained across all sessions (range = 105 to 2400 min); total number of sessions (range = 3 to 36 sessions); total number of training weeks (range = 3 to 18 weeks); and number of minutes per session (range = 15 to 60 min).

2.4. Planned analyses

The Tier I analyses examined 17 studies reporting post-treatment outcomes on tasks similar to the training tasks (immediate, near transfer effects; 58 effects sizes); Tier II examined the 3 studies reporting long-term follow-up of near transfer effects (long-term, near transfer effects; 20 effect sizes). The Tier III analyses examined 21 studies (22 independent subgroups) reporting post-treatment data on outcomes dissimilar to training tasks (immediate, far transfer effects; 233 effect sizes); Tier IV examined the 7 studies reporting long-term follow-up of far transfer effects (long-term, far transfer effects; 125 effect sizes), respectively. Moderator analyses were conducted using a tiered approach, wherein categorical variables (i.e., Training Target, Outcome Type) were analyzed first using the mixed effects maximum likelihood

[8] Interestingly, most of the FIT programs marketed as "working memory" training failed to meet established criteria for working memory tasks, and are more accurately classified as short-term memory (STM) training (i.e., they provide only incidental training of central executive processing; Shipstead et al., 2012).

[9] The most rigorous control group was contrasted with the FIT group when multiple control groups were reported.

Table 4
Facilitative intervention training (FIT) for ADHD: meta analytic summary.

	Near transfer effects			Far transfer effects		
	Immediate (Tier I) *k* = 17	Pre to follow-up (Tier IIa) *k* = 3	Post to follow-up (Tier IIb) *k* = 3	Immediate (Tier III) *k* = 22	Pre to follow-up (Tier IVa) *k* = 7	Post to follow-up (Tier IVb) *k* = 7
Cohen's *d* effect size:	0.46 (0.26 to 0.66)	0.73 (0.46 to 0.99)	−0.18, *ns* (−0.42 to 0.06)	0.38 (0.21 to 0.54)	–	–
Corrected for sampling error	0.45 (0.25 to 0.65)	0.71 (0.45 to 0.97)	−0.17, *ns* (−0.41 to 0.06)	0.36 (0.20 to 0.51)	–	–
Corrected for sampling error/publication bias	0.23 (0.04 to 0.42)	0.71 (0.45 to 0.97)	−0.20, *ns* (−0.42 to 0.01)	0.36 (0.20 to 0.51)	–	–
Cohen's *d* effect size corrected for sampling error/publication bias						
Moderator analysis: training target						
STM only	0.63 (0.46 to 0.80) *k* = 8	–	–	0.39 (0.13 to 0.66) *k* = 9	–	–
Attention	0.05, *ns* (−0.29 to 0.38) *k* = 5	–	–	0.33 (0.08 to 0.57) *k* = 3	–	–
Mixed EF	0.06, *ns* (−0.22 to 0.33) *k* = 3	–	–	0.28 (0.10 to 0.45) *k* = 9	–	–
Set-shifting	0.70, *ns* (−0.17 to 1.57) *k* = 1	–	–	0.44, *ns* (−0.42 to 1.30) *k* = 1	–	–
Moderator analysis: Outcome Type						
Cognitive performance	–	–	–	0.14 (0.03 to 0.25) *k* = 11	0.45 (0.17 to 0.74) *k* = 2	−0.003, *ns* (−0.41 to 0.40) *k* = 2
Academic achievement	–	–	–	0.15, *ns* (−0.15 to 0.45) *k* = 3	0.28, *ns* (−0.13 to 0.69) *k* = 2	0.11, *ns* (−0.30 to 0.52) *k* = 2
Blinded subjective ratings	–	–	–	0.12, *ns* (−0.02 to 0.25) *k* = 8	0.15, *ns* (−0.19 to 0.49) *k* = 2	−0.11, *ns* (−0.45 to 0.23) *k* = 2
Unblinded subjective ratings	–	–	–	0.48 (0.30 to 0.66) *k* = 13	0.52 (0.31 to 0.73) *k* = 5	0.07, *ns* (−0.13 to 0.28) *k* = 5

Note: Cohen's *d* effect sizes (95% confidence intervals (CI) in parentheses) were corrected for sample size due to the upward bias of small *N* studies. Effect sizes are considered significantly different from 0.0 (statistically significant at $p < .05$) if their 95% confidence interval does not include 0.0. Moderator subgroup effect sizes are corrected for sampling error and publication bias when significant. *ns* = non-significant (95% CI includes 0.0; $p > .05$). *k* = number of studies; STM = short-term memory; mixed EF = studies training two or more executive functions.

