

Computerized Cognitive Interventions for Adults With ADHD: A Systematic Review and Meta-Analysis

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Objective: Treatments for adults with attention-deficit hyperactivity disorder (ADHD) are understudied, compared to children and adolescents with the same condition. In this systematic review and random-effects meta-analysis, we aim to evaluate the outcomes of computerized cognitive training (CCT) interventions in randomized controlled trials (RCTs) including adults with ADHD. **Method:** Cognitive outcomes and ADHD symptom severity were analyzed separately. In addition, the Cattell-Horn-Carroll (CHC) theory of cognitive abilities was used to categorize outcome variables into subdomains, which were analyzed separately in a subsequent analysis. **Results:** The results revealed a small positive change in overall cognitive functioning, a measure of all cognitive outcomes in each study, for individuals who took part in CCT compared to controls ($k = 9$, Hedge's $g = 0.235$, 95% CI [0.002, 0.467], $p = 0.048$, $\tau^2 = 0.000$, $I^2 = 0.000$). However, neither symptom severity nor specific cognitive outcomes (executive functioning, cognitive speed, or working memory) showed a significant improvement. **Conclusions:** We analyzed the risk of bias in the chosen studies and discuss the findings in terms of effect size. It is concluded that CCT has a small positive effect in adults with ADHD. Due to the lack of heterogeneity in intervention designs across the included studies, increased heterogeneity in future studies could help inform clinicians about the aspects of CCT, such as training type and length, that are most beneficial for this group.

Key Points

Question: This article addresses the effectiveness of computerized cognitive training (CCT) as a treatment option for adults who have attention-deficit hyperactivity disorder (ADHD). **Findings:** A synthesis of nine randomized controlled trials in this area showed an increase in overall cognitive abilities for adults with ADHD following CCT. **Importance:** The findings should help clinicians and researchers when considering the debate about the usefulness of brain training for treating ADHD in adults. **Next Steps:** Future research should test varied types of CCT programs in order to find out exactly which aspects are beneficial, such as changing the amount of training time or the difficulty level.

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The study is registered on the Prospero site (Registration Number: CRD42020190142).

 The preregistered design is available at https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=190142.

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Attention-deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder, which is usually first diagnosed in childhood, impacting a range of different behaviors, brain regions, and cognitive processes. The symptoms of ADHD are divided into two core dimensions, inattention and hyperactivity/impulsivity, in the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (American Psychiatric Association, 2013). Treatments include both pharmacological (e.g., stimulants for increasing focus) and nonpharmacological treatments, such as cognitive behavioral therapy (Geffen & Forster, 2018). The prevalence of ADHD is estimated to be between 4.4% and 5.2% in ages 18- to 44-year-olds (J. L. Young & Goodman, 2016).

In ADHD, the cognitive processes which are impacted are diverse and vary among individuals; however, there are some commonalities in executive functioning deficits. One of these executive functions (EFs), working memory, which deals with temporary storage and manipulation of information (Baddeley, 2000; Baddeley et al., 1984), can be impacted in ADHD. A meta-analytic comparison of healthy adults and adults with ADHD revealed working memory deficits with moderate effect sizes (Alderson et al., 2013). Higher order cognitive processes, known as EFs, are associated with frontal lobe processes guiding voluntary goal-directed behavior (Friedman & Miyake, 2017). Executive functioning deficits can impact the daily lives of adults with ADHD in many ways, including lower reading speed and accuracy, reading comprehension, and metacognitive skills (Miranda et al., 2017).

In light of the deficits observed in EF, research has focused on interventions to treat these deficits and thereby alleviate some of the symptoms of ADHD. Research on behavioral interventions in ADHD and its common comorbidities in adulthood has resulted in interest in computerized cognitive training (CCT) of higher cognitive functions, including EFs and working memory (e.g., Shah et al., 2017). In most cases, CCT involves sitting in front of a screen with instructions and visual information and making responses on a keyboard, for example, confirming on a keyboard whether or not two shapes are identical (Klingberg et al., 2002). These tasks resemble the cognitive tasks used in attention research and intend to improve the attention skills and alleviate the symptoms of ADHD, with variable number of practice hours (e.g., 25 hr per week; Klingberg et al., 2005). CCT treatments have been tested in multiple populations, including schizophrenia, mild cognitive impairment, Parkinson's disease, and multiple sclerosis (Harvey et al., 2018). For example, one recent review of 12 studies on people living with HIV found improvements in daily functioning and EF processes (Wei et al., 2022). This review involved 596 participants (mean age range 47.5–59.7). Another review found improvements in only some areas following CCT for 679 individuals who have Parkinson's disease (Gavelin et al., 2022). The 17 included studies ranged in mean age from 59.70 to 71.44. Generalizing to untrained skills may be more difficult, as was found in a review on autism spectrum disorder involving 705 participants from 19 studies with a range of mean study age of 4–20 (Pasqualotto et al., 2021). The success of CCT treatments in specific populations is mixed, as it depends on the population targeted. In other words, variable findings

could be due to the difference in starting points of cognitive abilities across patient populations. Certain groups of participants might not exhibit improvements in training due to a ceiling effect, meaning that they are already performing well on the task at pretest, so improvements at posttest are not noticeable. Another explanation for the variable findings might be the similarity of the outcome measures to the task being trained (Luis-Ruiz et al., 2020). It can be easier to find an improvement if the task being trained is very similar to the task being tested (Zhang et al., 2019), as demonstrated by the methodological issues identified by a review on CCT for mild cognitive impairment in 690 older adults. The number of studies and participants included could also impact the results. These factors could underlie the difference between making a strong conclusion about a small effect and not finding any effect at all. For instance, one 64-study meta-analysis on CCT for 3,954 older adults found that a small training effect for fluid intelligence became nonsignificant after adjusting for publication bias (Nguyen et al., 2019).

