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Efficacy of non-pharmacological interventions on executive functions in children and adolescents with ADHD: A systematic review and meta-analysis

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ABSTRACT

Objective: Although front-line doctors recommend medications, this kind of treatment has limited efficacy in improving executive functions (EFs) in children and adolescents with attention-deficit/hyperactivity disorder (ADHD). This study explored the effects of non-pharmacological intervention on EFs in children and adolescents with ADHD.

Methods: In accordance with the Preferred Reporting Items for Systematic Review and Meta-analyses guidelines, we searched seven electronic databases: APA PsycINFO, CINAHL Complete, EMBASE, ERIC, Medline, Pubmed, and Web of Science, from inception to March 2022. Two authors independently screened studies for eligibility, extracted data, and assessed bias risk using the Physiotherapy Evidence Database scale. Our analyses included randomized controlled trials and non-randomized comparison studies of non-pharmacological interventions and assessed EFs through neurocognitive tasks in children and adolescents between 5 and 18 years.

Results: Sixty-seven studies with 3147 participants met the inclusion criteria. The final meta-analysis included 74 independent interventions categorized into six categories: cognitive training, EF-specific curriculum, game-based training, mindfulness practice, neurofeedback training, and physical exercise. Overall, non-pharmacological interventions (combined) produced significant moderate to large effects on overall EFs in children and adolescents with ADHD (g=0.673). Physical exercise had a large positive effect on domain-specific EFs, including inhibitory control (g=0.900) and cognitive flexibility (g=1.377). Cognitive training had a large training effect on working memory (g=0.907), and an EF-specific curriculum had a small to moderate beneficial effect on planning performance (g=0.532).

Conclusion: Non-pharmacological interventions, particularly physical exercise, cognitive training, and an EF-specific curriculum, appear to have beneficial effects on EFs in children and adolescents with ADHD.

1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a common childhood psychiatric disorder with core inattention, impulsivity, and hyperactivity symptoms (American Psychiatric Association, 2013). The estimated global lifetime incidence is 5% in school-age children (Sayal et al., 2018), thus making this disorder a major global public health concern. ADHD symptoms are thought to reflect underlying executive function (EF) impairments, which affect around 50% of children with ADHD (Lambek et al., 2011). EFs encompass various top-down control processes orchestrated by activities within the prefrontal cortex and used for automatic planning, organizing, and monitoring of complex goal-directed behaviors (Diamond, 2013). EFs are comprised of three core functions (viz., inhibitory control [IC], working memory [WM], and cognitive flexibility [CF]) and higher-level functions (reasoning, planning, and problem-solving) (Diamond, 2013). Children with ADHD commonly show developmental delays in core EFs (vs. typically developing peers) (Shaw et al., 2007), which can persist throughout

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individuals' lifetimes if not treated (Shaw et al., 2007).

There is no curative intervention for EFs in children with ADHD. Although the first-line treatment is pharmacological therapy (e.g., methylphenidate) (Coghill et al., 2014), researchers identified several limitations for this type of treatment, including possible side effects (e.g., reduced appetite and sleep disturbances) and partial responses (Biederman et al., 2019; Cortese et al., 2013; Vanzin et al., 2020). Thus, existing medication treatments do not effectively address EFs impairments associated with ADHD; developing effective alternative treatments are necessary. Currently, several non-pharmacological interventions for improving EFs have been developed, including (1) computerized training, (2) a hybrid of computer and non-computer games, (3) aerobic exercise (AE) and sports, (4) martial arts and mindfulness practices, (5) classroom curricula, and (6) Montessori methods (Diamond and Lee, 2011; Takacs and Kassai, 2019).

We have identified four gaps in the literature. First, while non-pharmacological interventions (computer and non-computer training, physical exercise, EF-specific curricula, art activities, and self-regulation strategies) positively affected EFs in non-typically developing children (e.g., neurodevelopmental disorders or behavior problems; $g = 0.39$, 95% CI 0.25–0.53) (Takacs and Kassai, 2019), it is difficult to extrapolate these effects for children with ADHD because training effects may be over- or under-estimated in this group. Second, although reviews/meta-analyses have discussed non-pharmacological intervention effects on ADHD populations—including cognitive difficulties (Lambez et al., 2020), working memory deficits (Al-Saad et al., 2021), cognitive training (Veloso et al., 2020), physical activity interventions that target EFs (Liang et al., 2021), and neurofeedback intervention (Sampedro Baena et al., 2021), scholars have failed to comprehensively review all relevant studies, limiting interpretations of these effects for EFs. Third, few reviews differentiated behavioral interventions' specific effects on EFs in children and adolescents with ADHD (Lambez et al., 2020; Takacs and Kassai, 2019), hindering the identification of interventions that contribute to specific EF domains. Finally, few reviews distinguished between core and higher-level EFs (Diamond, 2013).