Analog to ANOVA approach recommended by Lipsey and Wilson (2001). Additional continuous moderators were examined using random effects regression for meta-analysis (Lipsey & Wilson, 2001) if significant between-study heterogeneity remained at the overall study or subgroup level after accounting for categorical variables.

2.5. Computation of effect sizes

Means, *SD*s, and sample sizes for each group were used to compute Cohen's *d* effect sizes and 95% confidence intervals using Comprehensive Meta-Analysis (v2.2). When these data were unavailable, effect sizes were estimated using reported test statistics. For between-group comparisons, these statistics included each group's sample size and *t* or *p* values, each group's means and the comparison *p* value, or reported effect sizes converted to Cohen's *d*. For within-subject comparisons, a pre-post correlation of .5 was assumed when these data were not reported as recommended (Smith, Glass, & Miller, 1980). Cohen's *d* effect sizes were corrected for study sample size due to the upward bias in effect size magnitude of small *N* studies (Lipsey & Wilson, 2001). Cohen's *d* effect sizes are in standard deviation units, such that an effect size of 1.0 indicates that two groups differ by one standard deviation. An effect size of 0.2 is interpreted as small (detectable only through statistics), 0.5 as medium (detectable to a careful observer), and 0.8 as large (obvious to any observer; Cohen, 1988). Overall effect sizes were computed using a random effects model in which each study is weighted by its inverse variance weight ($1/SE^2$) as recommended by Hunter and Schmidt (2004). Meta-analysis macros for SPSS using random/mixed effects were used for all moderator analyses, and random effects models with inverse variance weighting were used for effect size calculation and all moderator analyses to correct for study-level sampling error (Hunter & Schmidt, 2004; Lipsey & Wilson, 2001).

2.5.1. Multiple effect sizes

Most studies reported data sufficient to calculate multiple effect sizes. The most common reason for studies reporting multiple effects sizes was the inclusion of near and far transfer effects across multiple tasks. Separate effect sizes were calculated for each task/outcome to be comprehensive and to allow studies to be included in as many analysis subsets as possible. To meet the independence assumption, only one effect size was used for each study in any given analysis (Lipsey & Wilson, 2001). This effect size reflected the average of all relevant effect sizes for that particular analysis (e.g., multiple rating scale scores reported in a study are averaged and imputed as a single effect size for subjectively measured outcomes).

2.5.2. Publication bias: the file drawer problem

Four studies did not provide data sufficient to calculate effect sizes for a subset of outcomes, but reported no significant between-group differences. These outcomes were retained in the analysis and assigned an effect size of 0.00 because omitting them would artificially inflate overall effect size estimates due to publication bias (Rosenthal, 1995). Four tests of publication bias were used for each analysis subtest (Fail-safe *N*, Begg & Mazumdar's rank correlation test, Egger's test of the intercept, and Duval & Tweedie's trim-and-fill procedure; Lipsey & Wilson, 2001). These results are provided in Appendix C. For analyses in which significant publication bias was detected, overall effect sizes were corrected using the methods recommended by Duval and Tweedie (2000), as summarized in Table 4.

3. Results

3.1. Tier I: near transfer effects (immediate post-treatment)

3.1.1. Moderator-independent immediate near transfer effects

A total of 17 studies reporting data on 636 individuals with ADHD were included in analyses examining immediate near transfer effects of facilitative intervention training for children with ADHD (Table 3). Across studies, children with ADHD exhibited small magnitude improvements on tasks similar to the training tasks ($d = 0.23$, 95% CI = 0.04 to 0.42; 81% population overlap[10]). The overall test of homogeneity was significant, suggesting that there is more variance among effect sizes than would be expected based on study-level error alone, and supports the analysis of potential moderators ($Q = 49.52$, $df = 16$, $p < .0001$).