CCT relies in part on the idea of transfer: the phenomenon when effects of training are spread to other tasks and/or processes than those explicitly practiced. One of the ideas behind CCT is that training some domain-general processes can be done in the lab, such as working memory training, and this will then transfer to also influence EF processes in daily life. This spillover effect is known as far transfer, and it has proven difficult, if not impossible, to achieve in most settings (Sala et al., 2019). Near transfer, or learning that transfers to similar tasks, can be achieved more easily (Sala et al., 2019). The question of whether or not near transfer is enough to impact ADHD symptomatology remains.

CCT has also been extensively studied in children and adolescents with ADHD (for reviews, see, e.g., Sonuga-Barke et al., 2014; van der Donk et al., 2015). Although outcomes have been mixed, positive results led to the development of CCT software for children, including mobile games that are being considered in addition to the more traditional stimulant treatments (Lumsden et al., 2016; Rosetti et al., 2020; Ruiz-Manrique et al., 2014). Not many of these studies have been able to find a significant positive effect of CCT, but public interest in ADHD treatments has grown (e.g., Giacobini et al., 2018; Philippsen & Döpfner, 2020). This interest in behavioral treatments (for a review, see Lambez et al., 2020) has spilled over to the adult cohort, which is the focus of this study.

Adults exhibit a different array of ADHD symptoms compared to children. This is not only because children's lives are so different from adults but also might be in part due to neural differences between individuals whose symptoms persist in adulthood and those who are diagnosed in childhood but experience little or no symptoms in adulthood (Moffitt et al., 2015). It has been suggested that ADHD is actually an array of different neurophysiological problems that manifest in similar symptom clusters (Gonen-Yaacovi et al., 2016; Luo et al., 2019). Therefore, adults with ADHD should be investigated separately from children or adolescents with ADHD, and novel CCT treatments should be designed that fit this population specifically. CCT interventions for adults with ADHD have been assessed in several randomized controlled trials (RCTs) within the

last decade (included in the present meta-analysis), but to the best of the authors' knowledge, these have until now not been synthesized in a meta-analytic framework. In 2020, a meta-analysis was published on nonpharmacological interventions for all age groups of ADHD, including physical exercise and therapies (Lambez et al., 2020). This analysis included 18 studies with interventions of neurofeedback trials, cognitive behavioral therapy, cognitive training, and physical exercise. Studies from 1980 to 2017 were included. The most effective intervention type on ADHD cognitive symptomatology was found to be physical exercise. This wider scope was useful in showing that nonpharmacological interventions, such as cognitive behavioral therapy are promising. The focus of this review is CCT interventions, which have not been the subject of a comprehensive meta-analytic review in adults with ADHD.

The aim of this systematic review and meta-analysis is to evaluate the efficacy of CCT interventions on cognitive outcomes and symptom severity for adults with ADHD. Specifically, we aim to (a) evaluate the efficacy of CCT on overall cognitive outcomes and symptom severity in adults with ADHD; (b) evaluate outcomes according to the type of cognitive function being trained; (c) evaluate the quality and strength of evidence for cognitive training of adult individuals with ADHD; (d) identify elements of the computerized cognitive interventions that require further research in this population.

Method

The review targets publications with participant groups of individuals with ADHD in the control and treatment groups, where the average age reported by the study is over 18, and all of the participants have been diagnosed with ADHD in the past. The interventions include CCT with the intention of increasing working memory, attention, or any executive functioning in order to be as inclusive as possible and avoid selection bias. This study is preregistered on the Prospero site (CRD42020190142), where the protocol can be accessed.

Systematic Review: Search Strategy

The following databases were searched: Web of Science, American Psychological Association's (APA's) PsycINFO, PubMed, MEDLINE, and Education Resources Information Center on November 18, 2020, and an update to this search was performed on February 1, 2022. A librarian helped to develop the search strategy, including a detailed concept analysis, the design of the search query, and execution of the searches. The search query included the following:

("ADHD" OR "attention deficit hyperactivity disorder" OR "attention deficit disorder" OR "ADD" OR "attentional deficits") AND (train* OR transfer OR practice OR "brain training" OR plasticit* OR learn* OR improv* OR increase* OR benefit*) AND (attention OR attend OR "attentional control" OR memory OR task OR inhibit* OR focus* OR "cognitive task" OR "n-back" OR "cognitive control" OR executive function* OR "higher cognitive" OR "frontal lobe" OR intelligen* OR reasoning OR cognit*)

There were no restrictions on year of publication. This review was restricted to studies written in or translated to English. In order to minimize a bias introduced by the language of the search terms, the search included terms in all spellings of English dialects. After the databases were searched, the reference lists of the studies selected

after the full-text screen, as well as other recent reviews on ADHD, were checked for additional publications, and one was added as a result of this additional check. Additionally, we used the Semantic Scholar Paper Corpus (Ammar et al., 2018), accessed using the program Connected Papers (Tarnavsky Eitan et al., 2021) to check each included study for other related studies which could be eligible for inclusion. The software Covidence (Covidence Systematic Review Software, 2021) was used in the full-text review portion of the meta-analysis. One independent reviewer (P.E.) completed the title and abstract screening. Two independent reviewers (P.E. and C.B.) completed the full-text review. Disagreements were resolved by a third expert full-text reviewer (H.M.G.).

Systematic Review: Inclusion and Exclusion Criteria

The inclusion criteria were published studies of (a) RCTs, (b) a mean participant age between 18 and 65, (c) including persons with a primary diagnosis of ADHD, (d) receiving computerized cognitive behavioral training. Eligible interventions are those which intend to train aspects of cognition, such as executive functioning and working memory. The comparator group were participants with a diagnosis of ADHD in a passive (wait-list) or active (modified simple training) intervention. The eligible outcomes are standardized behavioral tests of cognition for use in the main analysis. The exclusion criteria were (a) studies which focus on a child participant group, where the average participant age is below 18; (b) review studies with no reports of original findings; (c) noncontrolled trials without a group-level reporting of outcomes; (d) studies in which the primary focus is a comorbid condition, disease, or behavior (e.g., gambling addiction); or (e) studies where a specific comorbidity was an inclusion criterion, except the formal diagnosis of a conduct or other attention disorder.

