Executive Function/Cognitive Training for Children with ADHD: Do Results Warrant the Hype and Cost?

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The expanding use of computer-based training exercises to strengthen underdeveloped executive functions (EFs) and related cognitive abilities in children with ADHD has generated considerable buzz in the field and a good deal of hopefulness in parents, teachers, and mental health providers. A shared premise of these programs is the expectation of *neuroplasticity*— that repeated practice will result in lasting benefits because the brain will create new pathways (*neurogenesis*) and rearrange/expand existing pathways (*synaptogenesis*). This improvement is then expected to transfer to other activities and abilities that rely on these same neural networks (a phenomenon called *far transfer*).

The need to develop new, innovative treatments is critical given the disheartening Multimodal Treatment Study of Children with ADHD (MTA) study results. In the MTA, our gold-standard treatments for children with ADHD (medication, behavioral treatment, and their combination) failed to produce significant and lasting improvement in important academic and learning outcomes (Abikoff et al., 2004; Molina et al., 2009). This lack of significant improvement was not entirely unexpected because the treatments neither targeted nor engaged well-documented executive function (EF) deficits characteristic of the disorder (cf. Rapport, Orban, Kofler, & Friedman, 2013, for a review). EFs are integral to a wide range of complex cognitive abilities such as decision-making, multitasking, self-regulation, novel reasoning, problem solving, and organization. They are also robust predictors of children's overall learning abilities, including both reading and math aptitude (Shipstead, Redick, & Engle, 2012).

Compelling evidence reveals under-activation and delayed development of key frontal and prefrontal brain regions that support EFs in children with ADHD. Brain scan (e.g., fMRI) studies show under-activation in frontal and prefrontal brain regions (Cortese et al., 2012; Dickstein, Bannon, Castellanos, & Milham, 2006) that is temporarily and partially corrected with psychostimulants (Bedard, Jain, Hogg-Johnson, & Tannock, 2007). However, activating these regions is insufficient to improve children's working memory performance (Rubia et al., 2014) due to the developmentally delayed brain structures themselves (there is a 3-year delay in the maturation of key prefrontal regions that support EFs; Shaw et al., 2007). In other words, psychostimulant medications activate but do not grow these critical brain regions. This is a critical limitation of medication that cognitive training strives to address.

The growing interest in computer-based cognitive training programs also coincides with the recent reconceptualization of ADHD as a neurocognitive disorder (American Psychiatric Association, 2013) and emergence of new theories that implicate deficient EFs as either underlying causes or associated features of ADHD (Barkley, 1997; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Rapport et al., 2008). Meta-analytic and factor analytic studies consistently identify three primary EFs—working memory, behavioral inhibition, and set shifting—two of which (working memory, set shifting) show developmental stability throughout the lifespan and have a strong independent genetic basis (Dickstein et al., 2006; Friedman et al., 2008; Huizingua, Dolan, & van der Molen, 2006; Miyake et al., 2000). All three have been targeted in recent cognitive training studies for children with ADHD; however, only working memory, set shifting, and some attention processes appear to be promising treatment targets as discussed below.

Working Memory. Working memory (WM) is a limited-capacity, multi-component system that allows individuals to retain and process information for purposes of guiding behavior. The *working* component of WM (also referred to as the central executive [CE]) is responsible for the mental processing of information using four primary, interrelated processes: *continuous updating* (adding and removing items from working memory), *mental manipulation/dual processing* (operating on information while simultaneously holding the same or different information in memory), *serial reordering* (mentally manipulating the temporal order of held information), and *interference control* (minimizing internal and external non-relevant thoughts, images, and memory traces from competing for access in WM). No memory/storage functions are ascribed to the working components of working memory; instead, these executive functions serve to process, manipulate, and preserve the information currently held within the two, anatomically distinct, short-term storage/rehearsal components: the phonological (PH) and visuospatial (VS) subsystems. These two short-term memory systems handle verbal and non-verbal information, respectively (Baddeley, 2007).