Thus, our systematic review and meta-analysis synthesized available empirical studies on non-pharmacological intervention effects on EFs in children and adolescents with ADHD.

2. Methods

This study complied with the PRISMA Statement (Page et al., 2021), and the protocol for the systematic review was registered with PROSPERO (CRD42022237763).

2.1. Search strategy

We conducted electronic searches in APA PsycINFO (via OVID), CINAHL Complete (via EBSCOhost), Pubmed, MEDLINE (via OVID), Web of Science, ERIC (via EBSCOhost), and EMBASE (via OVID) from inception through March 2022 to identify all relevant publications. We grouped non-pharmacological intervention approaches outlined previously (Diamond and Lee, 2011; Diamond and Ling, 2016; Lambez et al., 2020; Takacs and Kassai, 2019), including physical exercise, cognitive training, computer and non-computer games, neurofeedback, EF-specific curricula, and mindfulness. A snowball and citation search was conducted to identify relevant articles further (Table S1).

2.2. Eligibility criteria

2.2.1. Types of studies

All selected studies were included in the qualitative synthesis. The quantitative synthesis included only randomized controlled trial (RCT) or non-randomized comparison (NRS) studies published in peer-reviewed journals that reported sufficient statistical details for meta-analysis. These included studies reporting pre- and post-intervention measures with a control or comparison group. Studies without a comparison group and reports on between-group comparisons were excluded from the meta-analysis. Observational studies, review studies, case/government reports, conference papers, and book chapters were excluded.

2.2.2. Types of participants

Participants included children and adolescents aged 5–18 years with a formal ADHD diagnosis confirmed either through standardized diagnostic criteria (*Diagnostic and Statistical Manual of Mental Disorders,* 3rd/4th/5th editions or *International Classification of Diseases,* 10th/11th editions) or other diagnostic methods (e.g., parent reports). Studies including participants with other disabilities and studies that did not allow for differentiating data specific to children and adolescents with ADHD were excluded.

2.2.3. Types of intervention

We included clinical or field trial studies investigating non-pharmacological intervention effects on EFs, excluding those with combined interventions (i.e., behavioral training and medication). The main non-pharmacological intervention categories include physical exercise (e.g., aerobic exercise & cognitively engaged physical exercise), cognitive training (e.g., Cognitive Working Memory Training), computer and non-computer games (e.g., board games or Lego games), neurofeedback (e.g., Theta/beta ratio training), EF-specific curricula (e.g., parental behavioural training), and mindfulness.

2.2.4. Types of outcome measures

Following prior research (Liang et al., 2021; Takacs and Kassai, 2019), we included studies that measured EFs through neurocognitive tasks conducted with children and excluded those that measured EFs through parent- or teacher-reported questionnaires (e.g., Behavior Rating Inventory of Executive Function) (Gioia et al., 2000).

2.3. Study selection and data extraction

Two independent reviewers (XL and HQ) conducted a multi-step search to ensure an accurate systematic search. Discrepancies between reviewers were discussed to reach consensus; upon not reaching consensus, a third reviewer (PW) made the final decision. We developed a standardized data extraction form to extract study's characteristics, including relevant bibliographic details (author(s), publication year, data collection country/region), research design (RCT or NRS), participant characteristics (age range, sex, clinical diagnosis method, and sample size), intervention components (setting, intervention program, frequency, length), outcome measures (neurocognitive task), major findings, and follow-up.

2.4. Quality assessment

Two independent reviewers used the Physiotherapy Evidence Database scale (Herbert et al., 1998), which is reliable/valid for quality assessment of RCT and NRS with children with ADHD (Liang et al., 2021). It includes 11 rating criteria on eligibility, randomization, allocation, blinding (participants and experimenter), intention-to-treat, between-group comparison, and point measures (Maher et al., 2003). Scores of the scale range from 0 to 10 (average score, 5.2)(Maher et al., 2003) and are divided into high ($\geq$6), adequate (4–5), and low quality ($\leq$3) (Liang et al., 2021).

2.5. Meta-analytic procedures

The meta-analysis was conducted using the Comprehensive Meta-Analysis software (version 3.0). After examining overall EFs, we performed subgroup analyses based on core and higher-level EFs. Effect sizes were calculated using Hedges' *g* because it corrects for bias in small