Data Management

Data extraction was completed using an Excel spreadsheet. One author (P.E.) extracted all of the data, and a second author (C.B.) extracted a randomly selected sample of 50% of the studies. The variables collected were the date and individual(s) who extracted the data, the year of publication, the comparison of groups as described in the publication, the name of the outcome test as described in the publication, the pre- and postaverage scores for each of these outcome tests and for each condition, and the effect direction. Cognitive outcomes included all tasks designed to measure cognition (e.g., EF and cognitive speed). All tasks which analyzed the skill or knowledge of the operator in performing the task and reported a measurement of accuracy, speed, or other score reflecting participant's skill level were included. There were no disagreements between the authors about the inclusion of cognitive tasks reported in the included studies. These outcome statistics were then analyzed using the software Comprehensive Meta-Analysis (Borenstein et al., 2013) by first calculating Hedge's *g*, standard error, and variance. Other variables which were extracted are outcome categories, the nature of the outcome (lab task or self-reported outcome measure), the name of the program used for computerized cognitive testing, the type of supervision, the total training time in weeks, the total dose of training in hours, the length of each session in minutes, the number of sessions received per week, the total number of sessions received, whether the control condition was active or passive, the activity the control group completed, whether or not the trial was registered,

the country the data were collected in, the mean age of participants, the mean IQ of participants, the mean adult ADHD self-report score (ASRS) of participants, the percentage of female participants, the percentage of participants with pharmacological treatments, and the mean years of education. Some of these complementary variables were not included in all studies (e.g., mean IQ score or mean years of education). The main outcome measure of the meta-analysis, overall cognitive outcomes, includes all nontrained tasks that were listed in the Results section of the included studies. The categorization into cognitive domains was performed using the broad domains heuristic of Cattell–Horn–Carroll (CHC) theory of cognitive abilities (McGrew, 2009). This theory about the structure of human cognitive abilities is used to study the psychometric properties of test batteries in factor-analytic research, as well as being a useful heuristic for review studies. A complete list of included tasks per study can be found in the [Supplemental Table S1](#).

Assessment of Bias

Risk of bias, focusing on different aspects of study design, conduct, and reporting, in the included studies was assessed using the Cochrane Risk of Bias 2 (RoB-2) tool (Sterne et al., 2019). Judgments for each category of risk can be “low,” “high,” or finding “some concerns.” The likelihood that features of the study design will give misleading results is graded based on the judgments of low risk, some concerns with the risk, and high risk. Each of the judgments refers to predetermined assessment for each domain of bias: selection bias, performance bias, detection bias, attrition bias, and reporting bias. Signaling questions were used in the algorithm of the most recent version of the RoB-2 tool (2019), which was then independently assessed by two independent reviewers (P.E. and C.B.). Disagreements were resolved by a third reviewer (H.M.G.).

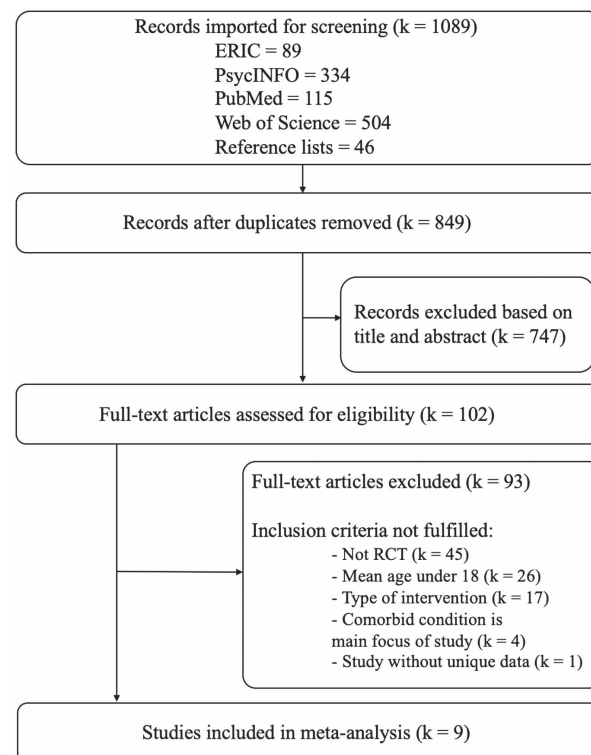
Statistical Analysis

The random-effects meta-analysis was performed using the software Comprehensive Meta-Analysis. The main outcome of interest was Hedge’s g with a 95% confidence interval (CI), calculated from the standardized mean differences of overall nontrained cognitive outcomes in each of the included studies. Heterogeneity (variability in study results) was assessed using the measure of inconsistency (percentage of total variation across studies due to heterogeneity) proposed by Higgins et al. (2003). Additionally, random-effects meta-analyses were performed to investigate nonprimary outcomes (symptom severity and cognitive domains based on the CHC framework). The outcome of symptom severity was extracted as ADHD symptom total scores. The additional outcomes of broad cognitive domain categories (cognitive speed, EFs, and general short-term memory) were created based on the CHC theory of broad cognitive abilities. Since the sample sizes in most of the included studies were low, metaregression for covariates, such as gender, was ruled out. Following our a priori protocol, we excluded publications that rely on data from the same data set or overlapping data sets ($k = 1$).