Distinguishing between working (CE) and short-term memory deficits is critical for treatment development. Specifically, children with ADHD demonstrate large magnitude impairments in the CE (*working*) component of working memory (Kasper, Alderson, & Hudec, 2012; Rapport et al., 2008). More impor-

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tantly, experimental research indicates that these impairments may underlie their inattention (Burgess et al., 2010; Kofler, Rapport, Bolden, Sarver, & Raiker, 2010), hyperactivity (Rapport et al., 2009), impulsivity (Raiker et al., 2012), and social problems (Kofler et al., 2011). In contrast, short-term memory deficits in ADHD are much smaller, and appear to be generally unrelated to ADHD behavioral symptoms and functional outcomes (Alderson, Rapport, Hudec, Sarver, & Kofler, 2010; Raiker et al., 2012; Rapport et al., 2009). The working (CE) components of working memory are also intricately involved in a wide range of academic and intellectual abilities, ranging from math, reading, and listening comprehension, to complex learning and fluid reasoning (Swanson & Kim, 2007), whereas short-term memory is associated with more limited roles in learning outcomes (cf. Sarver et al., 2012, for a review).

Collectively, the brain regions and neural circuitry (primarily frontal/prefrontal) underlying CE working memory abilities represent highly promising engagement targets. Further, recent estimates indicate that 81% to 98% of children with ADHD are expected to have CE working memory deficits (Kasper et al., 2012; Rapport et al., 2013)—suggesting that an intervention that successfully improves CE working memory could have a broad impact for many if not most children with ADHD.

Behavioral Inhibition. Behavioral inhibition (BI) involves the ability to withhold or stop an ongoing or well-learned response. Among children with ADHD, evidence for BI deficits is relatively weak. Meta-analytic reviews indicate that impaired performance on BI tasks is more parsimoniously explained by basic attention, performance variability, and/or working memory process deficits (Alderson, Rapport, & Kofler, 2007) and is weakly or unrelated to core and secondary ADHD symptomatology (Alderson, Rapport, Kasper, Sarver, & Kofler, 2012; Solanto et al., 2001). Collectively, BI processes appear to be poor targets for cognitive training interventions given that BI processes are relatively intact among children with ADHD and weakly or unrelated to the disorder's core or secondary clinical features.

Set Shifting. Set shifting is the ability to switch between tasks or mental sets. Meta-analytic reviews reveal moderate magnitude set-shifting deficits in children with ADHD (e.g., Frazier, Demaree, & Youngstrom, 2004), and indicate that approximately 25% to 35% of children with ADHD exhibit deficits related to this domain. Studies examining the correspondence between set shifting and ADHD core symptoms reveal a modest (Willcutt et al., 2001) to moderate (Chhibaldas, Pennington, & Willcutt, 2001) relationship; however, the relationships among set shifting and ecologically valid outcomes such as reading and math aptitudes are more pronounced (Titz & Karbach, 2014). As a result, set shifting represents an additional promising target for engagement due to its prominent role in academic and educational success.

Attention. Several computer-based cognitive training programs directly target one or more attention-related processes in an effort to reverse the well-documented attention problems among children with ADHD. Because attention is considered an integral component of all EFs, it is often anticipated that targeting attention-related processes in children with ADHD will result in generalized performance improvements across multiple EFs. Among the diverse models of attention, studies of childhood ADHD frequently focus on four attention-related processes: orienting/alertness, selective/focused attention, divided attention, and vigilance/sustained attention.

Converging evidence indicates that approximately 33% to 55% of children with ADHD demonstrate vigilance/sustained attention deficits; however, performance on vigilance/sustained attention tasks is correlated weakly to moderately with parent and teacher ratings of core ADHD symptoms (Epstein et al., 2003) and objectively observed classroom attention (Barkley, 1991). Deficient sustained attention, however, is associated with poorer academic performance, lower grades and standardized test scores, and higher rates of special education placement and comorbid learning disabilities (Rapport, Denney, DuPaul, & Gardner, 1994). In contrast, orienting/alertness processes appear to be intact in ADHD, whereas evidence is mixed for selective/focused and divided attention processes.

METHOD

To understand the (potential) benefits of cognitive training for ADHD, we conducted a meta-analysis. Meta-analysis is a powerful method for statistically combining the results of multiple studies. It allows us to detect benefits of a treatment that individual studies might have missed. For example, many treatment studies are based on a small number of children, which means that the treatment's benefits must be very large for that study's statistics to detect them. By combining across every ADHD cognitive training study, we are able to detect smaller effects and have more confidence in the findings. Meta-analysis also allows us to compare across studies, to see if studies with certain characteristics find larger benefits than other studies (moderator analysis). For example, we were able to test whether treatments that trained short-term memory worked better than treatments that trained behavioral inhibition, and whether studies that trained a single executive function worked better than studies trying to train several executive functions. These moderator analyses also allowed us to test whether cognitive training has benefits on specific outcomes, such as academic achievement and ADHD behavioral symptoms.