3.1.2. Categorical moderators of immediate near transfer effects

Outcome Type was not examined as a potential moderator because all near transfer effects were based on objective laboratory task performance. Training Target was examined initially using mixed effects (maximum likelihood estimation) Analog to ANOVA (Lipsey & Wilson, 2001) to examine the extent to which effect sizes differed systematically as a function of cognitive training target. Studies were classified into three categories: STM Only ($k = 8$), Mixed Executive Functions ($k = 3$), and Attention only ($k = 5$). There were no studies targeting working memory alone or in combination with other EFs/Attention that reported near transfer effects (Table 1). Set shifting ($d = 0.70$, 95% CI = −0.17 to 1.57, *ns*) was examined qualitatively but not included in the analyses due to insufficient degrees of freedom (k = 1).

Analog to ANOVA results revealed that Training Target explained significant between-study differences ($Q_B = 30.86$, $df = 2$, $p < .0001$), such that no significant between-study residual differences remained after accounting for Training Target ($Q_W = 17.65$, $df = 13$, $p = .17$). As shown in Table 4, studies targeting short-term memory only ($d = 0.63$, 95% CI = 0.46 to 0.80; 60% population overlap) were associated with moderate magnitude increases in short-term memory. In contrast, studies targeting Attention Only ($d = 0.05$, 95% CI = −0.29 to 0.38, *ns*) and Mixed Executive Functions ($d = 0.06$, 95% CI = −0.22 to 0.33, *ns*) failed to find post-treatment changes in their training target (e.g., targeting attention did not result in significant improvement on other near transfer measures of attention).

Within-group residual variance was nonsignificant for the STM Only ($Q = 5.87$, $df = 7$, $p = .56$), Attention Only ($Q = 9.44$, $df = 4$, $p = .05$), and Mixed Executive Functions ($Q = 2.34$, $df = 2$, $p = .31$) groups, indicating that within each treatment group, effect sizes did not differ more than expected based on study-level sampling error. These findings indicate that Training Target was sufficient to account for between-study heterogeneity in effect size magnitude, and that additional moderator analyses are not warranted.[11]

[10] Percent overlap refers to the proportion of participants whose post-treatment scores remained within the range of pre-treatment scores (i.e., failed to demonstrate clinically significant improvement; Jacobson & Truax, 1991, criterion A). For this analysis, the 81% population overlap indicates that only 19% of individuals with ADHD showed clinically meaningful improvements at post-treatment on tasks highly similar to the cognitive training tasks they recently completed.

[11] Training target was correlated with additional potential moderators to examine the extent to which the obtained effect may be attributable to potential multicollinearity among moderators (e.g., STM-Only studies may differ systematically from studies targeting other/mixed EFs, leading to the appearance of a training target effect that is attributable instead to a secondary variable). Training Target coded dichotomously (STM Only, All Others) was not correlated significantly with any additional planned moderators including Control Group, Total Minutes, Total Sessions, Minutes Per Session, Total Weeks, and Publication Year (all p values ≥ .20). Thus, the most parsimonious conclusion is that the Training Target moderator effect is attributable to between-study differences in training targets rather than secondary moderator effects.

3.2. Tier II: near transfer effects (long-term follow-up)

Of the 17 studies reporting near transfer effects, only three studies (total $N = 101$) reported data sufficient to calculate long-term follow-up effect sizes; results should therefore be interpreted with caution. All three studies trained short-term memory. Follow-up duration ranged from 3- to 6-months across studies.

3.2.1. Pre-treatment vs. follow-up

Across studies, individuals with ADHD exhibited medium magnitude improvements between pre-treatment and long-term follow-up ($d = 0.71$, 95% CI = 0.45 to 0.97, $k = 3$). This effect was highly similar to the immediate, near transfer effect for studies targeting short-term memory only (Tier I: $d = 0.63$), suggesting maintenance of gains in these three studies. Heterogeneity tests and moderator analyses were not conducted given the small number of studies reporting long-term follow-up data.

3.2.2. Post-treatment vs. follow-up

Across the three studies reporting these data, individuals with ADHD maintained similar levels of performance between post-treatment and follow-up ($d = -0.20$, 95% CI = −0.42 to 0.01, *ns*). Heterogeneity tests and moderator analyses were not conducted given the small number of studies reporting long-term follow-up data.

Collectively, results from the three studies reporting long-term follow-up data suggest that short-term memory training is associated with medium magnitude improvements on non-trained short-term memory tasks, and that these gains are maintained across 3 to 6 month follow-up. These conclusions must be considered tentative, however, due to the small number of studies reporting long-term maintenance effects.