Transparency and Openness

These systematic review and meta-analysis follow a preregistered protocol (CRD42020190142). All data used in this study were taken from previously published articles (see References section) and can

Figure 1
Systematic Review Flowchart



Note. RCT = randomized controlled trial; ERIC = Education Resources Information Center.

be accessed through the original sources. The template data collection form, the data extracted from included studies, the data used for all analyses, and the analytic code are available on request from the corresponding author. This study follows the APA Style Journal Article Reporting Standards for articles reporting meta-analyses.

Results

Systematic Review

Figure 1 shows the study selection process. This figure describes the process of evaluating the literature and eliminating studies which do not fit the inclusion criteria in this review. Nine publications were selected into the systematic review (Dentz et al., 2020; Gropper, 2014; Jaquerod et al., 2020; Mawjee et al., 2015, 2017; Ryoo & Son, 2015; Stern et al., 2016; Virta et al., 2010; Zilverstand et al., 2017). See Table 1, for a description of the participants and Table 2, for a description of the studies. Table 3 shows the risk of bias results. In Table 4, a summary of the meta-analytic results using Hedge’s g for cognitive outcomes can be found. The additional random-effects meta-analyses of cognitive domain categories (executive functioning, cognitive speed, and general short-term memory) are listed below, with figures in the [Supplemental Materials](#).

Characteristics of the Included Studies

The included studies and some of their key characteristics can be seen in Table 1 (see Appendix for references). Each study includes a

Table 1
Characteristics of Participants in the Included Studies

Study	<i>N</i>		Age (<i>M</i>)		Gender (% women)		Pharmacological treatment (%)		ASRS score (<i>M</i>)		Location (country)
	Control	CCT	Control	CCT	Control	CCT	Control	CCT	Control	CCT	
Dentz et al. (2020) ^a	21	23	43.90	39.48	52.38	69.57	57.14	69.57	—	—	France
Gropper (2014) ^b	21	24	28.04	28.04	66.13	66.13	26.00	26.00	41.98	41.98	Canada
Jaquero et al. (2020) ^{a,b}	14	14	21.10	21.10	25.00	25.00	0.00	0.00	—	—	Switzerland
Mawjee et al. (2015)	32	32	23.53	23.78	56.25	59.30	59.37	59.37	49.19	49.00	Canada
Mawjee et al. (2017)	9	8	23.11	23.67	58.33	44.44	60.50	60.5	48.44	51.33	Canada
Ryoo and Son (2015) ^b	8	8	—	—	—	—	—	—	—	—	Korea
Stern et al. (2016) ^a	13	26	36.41	37.99	57.69	65.91	38.30	38.46	45.74	45.79	Israel
Virta et al. (2010)	10	9	34.0	32.0	60.00	22.22	70.00	55.56	—	—	Finland
Zilverstand et al. (2017) ^a	6	7	39.8	34.0	50.00	57.14	50.00	42.86	—	—	The Netherlands

Note. CCT = computerized cognitive training; ASRS = Adult ADHD Self-Report Scale; ADHD = attention-deficit hyperactivity disorder. *N* reflects those participants who completed the study, excluding dropouts. Missing data occur when studies have not reported the variable in the publication.

^a Four out of nine studies used an active control condition, which was described as (a) a low-intensity shorter training comparison, (b) baseline nonadaptive 1-back, (c) a simple nonhierarchical version with less executive function demands, and (d) active control group without feedback. ^b Studies that did not report separate demographics for each treatment group. The values presented in these cases are demographics across all included participants.

modest number of participants (range 13–64), with no exclusion criteria for medication, and ages ranging on average from young to middle adulthood (mean age range 21.1–41.6). The gender distributions, location, mean pharmacological treatment use, and mean ASRS scores lend further information about the included studies. The total number of individuals in the control groups across all studies was 134, and the total number of individuals receiving a CCT intervention was 151. An introduction to the nine included studies will now be presented, in order of publication date.

The first of the studies included in this review focused on 19 individuals with ADHD who were all diagnosed by a specialist at the start of the study (Virta et al., 2010). The intervention used was a series of nine tasks, such as an adaptive version of a continuous performance task, attempting to train a host of different functions. A neuropsychological test battery called CNS Vital Signs was used as a cognitive outcome measure. The authors conclude that a completely blinded study which aims to eliminate placebo effects would be almost impossible to carry out reliably.

In the second included study, Gropper et al. (2014) carried out an intervention involving 45 individuals. Cogmed's working memory training was used as the intervention program. The authors state that a benefit of this program is that the participant can choose the time of the training to fit their schedule. The third included study on 16 university students with ADHD used a continuous performance task described as similar to a go/no-go paradigm as an outcome measure (Ryoo & Son, 2015). A Korean CCT task where participants practice a game of archery and racing was used. Fourth and fifth of the studies in the meta-analysis, there are two studies authored by Mawjee et al. (2015, 2017), one of which is a pilot study with 17 individuals. The other Mawjee et al.'s study had 64 intervention participants and control participants, the biggest among the included studies. These studies used a battery of measures for working memory, and the intervention was working memory training by Cogmed. A software used in the sixth study was AttenFocus (Stern et al., 2016). There were 39 participants who completed the training, but 60 participants were originally recruited and randomized into

Table 2
Design of Interventions in the Included Studies

Study	Training program	Control group type ^a	Dose total (hr)	Session length (min)	Sessions per week	Number of sessions (total)	Total training time (weeks)
Dentz et al. (2020)	CWMT	Passive	17.45	41.89	5	25	5
Gropper (2014)	CWMT	Passive	18.75	45	5	25	5
Jaquero et al. (2020)	Adaptive dual <i>n</i> -back task	Active	9	30	4.5	18	4
Mawjee et al. (2015)	CWMT	Passive	18.75/6.25 ^c	45/15 ^c	5	25	5
Mawjee et al. (2017)	CWMT	Passive	18.75/6.25 ^c	45/15 ^c	5	25	5
Ryoo and Son (2015)	Laxtha neurofeedback	Passive	10	40	3	15	5
Stern et al. (2016)	AttenFocus	Active	18	20	4.5	54	12
Virta et al. (2010)	A series of cognitive tasks ^b	Passive	20	60	2	20	10
Zilverstand et al. (2017)	Mental calculation task	Active	4	60	1	4	4

Note. Training program = the name of the software used for computerized cognitive training; CWMT = Cogmed working memory training. Dose and session length are at times presented as an average and otherwise reported as the training program goal.