A meta-analysis derives its power by including every study conducted on a topic. To ensure we found every ADHD cognitive training study, we scoured all of the primary databases in our field, sent emails to relevant professional organizations, and even checked all the studies cited by other cognitive training studies. At the time we conducted our review, there were 25 published and unpublished cognitive training studies that included a total of 913 children with ADHD. Thus, we were able to draw firm conclusions about the current status of cognitive training for ADHD. As we describe in more detail below, the results were generally disappointing. None of the "working memo-

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ry training" programs actually trained working memory (which is why we call them "short-term memory training" in the tables). More importantly, cognitive training did not decrease ADHD behavioral symptoms, did not improve academic achievement, and in most cases did not even improve the cognitive functions they were trying to improve. On the positive side, we were able to identify several reasons why these cognitive trainings do not work as advertised. Thus, we remain optimistic about the potential for next-generation cognitive training programs.

Studies were included in the meta-analysis if they met the following criteria:

- The cognitive training program was designed to improve one or more executive functions or attention abilities, and used computer-based or automated training exercises involving extensive repetition, practice, and feedback. Most programs used an *adaptive* training platform, wherein each task's difficulty level was adjusted dynamically based on children's performance. Adaptive training is expected to continually challenge targeted EFs or attention processes by getting harder as children's abilities improve.
- The study included children/adolescents with a primary diagnosis of ADHD and/or children identified as experiencing significant attention and/or hyperactivity-impulsivity problems as indicated by parent and/or teacher rating scale and/or clinical evaluation.
- The study reported sufficient data for us to estimate the magnitude of change (called an *effect size*) from pre-treatment to post-treatment, and/or study authors provided the necessary data when requested.

Study data were categorized to address the following central questions:

- To what extent does cognitive training improve performance on untrained tasks measuring the identical EFs targeted in training (i.e., *near transfer* effects[1])?
- To what extent does cognitive training improve behavior, cognitive functioning, or other important outcomes that are different from those used during training, but that involve overlapping brain regions and depend on the cognitive abilities targeted during training (i.e., *far transfer* effects[2]).

Five potential moderators were examined:

- Training target—categorized based on whether training focused on improving a specific EF, one or more attention processes, set shifting, or a combination of EFs.[3]
- Outcome measurement—coded using four mutually exclusive categories (*blinded* parent/teacher ratings, *unblinded* parent/teacher ratings, academic achievement, and cognitive test performance).
- Outcome measurement interval—coded as (a) *immediate* to assess potential benefits shortly after training concluded; or (b) *long-term* to assess maintenance effects one to nine months after treatment was finished.
- Training intensity— studies were coded based on *total minutes trained*, *total sessions trained*, *total training weeks*, and *minutes per session*.
- Control group—coded as *none*, *wait-list*, *active/non-adaptive*, *active/adaptive*: Active control involved receiving a placebo or alternative treatment concurrently; adaptive control received adaptive non-EF training, controlled for expectation bias, and involved a similar number of contact hours for both groups.

RESULTS

The Cohen's *d* effect sizes (ES) corrected for sample size reported below are in standard deviation units, such that an ES of 1.0 indicates a change in one standard deviation from pre-treatment to post-treatment. An ES 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).

The effectiveness of cognitive training programs on near transfer effects (i.e., measures similar to the abilities trained during the intervention) measured immediately at the conclusion of training was examined initially. Studies that trained short-term memory (STM) resulted in medium improvements ($d = 0.63$) in short-term memory (but no improvement in working memory). In contrast, studies attempting to improve attention ($d = 0.05$, *non-significant*) or multiple executive functions ($d = 0.06$, *non-significant*) did not significantly improve the cognitive functions they were trying to improve. Only one study tested set shifting training, and found a large ($d = 0.70$), albeit *nonsignificant* effect.

Only three of the 17 studies examined long-term follow-up data of near transfer effects, and for these, gains were maintained for 3–6 months. All three studies targeted short-term memory and represented a small subset of studies associated with medium magnitude EF improvements on immediate near transfer measures.