3.3. Tier III: far transfer effects (immediate post-treatment)

3.3.1. Moderator-independent immediate far transfer effects

A total of 21 studies with 22 independent subgroups (k = 22) reporting data on 733 individuals with ADHD were included in analyses examining immediate far transfer effects of cognitive training for children with ADHD (Table 3). Across studies, individuals with ADHD exhibited small to medium magnitude improvements on measures dissimilar to the training tasks ($d = 0.36$, 95% CI = 0.20 to 0.51; 78% population overlap). The overall test of homogeneity was significant, which indicates more variance among effect sizes than would be expected based on study-level error alone, and supports the analysis of potential moderators ($Q = 62.52$, $df = 21$, $p < .0001$).

3.3.2. Categorical moderators of immediate far transfer effects

Training Target was examined initially using mixed effects (maximum likelihood estimation) Analog to ANOVA to examine the extent to which effect sizes differed systematically as a function of cognitive training target. Studies were classified into three categories based on the Tier I results: STM Only (k = 9), Attention Only (k = 3), and Mixed Executive Functions (k = 9). Set Shifting ($d = 0.44$, 95% CI = −0.42 to 1.30, *ns*) was examined qualitatively but not included in the analyses due to insufficient degrees of freedom (k = 1). In contrast to the Tier I findings, the Analog to ANOVA results revealed that Training Target did not explain significant heterogeneity across studies ($Q_B = 1.08$, $df = 2$, $p = .58$). Based on this finding, all 21 studies (k = 22 independent subgroups) reporting data for far transfer outcomes were included in analyses of additional moderators.

Outcome Type was examined next to determine which aspects of children's functioning (academic achievement, cognitive test performance, and blinded and unblinded behavior ratings) are impacted by facilitative intervention training. Because most studies reported outcomes for multiple outcome categories, we elected to compute effect sizes separately for each outcome category and compare the obtained effect sizes using confidence interval analyses (Cumming & Finch, 2005). This method was selected for practical reasons as a compromise between meeting the independence assumption (Rosenthal, 1995) and including as many studies as possible in moderator analyses. For objective outcomes, results revealed significant, small magnitude improvements for cognitive test performance ($d = 0.14$, 95% CI = 0.03 to 0.25; k = 11), but nonsignificant changes in objectively measured academic achievement ($d = 0.15$, 95% CI = −0.15 to 0.45, *ns*; k = 3).

For subjective outcomes, results revealed medium magnitude improvements according to unblinded behavior ratings ($d = 0.48$, 95% CI = 0.30 to 0.66; k = 13), but nonsignificant behavior changes according to blinded behavior ratings ($d = 0.12$, 95% CI = −0.02 to 0.25, *ns*; k = 8). Confidence interval analysis (cf. Cumming & Finch, 2005) revealed that unblinded raters reported larger magnitude improvements relative to blinded raters ($p < .01$; non-overlapping 95% CIs) and objective measures of children's cognitive performance ($p < .01$; non-overlapping 95% CIs). Cognitive test performance, standardized academic achievement measures, and blinded ratings did not differ significantly in obtained effect sizes (all p values > .05; proportion CI overlap > .99). Comparison of objective measures and blinded ratings with unblinded ratings suggests that Hawthorne/experimenter effects were small to moderate (ES = 0.34 to 0.36).

Homogeneity tests for studies reporting cognitive test performance ($Q = 9.33$, $df = 10$, $p = .50$), academic achievement ($Q = 1.26$, $df = 3$, $p = .74$), and blinded behavior ratings ($Q = 4.87$, $df = 7$, $p = .68$) were all non-significant. These findings indicate that, within each subgroup, effect sizes did not differ more than expected based on study-level sampling error, and that additional moderator analyses are not warranted for these subgroups. In contrast, significant between-study heterogeneity was observed for the subgroup of studies using unblinded behavior ratings ($Q = 25.85$, $df = 12$, $p = .01$), supporting examination of additional moderators for this subgroup.

3.3.3. Continuous moderators of unblinded ratings of post-treatment far transfer effects

To examine factors potentially influencing unblinded behavior ratings, a mixed effects regression was conducted using the following variables defined previously: Control Group, Total Minutes, Total Sessions, Minutes per Session, Training Target (coded dichotomously based on the Tier I results), and Total Weeks. Results indicated that the model explained a significant degree of between-study variance ($R^2 = .77$, $Q_R = 19.99$, $df = 6$, $p = .003$), such that no residual between-study variance remained after accounting for the model ($Q_E = 5.88$, $df = 6$, $p = .44$). Only Control Group ($B = -0.31$, $p = .01$) was a significant predictor (all other p values > .45). These results are consistent with traditional views regarding experimental control, and indicate that effect sizes based on unblinded observer ratings decrease as experimental control increases.