^a Control group type can be either an active intervention, usually a simple task such as 1-back, or passive, such as a wait-list control. ^b Continuous performance task; digit search; circle-letter sequence; digit arrangement; alternating rules; digit-letter search; counting while reading; circle sequences. ^c These values are (a) for the standard-length training condition and (b) for the short-length training condition. The standard-length condition was used for the meta-analyses.

Table 3
Cochrane RoB-2 Tool Overview of Results

Study	D1	D2	D3	D4	D5	Overall
Dentz et al. (2020)	+	!	!	+	!	!
Gropper (2014)	+	!	!	–	–	–
Jaquerod et al. (2020)	+	!	!	–	–	–
Mawjee et al. (2015)	+	+	+	–	!	–
Mawjee et al. (2017)	+	–	!	–	+	–
Ryoo and Son (2015)	+	+	+	–	!	–
Stern et al. (2016)	+	–	!	+	!	–
Virta et al. (2010)	+	!	+	+	!	–
Zilverstand et al. (2017)	+	!	!	–	!	–

Note. RoB-2 = Risk of Bias 2; D = domain. Low risk (+), some concerns (!), high risk (–). Domain 1 = randomization process; Domain 2 = deviations from the intended interventions; Domain 3 = missing outcome data; Domain 4 = measurement of the outcome; Domain 5 = selection of the reported result.

treatment groups, showcasing the considerable attrition common in this population and intervention type. A neuropsychological test battery called IntegNeuro was used to assess outcomes.

The study with the lowest number of participants ($n = 13$) had an intervention that involved a unique mental calculation task with an active control group (Zilverstand et al., 2017). One positive aspect of this seventh included study was a strict set of inclusion criteria for participants, considering comorbid conditions and diagnostic thresholds for ADHD at the recruitment stage. The eighth study included 28 participants and chose a dual n -back task as the training task for working memory training (Jaquerod et al., 2020). Specifically, training selective attentional processes using tasks which require a high cognitive load might be a promising approach for patients with ADHD, which this study aimed to investigate. Finally, in the ninth study included in this review, Dentz et al. (2020) used the Cogmed software in their study of 44 participants and about half of the participants in each group reported taking medication to treat the symptoms of ADHD, as is typical across most of the included studies.

The CCT for ADHD is usually practiced using a software program which the participant has access to for a limited amount of time each day. The participant is told how many minutes to practice in a certain time span in order to be part of the study. Table 2 details the type and amount of training, as well as the type of control condition employed by each of the studies.

Risk of Bias

In all cases, the authors' assessments of risk corresponded to the algorithm responses of the Cochrane RoB-2 tool (see Table 3). One study resulted in some concerns, while the rest had overall high risk of bias scores, using the RoB-2 tool algorithm. The overall bias score is rated as high risk if any one of the domains is high risk. None of the studies in this review were judged to have an overall low risk of bias. All, except one study, were judged as high risk of bias.

Meta-Analytic Results

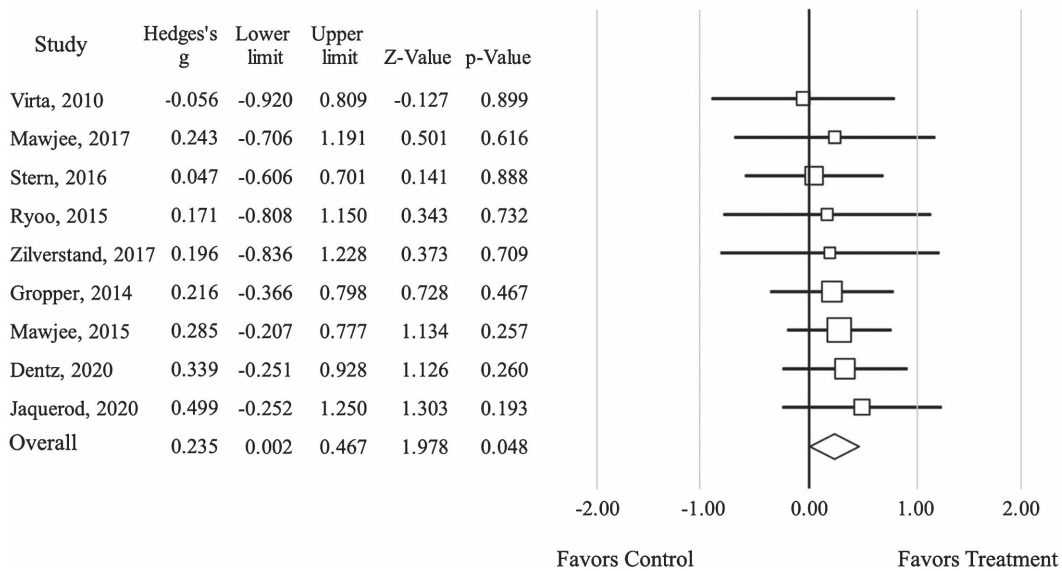
The results of the random-effects meta-analysis for the main outcome of all cognitive outcomes showed a small and statistically significant effect size ($k = 9$, Hedge's $g = 0.235$, 95% CI [0.002, 0.467], $p = 0.048$, $\tau^2 = 0.000$, $I^2 = 0.000$, Prediction Interval [PI] = 0.00–0.47; Figure 2). There were no indications of funnel plot asymmetry based on visual inspection. Table 4 lists the details of these results. A sensitivity analysis using a leave-one-out procedure was conducted. By recalculating the summary effect after iteratively removing the studies one at a time, the studies can be ranked by how much influence they have over the overall result of the meta-analysis. The highest influence over the overall result was a difference in Hedge's g of 0.06 (Mawjee et al., 2015), indicating that none of the studies had a significant amount of influence over the overall cognitive outcome.