Collectively, short-term memory training (often inappropriately marketed as working memory training) appears to result in moderate improvements in short-term memory that would be noticeable to a careful observer. These benefits appear to last up to 6 months in the small subset of the studies examining maintenance effects. In contrast, training attention or training multiple executive functions at the same time did not improve attention or executive functioning, respectively. Next, we tested the more important question: Does cognitive training decrease ADHD symptoms or improve academic achievement? As you will see,

1. Training children's short-term verbal memory using an adaptive digit span task and demonstrating that training transfers to improved performance on a word list memory task is an example of a near transfer effect.
2. Training children's working memory and demonstrating that training improves academic achievement or behavioral functioning that relies to some extent on working memory processes are examples of far transfer effects.
3. It was interesting to note that 68% of the 25 cognitive training studies included in the meta-analysis describe working memory as a primary target for remediation; however, nearly all of them targeted primarily short-term memory (STM) rather than working memory processes.

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TABLE 1. Cognitive Training Study Characteristics

First Author [4] (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 & 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. (2012)	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. (2012)	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

Note. 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.

4. cf. Rapport et al., 2013, for references of the studies included in the meta-analytic review.

TABLE 2. Cognitive Training 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.

the answer is unfortunately "no" at this time.

Twenty-one of the 25 studies reported data on one or more far transfer outcomes. Far transfer refers to changes in behavior, skills, and abilities that rely to some extent on the trained executive function(s) or attention abilities. Overall, we found no differences across studies training different cognitive functions, which was surprising because of our earlier finding that only short-term memory training actually improved the cognitive function it was trying to train. Instead, the size of the benefits depended on whether the researchers measured behavior, academic performance, or untrained cognitive functions. Unfortunately, the only significant benefits were for *unblinded* parent and teacher ratings of behavior (d = 0.48). In contrast, we found nonsignificant or negligible benefits on cognitive test performance (d = 0.14), academic achievement (d = 0.15, *non-significant*), and *blinded* parent/teacher ratings of behavior (d = 0.12, *non-significant*). *Blinded* ratings mean that the parent or teacher did not know whether the child was in the treatment or the control group. They are more difficult and costly to obtain, but are considered to be more accurate reflections of actual changes in behavior. *Unblinded* ratings come from parents or teachers who know that their child is receiving the active treatment and who are often actively involved in delivering the treatment. We typically see bigger changes in *unblinded* ratings than in *blinded* ratings due to placebo effects and other well-documented biases. In our case, we found (a) benefits based on *unblinded* raters but no benefits based on *blinded* raters, and (b) similar "benefits" whether or not the trained cognitive ability actually improved. Taken together, these results suggest that children's behavior does not actually change (even though we really want it to). In other words, marketing claims that cognitive training is effective for ADHD are unsubstantiated at this time.

Collectively, cognitive training programs did not substantially improve cognitive abilities or chip away at the academic under-achievement associated with ADHD. They also do not appear to improve any aspect of children's behavior (e.g., inattention, hyperactivity, impulsivity) based on parent/teacher ratings when the raters were unaware of their child's treatment status. Conversely, parents and teachers who were aware that children were actively participating in a cognitive training regimen (and, in many cases, actively involved with treatment delivery) rated children's behavior as somewhat improved. This latter result is consistent with the well-documented placebo, Hawthorne, and illusory bias (uncontrolled expectancy) effects. In other words, claims regarding the benefits of cognitive training for ADHD appear to be unsupported, and data supporting cognitive training for ADHD is limited to placebo effects.

SUMMARY

Our meta-analytic review indicates that claims regarding the effectiveness of cognitive training programs to significantly improve academic achievement, cognitive performance, and core symptoms (inattention, hyperactivity, impulsivity) in children with ADHD are unsupported by empirical evidence. However, it would be premature to conclude that successfully training cognitive abilities in children with ADHD is unattainable. We identified several critical design and methodological limitations of existing cognitive training programs. One of the most fundamental design issues entails the lack of correspondence between the cognitive functions targeted by cognitive training programs and empirical evidence. For example, most of the studies advertised as training *working memory* relied on exercises that trained primarily short-term memory (i.e., the *memory* components instead of the *working* components of working memory). These *memory* components are minimally impaired in children with ADHD and generally unrelated to the disorder's core and secondary features. Thus, it is not surprising that improving short-term memory did not improve behavior or academic performance, any more than we would expect to strengthen our leg muscles by doing arm curls at the gym. Future cognitive training programs may hold more promise if they are designed to target the executive functions that are the most impaired in ADHD and, more importantly, are involved in the behavioral, academic, and functional outcomes associated with ADHD.