3.4. Tier IV: far transfer effects (long-term follow-up)

Seven of the 21 studies reporting far transfer outcomes reported long-term follow-up data sufficient for effect sizes calculation (total $N = 231$). Three trained short-term memory, three trained mixed executive functions, and one trained attention; however, only 2 of the 7 studies reported outcomes other than unblinded behavior ratings, which limit the interpretability of the findings. Post-treatment follow-up duration ranged from 1 month to 9 months across studies.

3.4.1. Pre-treatment vs. follow-up

As shown in Table 4, when measured from pre-treatment to long-term follow-up, children with ADHD exhibited small-to-medium magnitude improvements according to unblinded raters ($d = 0.52$, 95% CI = 0.31 to 0.73, k = 5), but small to nonsignificant improvements according to blinded raters ($d = 0.15$, 95% CI = −0.19 to 0.49, *ns*; k = 2), cognitive test performance ($d = 0.45$, 95% CI = 0.17 to 0.74, k = 2), and academic achievement testing ($d = 0.28$, 95% CI = −0.13 to 0.69, *ns*; k = 2). These effect sizes were consistent with the immediate far transfer effects (Tier III). Heterogeneity tests and moderator analyses were not conducted given the small number of studies providing this data.

3.4.2. Post-treatment vs. follow-up

Children with ADHD maintained similar levels of performance between post-treatment and follow-up according to unblinded raters ($d = 0.07$, 95% CI = −0.13 to 0.28, *ns*; k = 5), blinded raters ($d = -0.11$, 95% CI = −0.45 to 0.23, *ns*; k = 2), academic achievement tests ($d = 0.11$, 95% CI = −0.30 to 0.52, *ns*; k = 2), and cognitive test performance ($d = -0.003$, 95% CI = −0.41 to 0.40, *ns*; k = 2). Heterogeneity tests and moderator analyses were not conducted given the small number of studies.

4. Discussion

The current meta-analytic review evaluated the extent to which facilitative intervention training (FIT) programs improve the cognitive and behavioral functioning of children with ADHD. These programs were developed based on the dual suppositions that (a) executive functions (EFs) and/or attentional processes integral to successful EF operation are significantly underdeveloped or impaired in children with ADHD; and (b) that the maturation and/or efficiency of neural circuitry underlying targeted executive functions can be accelerated by means of protracted training, practice, and feedback. Our review of extant empirical evidence provided mixed support for the first supposition. Of the executive functions and related attentional processes reviewed, only working memory (WM) central executive processes and vigilance/sustained attention abilities were associated with large magnitude deficits and related to core symptoms and/or functional outcomes in children with ADHD, rendering them the most promising candidates for FIT programs. In contrast, medium magnitude deficits were reported for the more specialized WM phonological and visuospatial storage-rehearsal subsystems (i.e., short-term memory) and the preponderance of evidence indicated intact inhibitory processes in children with ADHD (see Alderson et al., 2010, and Lijffijt et al., 2005, for meta analytic reviews). As a result, short-term memory and inhibition processes appear to represent less attractive and unbefitting candidates for FIT programs, respectively. Finally, too few studies examined EF set-shifting processes and their relation to ADHD-related functional outcomes to determine whether it represents an appropriate target for facilitative training.

The complementary supposition of FIT programs – that the maturation and/or efficiency of EF-related neural substrates can be accelerated by means of extensive training, practice, and feedback – was evaluated by meta-analysis. Prior to discussing these findings, we highlight a few key points to provide context for evaluating the extent to which gains in various outcome domains can be attributed to training programs designed to strengthen particular EFs and/or attentional processes. The first of these involves the extent to which training specific EFs and/or related attentional processes transfers to untrained tasks that rely on identical cognitive processes (i.e., near transfer effects). Documenting near transfer effects is necessary to ensure that improvement is associated with training as opposed to task-specific factors associated with practice or expectancy effects, and also helps validate the mechanisms responsible for potential transfer to more distal (far transfer) cognitive and behavioral outcomes (Shipstead et al., 2012). Demonstrating far transfer effects, however, is by far the more critical training objective given that the goal of FIT programs is not to improve children's scores on laboratory-based EF tasks, but to improve their general cognitive abilities and the myriad functional outcomes dependent upon these abilities. When evaluating the extent to which FIT programs result in far transfer effects, it is important to emphasize that improvement in far transfer outcomes is limited to a considerable extent by two factors: the magnitude of documented near transfer change, and the degree to which the far transfer outcome is dependent on the trained EF for successful execution (Redick et al., 2013).