The additional analyses resulted in data for three domains. Five of the included studies assessed at least one measure of executive functioning and the results of the meta-analysis were nonsignificant ($k = 5$, Hedge's $g = 0.314$, 95% CI [–0.282, 0.909], $p = 0.302$, $\tau^2 = 0.267$, $I^2 = 58.786$, PI = –0.23–0.91). Likewise, the effect of the intervention on cognitive speed was nonsignificant ($k = 4$, Hedge's $g = 0.104$, 95% CI [–0.216, 0.425], $p = 0.523$, $\tau^2 = 0.000$, $I^2 = 0.000$, PI = –0.22–0.43). The third cognitive domain category, general short-term memory, included eight studies and resulted in a nonsignificant effect ($k = 8$, Hedge's $g = 0.230$, 95% CI [–0.009, 0.469], $p = 0.059$, $\tau^2 = 0.000$, $I^2 = 0.000$, PI = –0.06–0.47). The PIs indicate that we can assume that if another similar study was added to the results of this review, all three of the above listed cognitive domain categories would either have small positive effects of the intervention, or perhaps even indicate a small advantage to being in

Table 4
Meta-Analytic Results for Overall Cognitive Outcomes

Study	Hedge's g	SE	Variance	Lower 95% CI	Upper 95% CI	Z score	p value
Virta et al. (2010)	–0.056	0.441	0.195	–0.920	0.809	–0.127	0.899
Mawjee et al. (2017)	0.243	0.484	0.234	–0.706	1.191	0.501	0.616
Stern et al. (2016)	0.047	0.333	0.111	–0.606	0.701	0.141	0.888
Ryoo and Son (2015)	0.171	0.500	0.250	–0.808	1.150	0.343	0.732
Zilverstand et al. (2017)	0.196	0.527	0.277	–0.836	1.228	0.373	0.709
Gropper (2014)	0.216	0.297	0.088	–0.366	0.798	0.728	0.467
Mawjee et al. (2015)	0.285	0.251	0.063	–0.207	0.777	1.134	0.257
Dentz et al. (2020)	0.339	0.301	0.090	–0.251	0.928	1.126	0.260
Jaquerod et al. (2020)	0.499	0.383	0.147	–0.525	1.250	1.303	0.193
Overall	0.235	0.119	0.014	0.002	0.467	1.978	0.048

Note. SE = standard error; CI = confidence interval.

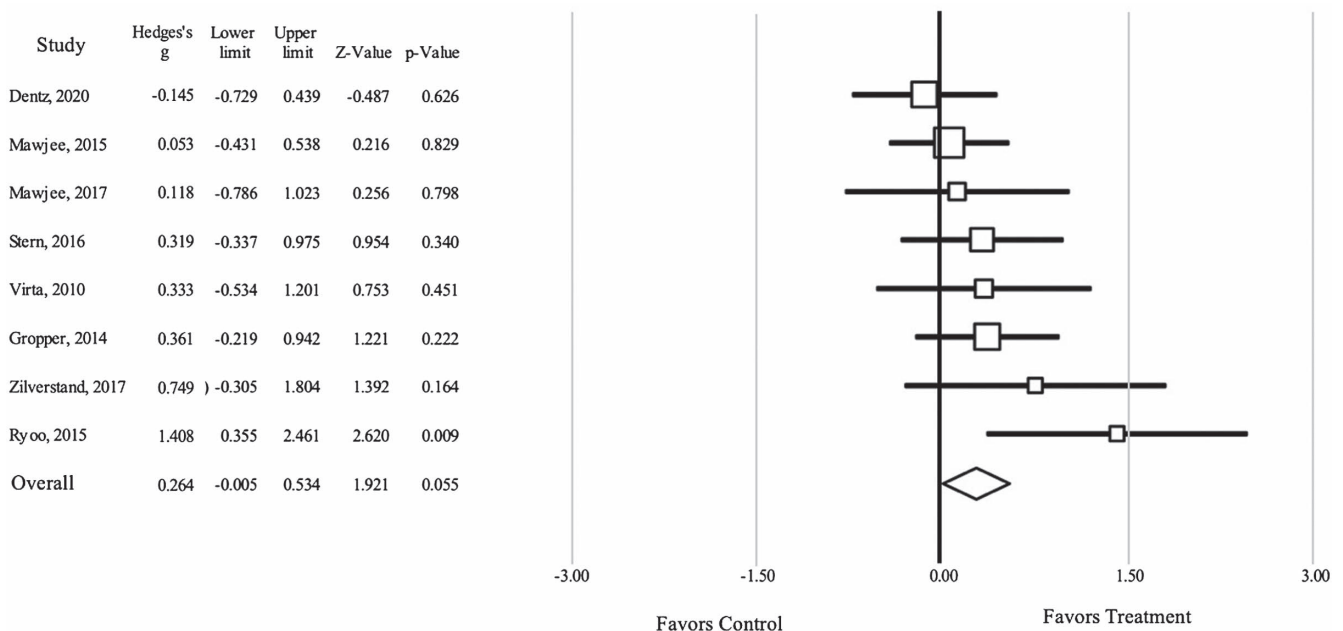
Figure 2*Overall Cognitive Outcomes Comparing Computerized Cognitive Training and Control*

Note. The lower limit refers to the lower 95% confidence interval (CI), and the upper limit refers to the upper 95% CI. The last row, overall, refers to the summary effect estimate. The size of the square refers to the sample size and weight of the included study.

the control condition, due to the lower end of the PI falling below zero.