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REFERENCES

Abikoff, H., Lechtman, L., Klein, R.G., Gallagher, R., Fleiss, K., Etcovitch, J., … Pollack, S. (2004). Social functioning in children with ADHD treated with long-term methylphenidate and multimodal psycho-social treatment. *Journal of the American Academy of Child and Adolescent Psychiatry, 43,* 820-829.

Alderson, R.M., Rapport, M.D., Hudec, K.L., Sarver, D.E., & Kofler, M.J. (2010). Competing core processes in attention-deficit/hyperactivity disorder (ADHD): Do working memory deficiencies underlie behavioral inhibition deficits? *Journal of Abnormal Child Psychology*, *38*, 597-507.

Alderson, R.M., Rapport, M.D., Kasper, L.J., Sarver, D.E., & Kofler, M.J. (2012). Hyperactivity in boys with attention deficit/hyperactivity disorder (ADHD): The association between deficient behavioral inhibition, attentional processes, and objectively measured activity. *Child Neuropsychology*, *18*, 487-505.

Alderson, R.M., Rapport, M.D., & Kofler, M.J. (2007). Attention-deficit/hyperactivity disorder and behavioral inhibition: A meta-analytic review of the stop-signal paradigm. *Journal of Abnormal Child Psychology*, *35*, 745-758.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: Author.

Baddeley, A. (2007). *Working memory, thought, and action*. New York: Oxford University Press.

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

Barkley, R.A. (1991). The ecological validity of laboratory and analogue assessment

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methods of ADHD symptoms. *Journal of Abnormal Child Psychology*, *19*, 149-178.

Bedard, A.C., Jain, U., Hogg-Johnson, S., & Tannock, R. (2007). Effects of methylphenidate on working memory components: Influence of measurement. *Journal of Child Psychology and Psychiatry, 48*, 872-880.

Burgess, G.C., Depue, B.E., Ruzic, L., Willcutt, E.G., Du, Y.P., & Banich, M.T. (2010). Attentional control activation relates to working memory in attention-deficit/hyperactivity disorder. *Biological Psychiatry*, *67*, 632-640.

Chhabildas, N., Pennington, B.F., & Willcutt, E.G. (2001). A comparison of the neuropsychological profiles of the DSM-IV subtypes of ADHD. *Journal of Abnormal Child Psychology*, *29*, 529-540.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Cortese, S., Kelley, C., Chabernaud, C., Proal, E., Di Martino, A., Millham, M.P., & Castellanos, F.X. (2012). Toward systems neuroscience of ADHD: A meta-analysis of 55 fMRI studies. *American Journal of Psychiatry, 169*, 1038-1055.

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.

Epstein, J.N., Erkanli, A., Conners, C.K., Klaric, J., Costello, J.E., & Angold, A. (2003). Relations between continuous performance test performance measures and ADHD behaviors. *Journal of Abnormal Child Psychology*, *31*, 543-554.

Frazier, T.W., Demaree, H.A., & Youngstrom, E.A. (2004). Meta-analysis of intellectual and neuropsychological test performance in attention-deficit/hyperactivity disorder. *Neuropsychology*, *18*, 543-555.

Friedman, N.P., Miyake, A., Young, S.E., DeFries, J.C., Corley, R.P., & Hewitt, J.K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology: General*, *137*, 201-225.

Huizinga, M., Dolan, C.V., & van der Molen, M.W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia, 44*, 2017-2036.

Kasper, L.J., Alderson, R.M., & Hudec, K.L. (2012). Moderators of working memory deficits in children with attention-deficit/hyperactivity disorder (ADHD): A meta-analytic review. *Clinical Psychology Review, 32*, 605-617.

Kofler, M.J., Rapport, M.D., Bolden, J., Sarver, D.E., & Raiker, J.S. (2010). ADHD and working memory: The impact of central executive deficits and exceeding storage/rehearsal capacity on observed inattentive behavior. *Journal of Abnormal Child Psychology*, *38*, 149-161.

Kofler, M.J., Rapport, M.D., Bolden, J., Sarver, D.E., Raiker, J.S., & Alderson, R.M. (2011). Working memory deficits and social problems in children with ADHD. *Journal of Abnormal Child Psychology, 39*, 805-817.