The obtained meta-analytic results revealed moderate magnitude improvement on near transfer measures of children's cognitive performance for FIT programs targeting STM, and these effects remained evident at 3 to 6 months in the circumscribed number of studies ($k = 3$) that examined near transfer maintenance. In contrast, FIT programs targeting mixed executive functions (e.g., combined inhibition and short-term memory training), set-shifting, or only attention processes were not associated with significant improvements in the trained cognitive process(es). Collectively, this pattern of results was consistent with expectations derived from our literature review of EF deficits in children with ADHD and their association with impaired functional outcomes with one exception: the lack of significant near transfer effects for FIT programs targeting vigilance/sustained attention deficits. This finding may reflect the limited time devoted exclusively to strengthening vigilance/sustained attention abilities due to time spent training attention components that are likely not impaired in children with ADHD (i.e., inadequate potency; mode = 3 additional attention components trained). The plausibility of this explanation is consistent with the attention training study outcomes, wherein the sole attention training study (Semrud-Clikeman et al., 1999) that limited training to two components (i.e., sustained and selective attention) was the only one associated with a large magnitude near transfer effect.

Turning to the more critical training objective, training target was expected to serve as a significant moderator of far transfer outcome measures for two reasons. First, only short-term memory training was associated with significant near transfer effects (based on objective, cognitive task performance); and second, far transfer effects are capped by the magnitude of near transfer effects (Klauer, 2001; Shipstead et al., 2012). As a result, only studies targeting short-term memory would be expected to find significant far transfer effects. The finding that short-term memory training did not result in significantly larger far transfer effects, despite resulting in medium magnitude near transfer effects, was incongruent with this expectation. It was, however, congruent with our literature review indicating that short-term memory deficits, while apparent in many children with ADHD, are unrelated to most of the behavioral and functional outcomes associated with the disorder (e.g., Rapport et al., 2009). Unfortunately, most tasks included in programs marketed as “working memory” training were more accurately classified as short-term memory training (Gibson et al., 2011; Shipstead et al., 2012). Thus, the disappointing findings of minimal-to-no objectively measured improvements in behavior, academics, and cognitive functioning may reflect the incongruence between the specific EFs implicated in ADHD and the EFs targeted for training. Alternatively, this pattern of results may reflect the imbalance among studies incorporating both near- and far transfer outcome measures, and/or the greater number and diversity of measures used to assess far relative to near transfer training effects.

The lack of a significant Training Target moderator effect sanctioned examination of all FIT programs incorporating far transfer measures across four, mutually exclusive outcome categories. These included two categories each of objective (i.e., cognitive and standardized academic achievement subtest scores) and subjective outcome measures (i.e., blinded and unblinded ratings). The meta-analytic results revealed no evidence that facilitative intervention training improves children's academic achievement or blinded ratings of their behavior; however, significant, small magnitude far transfer effects were evident among the 11 studies that included cognitive performance outcome measures. This enhanced performance, albeit marginal and detectable only by statistical analysis (Cohen, 1988), warrants scrutiny given that nearly three-fourths of the studies reporting far transfer cognitive performance outcomes either failed to incorporate near transfer measures (27%) or reported far transfer effects (46%) that were similar to or of greater magnitude than their near transfer effects. For the former studies, the lack of demonstrated near transfer improvements renders it impossible to determine the extent to which improved cognitive performance reflects random or systematic influences, such as task-specific practice and expectancy effects, rather than the assumed strengthening of cognitive functioning. The latter studies' findings are equally perplexing and incongruent with transfer theory predictions (Klauer, 2001), which limit the magnitude of transfer to the multiplicative relation between near transfer improvement (i.e., the near transfer ES estimate) and the established relation between the training target and far transfer constructs. As an example, Klingberg, Forssberg, and Westerberg (2002) reported that children demonstrated larger magnitude far transfer improvements (ES = 1.05) relative to near transfer improvements (ES = 0.86) following visuospatial short-term memory and inhibition/choice reaction time training. However, the far transfer measures used in the study – the Stroop task and Raven's Progressive Matrices – are predicted only modestly by visuospatial short-term memory measures ($\beta = 0.18$ and 0.28) (Engle, Tuholski, Laughlin, & Conway, 1999; St Clair-Thompson & Gathercole, 2006). A somewhat higher correlation is reported between tasks with combined inhibition/choice reaction time elements (e.g., stop-signal paradigm) and the Stroop (i.e., $\beta = 0.49$; St Clair-Thompson & Gathercole, 2006). Accordingly, the maximum far transfer training effect size expected for this study is between 0.16 and 0.24 (attributable to VS STM improvements) and 0.42 (attributable to inhibition/CRT improvements); transfer theory specifies that far transfer effect sizes in excess of this hypothesized ceiling cannot be attributable entirely to neuronal-level improvements in the trained cognitive functions.[12]