A visual representation of the effect sizes shows the lower 95% CI to be 0.002 and the upper 95% CI to be 0.467 (Figure 1), with a p value of 0.048, below our chosen α of 0.05.

We also analyzed symptom severity, which included any self-reported questionnaires of ADHD (Figure 3). The most commonly used scale was the Adult ADHD Self-Report Scale. The summary effect size estimate was not significant ($k = 8$, Hedge's $g = 0.264$, 95% CI $[-0.005, 0.534]$, $p = 0.055$, $\tau^2 = 0.000$, $I^2 = 0.000$, PI = $-0.01-0.53$).

Figure 3*Symptom Severity Comparing Computerized Cognitive Training and Control*

Note. The lower limit refers to the lower 95% confidence interval (CI), and the upper limit refers to the upper 95% CI. The last row, overall, refers to the summary effect estimate. The size of the square refers to the sample size and weight of the included study.

Interpreting the Effect Sizes

For the analysis of the impact on cognitive outcomes in general, a Hedge's g of 0.24 was found (95% CI [0.002, 0.467], $p = 0.048$). This result can be interpreted in several ways. First, using common-language effect size estimation (McGraw & Wong, 1992), there is a 56.5% chance that a randomly selected individual in the treatment group will have a higher posttest score compared to their pretest score. This has also been called *probability of superiority* (Magnusson, 2021). If this result is able to transfer to a clinical setting, this means that there could be, on average, a 56.5% chance of improvement in overall cognitive outcomes for adults with ADHD who receive a treatment of CCT like the ones included in this meta-analysis. Another way of interpreting the result would be to note that 90.8% of the pre- and posttest scores overlap. Based only on this evidence, and disregarding the risk of bias analysis for the moment, one could interpret this overall result to mean that a small improvement is possible, with the chances being marginally better than the flip of a coin. Results of the meta-analysis for the impact of the intervention on self-report scales for ADHD symptom severity—filled in by the participants before and after the training—are likewise inconclusive or discouraging, depending on how the data are interpreted. This is an important outcome which all studies measured, because it can show an individual's perception of the usefulness of the treatment for improving the symptoms of ADHD. In other words, "How good is the training at lessening the symptoms of ADHD?" A Hedge's g value of 0.264 may be too small to be of interest (and nonsignificant), and the lower end of the CI is less than zero (lower 95% CI [−0.005]). We were therefore also interested in whether or not there are any benefits of CCT for specific cognitive functions, and none of these meta-analyses proved significant. Interpreting the significant effect size results and CIs using Hedge's g for this review, it can be concluded that CCT is likely to improve overall cognitive outcomes, but that the size of the effect is, on average, very small (Fritz et al., 2012).

Discussion

The aim of this study was to perform a review and meta-analysis on CCT interventions in ADHD in adults. The result of the systematic review was nine publications with original data sets which followed a RCT design with pre- and posttest measures of cognition for adults with ADHD taking part in a CCT intervention. Based on the criteria recommended by Guolo and Varin (2017), it was deemed that there was enough data to perform the planned random-effects meta-analyses. The results of the meta-analysis and the risk of bias assessment will be discussed below. Implications for clinicians and future research are that CCT for adults with ADHD should be investigated in a more systematic way to allow for evidence-based practice.

The results of the random-effects meta-analysis showed that the CCT intervention may benefit overall cognitive outcomes, by a small amount. The results of the random-effects meta-analysis for symptom severity did not find a significant improvement. Neither did the random-effects meta-analyses on the CHC-categorized subdomains of cognition (EFs, cognitive speed, general short-term memory) provide any significant result, but more RCTs with varied outcome measures are needed.

For CCT to improve symptomatology, the idea of transfer of cognitive skills from one area to another (i.e., from training to daily

living) must be supported. Our findings of a slight positive effect of training on overall cognitive outcomes are in line with current research in the area of transfer of working memory training. Five-week training programs are commonly investigated in this area and seem robust in terms of training throughout adulthood (Dahlin et al., 2008). There is support for near transfer (Sala et al., 2019). However, evidence for improvement in core ADHD symptoms (i.e., far transfer; Bigorra et al., 2016) is not found. The outcome tests chosen for measuring possible improvements in cognition may influence if any improvement due to training can be found. To test if far transfer has occurred, researchers often aim to select outcome measures that are different from the originally trained tasks (Sala & Gobet, 2017). For instance, if the CCT involves memorizing strings of numbers, the outcome measures might look at closely related tasks such as memorizing the location of pictures on a map to test for near transfer but also for cognitive functions different from memory. In this example, a test that involves far transfer could be a self-reported questionnaire of ADHD symptoms.

This review also underscores the importance of selecting appropriate CCT outcome measures, including psychometric tests of cognitive functions commonly affected in ADHD (e.g., attentional control) and well-validated ADHD symptom inventories. One study, including 55 adults with ADHD, posited that questionnaire measures can sometimes reveal complaints about cognitive functioning that are not captured by objective tests (Fuermaier et al., 2015). However, the objective tools (such as selective attention, vigilance, and word recognition tasks, among many others) were also found to be instrumental in identifying other problem areas. In the present review, we have looked at both categories discussed by Fuermaier et al. (2015): objective measures, in other words "cognitive outcomes," and subjective measures, namely "symptom severity." This still leaves the question: Which cognitive tasks measure the deficits specific or indicative of ADHD? These are the tasks which we could expect to see an improvement in following a well-designed CCT intervention, if the intervention is successful in targeting the cognitive areas which are difficult for individuals with ADHD. For example, sustained attention might play a bigger role in ADHD, according to a recent study on mind-wandering in 27 participants with ADHD and 29 control participants (Bozhilova et al., 2021). It was reported that increasing demands on working memory were related to decreasing mind-wandering in participants with ADHD, but not for those without ADHD. Taken as a whole, the field of executive functioning has been developed by clinical psychology and research psychology in parallel, resulting in cognitive tasks which are not well-suited for measuring and understanding EF impairments. Snyder, Miyake, and Hankin recommend specific EF measures that have a narrower focus compared to some traditional neuropsychological measures, which sometimes test additional skills (Snyder et al., 2015). For example, the Tower of Hanoi task involves stacking rings between pegs and measures planning in addition to executive functioning. The aim of future CCT interventions for adults with ADHD should be to find improvements in specific areas of cognitive functioning, so selection of tasks and scoring which reflects current knowledge from psychopathology will lend the most translational benefits.