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., & Wager, T.D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49-100.

Molina, B., Hinshaw, S.P., Swanson, J.M., Arnold, L.E., Vitiello, B., Jensen, P.S., … MTA Cooperative Group (2009). The MTA at 8 years: Prospective follow-up of children treated for combined-type ADHD in a multisite study. *Journal of the American Academy of Child and Adolescent Psychiatry, 48*, 484-500.

Nigg, J.T., Willcutt, E.G., Doyle, A.E., & Sonuga-Barke, E.J. (2005). Causal heterogeneity in attention-deficit/hyperactivity disorder: Do we need neuropsychologically impaired subtypes? *Biological Psychiatry*, *57*, 1224-1230.

Raiker, J.S., Rapport, M.D., Kofler, M.J., & Sarver, D.E. (2012). Objectively-measured impulsivity and attention-deficit/hyperactivity disorder: Testing competing predictions from the working memory and behavioral inhibition models of ADHD. *Journal of Abnormal Child Psychology, 40*, 699-713.

Rapport, M.D., Alderson, R.M., Kofler, M.J., Sarver, D.E., Bolden, J., & Sims, V. (2008). Working memory deficits in boys with attention-deficit/hyperactivity disorder (ADHD): The contribution of central executive and subsystem processes. *Journal of Abnormal Child Psychology, 36, 825-837.*

Rapport, M.D., Bolden, J., Kofler, M.J., Sarver, D.E., Raiker, J.S., & Alderson, R.M. (2009). Hyperactivity in boys with attention-deficit/hyperactivity disorder (ADHD): A ubiquitous core symptom or manifestation of working memory deficits? *Journal of Abnormal Child Psychology*, *37*, 521-534.

Rapport, M.D., Denney, C., DuPaul, G.J., & Gardner, M.J. (1994). Attention deficit disorder and methylphenidate: Normalization rates, clinical effectiveness, and response prediction in 76 children. *Journal of the American Academy of Child & Adolescent Psychiatry*, *33*, 882-893.

Rapport, M.D., Orban, S.A., Kofler, M.J., & Friedman, L.M. (2013). 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. *Clinical Psychology Review, 33*, 1237-1252.

Rubia, K., Alegria, A.A., Cubillo, A.I., Smith, A.B., Brammer, M.J., & Radua, J. (2014). Effects of stimulants on brain function in attention-deficit/hyperactivity disorder: A systematic review and meta-analysis. *Biological Psychiatry, 76*(8), 616-628.

Sarver, D.E., Rapport, M.D., Kofler, M.J., Scanlan, S.W., Raiker, J.S., Altro, T.A., & Bolden, J. (2012). Attention problems, phonological short-term memory, and visuospatial short-term memory: Differential effects on near- and long-term scholastic achievement. *Learning and Individual Differences, 22*, 8-19.

Shaw, P., Eckstrand, K., Sharp, W., Blumenthal, J., Lerch, J. P., Greenstein, D., ... Rapoport, J. L. (2007). Attention-deficit/hyperactivity disorder is characterized by a delay in cortical maturation. *Proceedings of the National Academy of Sciences*, *104*, 19649-19654.

Shipstead, Z., Redick, T.S., & Engle, R.W. (2012). Is working memory training effective? *Psychological Bulletin, 138*, 628-654.

Solanto, M.V., Abikoff, H., Sonuga-Barke, E., Schachar, R., Logan, G.D., ... Turkel, E. (2001). The ecological validity of delay aversion and response inhibition as measures of impulsivity in AD/HD: A supplement to the NIMH multimodal treatment study of AD/HD. *Journal of Abnormal Child Psychology*, *29*, 215-228.

Swanson, H.L., & Kim, K. (2007). Working memory, short-term memory, and naming speed as predictors of children's mathematical performance. *Intelligence, 35*, 151-168.

Titz, C., & Karbach, J. (2014). Working memory and executive functions: Effects of training on academic achievement. *Psychological Research*, Epub ahead of print.

Willcutt, E.G., Pennington, B.F., Boada, R., Ogline, J.S., Tunick, R.A., Chhabildas, N.A., & Olson, R.K. (2001). A comparison of the cognitive deficits in reading disability and attention-deficit/hyperactivity disorder. *Journal of Abnormal Psychology*, *110*, 157-172.

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