Finally, non-blinded parent and teachers reported moderate magnitude improvement in children's behavior and/or executive functioning in the absence of objective evidence for these changes (i.e., illusory effects). The finding that far transfer gains were similar to or larger than near transfer improvement in several of these studies (e.g., Mezzacappa & Buckner, 2010), despite the modest relationship ($r = 0.18$ to 0.35) and limited variance (3% to 12%) shared between span measures and parent ratings (Naglieri, Goldstein, Delauder, & Schwebach, 2005), raises additional interpretative and methodological concerns that warrant scrutiny in future investigations.

Considered collectively, our meta-analytic review indicates that extant claims regarding the benefits associated with FIT programs, including improved academic achievement, cognitive performance, and reduced symptomatology in children with ADHD, are unsupported by empirical evidence. It would be premature, however, to conclude that bringing about fundamental and lasting changes in the cognitive abilities of children with ADHD is unattainable given the significant design and methodological limitations characteristic of the field.

One of the most fundamental design issues entails the lack of correspondence between the cognitive functions targeted by FIT programs and extant empirical evidence. Working memory is a patent example. Each of the STM FIT studies identified in the literature search relied on

[12] Multiplying the near transfer effect size (expressed in SD units) by the β-weight (which gives the SD change in the far transfer outcomes associated with a 1 SD change in the near transfer outcome), provides the maximum expected effect size for far transfer that is attributable to improvements in the near transfer (trained) construct. For example, if a 1 SD change in STM performance is associated with a 0.18 SD change in Stroop task performance, then a 0.86 SD change in STM performance (the near transfer effect size) could yield a maximum of 0.16 SD change in Stroop performance ($0.86 \times 0.18 = 0.16$). The obtained ES could be higher allowing for the possibility of synergistic effects, measurement unreliability, or improvements in unmeasured EF processes, but could also be lower due to the use of all incongruent Stroop trials in the study which nullifies its relationship with working memory (Hutchison, 2011).

a program which describes itself as "an evidence-based intervention for improved working memory".[13] A majority of their exercises, however, focus on training the least impaired aspects of WM in children with ADHD (viz., visuospatial and phonological short-term storage capacity; Gibson et al., 2011), as opposed to the significantly larger magnitude central executive processing deficits associated with impaired functional outcomes identified in the ADHD literature (Burgess et al., 2010; Kofler et al., 2011; Rapport et al., 2009). This latter point raises an interesting possibility for designing future FIT programs that warrants consideration. Although a great deal of work remains to be completed in terms of understanding the extent to which specific EF components and/or related processes are impaired in children with ADHD, it may prove worthwhile to adopt a complimentary yet unconventional approach by transposing the independent and dependent variables under investigation. For example, far transfer measures such as academic performance and achievement, which are known to be impaired in most children with ADHD, clearly reflect the composite influence of multiple interacting EF-related processes. Determining the degree to which these impaired functional outcomes require singular, additive, and synergistic contributions by specific EF-related processes may contribute meaningfully to the design of future interventions and allow them to uniquely target specific far transfer constructs. Finally, the significant methodological shortcomings that characterize FIT studies have been summarized succinctly in recent seminal reviews (Redick et al., 2013; Shipstead et al., 2012) and these reviews provide critical guidance for future experimental and outcome research.

Appendix A. Supplementary data

Appendices A, B, C, D. Supplementary data.

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