The theoretical limitation of the concept of overall cognitive functioning has been investigated by Webb et al. (2018), with the finding that CCT interventions may fall victim to a Type II error when combining various outcome measures (Webb et al., 2018).

They recommend by including narrow outcomes from the CHC framework. The present analysis of narrow outcomes did not result in a significant improvement in any area. A clear indication of a Type II error in the overall cognitive functioning analysis is not indicated when regarding the narrow outcome results in this case. Nevertheless, this theoretical problem should be remembered when interpreting the results.

The risk of bias assessment indicates that most studies within this field could be improved in ways that would significantly reduce bias and lead to more reproducible research. Efforts to make psychological research more transparent include publishing data, which can be beneficial for meta-analytic studies (Aarts et al., 2015; Klein et al., 2018). From the risk of bias assessment, it is evident that future RCTs in this area could be improved by including the elements of good research design, such as preregistering protocols and reporting all outcome measures. Attrition is an area of potential bias which is difficult to correct in this population. Schemes which incentivize the completion of the training interventions through the use of rewards or gamification may help with this.

Studies which vary the amount of training time and nature of the training exercises would help to uncover the exact characteristics of the most successful behavioral interventions. Another factor which is difficult to control in this adult population is the use of medication during the intervention. All except one of the included studies recruited some participants who reported using pharmacological treatments for ADHD during the training intervention. Most studies in this area include patients with varying types and amounts of pharmacological treatments.

Salami publishing, or the slicing of study data into smaller units of publishable results, disrupts the ability of drawing conclusions by introducing bias (Ding et al., 2020). This publishing of multiple studies using the same data set is an issue we encountered. Results from the same group of participants which covary threaten the validity of the conclusions which can be made from a meta-analytic review. In this case, we have made our best attempts to correct the problem of codependent estimates by excluding the publications with overlapping samples. Other aspects of research design which could be improved in future studies are the use of a comparable control group of ADHD adults with randomized assignment to groups and blinding of participants and researchers. The use of active control conditions instead of wait-list controls could alleviate the difficulty of blinding of treatment conditions. Blinded assessment of outcome measures, such as self-report questionnaires, is also more difficult in the adult population compared to studies on children, which may include proximal assessors like teachers and parents.

It is noteworthy that the included studies in this meta-analysis all include relatively young adult participants. The highest average age was 41.6 years (Dentz et al., 2020) out of the included studies, with the other studies having participants in their 20s and 30s. Since the ages of each individual participant are not reported, we cannot be certain some studies on adult participants also included late adolescents in their samples. The generalizability of this meta-analysis should be interpreted in regard to this age range.

Questions that remain are those related to potential moderators of the relationship between training cognition and the outcomes of overall cognition or symptom severity. A variable which one could assume may impact the efficacy of CCT is the length of the training. Insufficient heterogeneity in training lengths between the included studies should be addressed in future studies. It could be that a

much longer training time is needed to increase the effect sizes (for similar conclusions, see, e.g., Schmiedek et al., 2010, 2014). Another important factor which should be considered by future researchers is the participant's specific ADHD symptomatology. There may be differences in the effectiveness of the intervention if the individual has primarily inattention or hyperactivity/impulsivity symptoms. Finally, gender in ADHD could have variable prevalence between age cohorts (London & Landes, 2021), and undersampling of women in older ages may occur in the adult groups included in this review. Future studies should follow common reporting standards, including factors like socioeconomic status, immigration history, ethnicity, and any clinical comorbidities.

The recent results from the Enhancing Neuro-imaging Genetics through Meta Analysis consortium (Hoogman et al., 2022) have revealed similarities between some neurodevelopmental conditions in brain structure abnormalities, pointing to the idea that these conditions, prominently ADHD and autism spectrum disorder, share structural brain abnormalities as well as phenotypic presentation (Opel et al., 2020). This leads back to the question of far transfer and whether or not behavioral training can support brain development in adulthood and help individual functioning in daily life. Future studies on adults with ADHD could focus on finding behavioral treatments, such as CCT, to augment the positive impacts of the medication as well as evidence-based nonpharmacological treatments such as cognitive behavioral therapy (Z. Young et al., 2020).

The conclusions of this review are limited by the small number of RCTs in this area, the high risk of bias in the design of these studies, and the imprecise results (for detail, see the explanation about effect sizes above). We recommend future studies to perform more methodologically robust, well-powered trials to be able to make firm conclusions.

Considering the small positive effect in this meta-analysis for overall cognitive outcomes, together with the lack of evidence for far transfer, practitioners and individuals with ADHD should weigh the costs (resources and time) against the benefits of training. As a very low-risk treatment option which can be combined with behavioral therapies, lifestyle changes, and pharmaceutical treatment, the evidence presented could be seen as sufficient to enroll in a CCT program. That being said, the exact nature of the CCT which provides the most benefit is uncertain, so research should identify the factors which require training in adult ADHD patients and fine-tune the CCT to provide optimal—perhaps even personalized—training for the given neural characteristics.

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