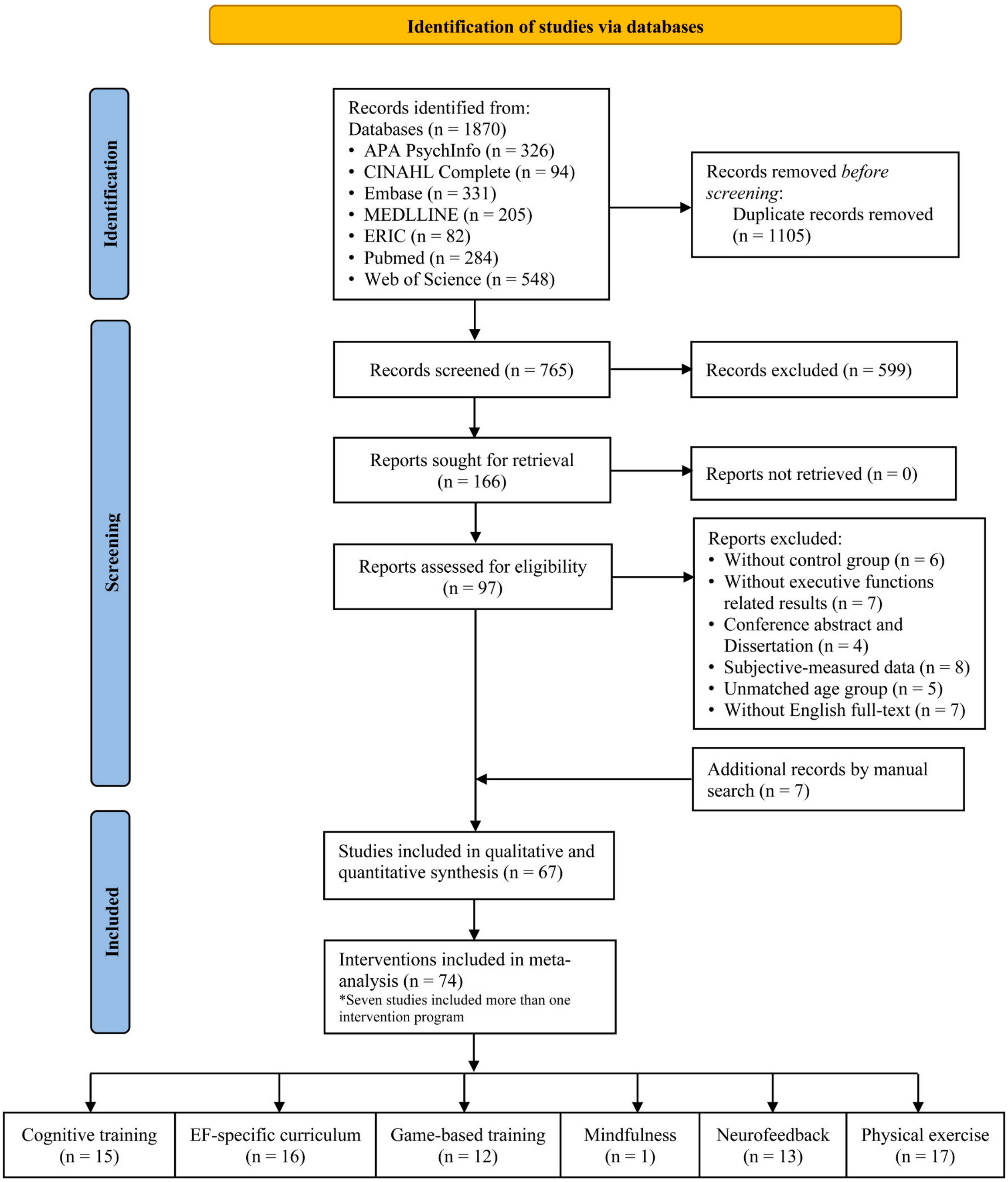

Fig. 1. PRISMA flow diagram of the selection of studies.

sample sizes (Lakens, 2013), and effect sizes could be small (<0.2), moderate (0.5), and large (>0.8) (Hedges and Olkin, 1985). To compute potential heterogeneously distributed effect sizes, we used a random-effects model because it uses both sampling error and between-study variance to estimate effect size (Borenstein et al., 2009). Statistical heterogeneity (I^2) was assessed with a p-value calculated for Q statistics, where I^2 values signified whether heterogeneity was small (≤25%), medium (50%), or large (≥75%) (Higgins and Thompson, 2002). An $I^2 > 50\%$ was adopted as the heterogeneity cut-off point. We conducted sensitivity analysis (one study removed) to inspect outlier retention/removal impact and outlier influence on overall effect size, assuming outlier status if the results remained significant ($p < .05$) and within the 95% confidence interval. Potential publication bias of included studies for overall EFs was conducted using a funnel plot that calculated standard error (y-axis) and effect size (x-axis), and used a "trim and fill" method (random-effects model) to estimate the publication-bias-adjusted true effect size and the number of studies needed to balance the plot (Duval and Tweedie, 2000). A $p < .05$ indicated statistical significance for all tests.

3. Results

3.1. Study identification

The initial search identified 1870 articles; 166 abstracts met the inclusion criteria; 97 articles (of 166) underwent full-text screening; 61 met inclusion criteria; six manually searched articles met the criteria; the final 67 articles were divided into six intervention categories (Fig. 1).

Table 1
Descriptive characteristics of included studies.

Study Name (Year, Country/ Region)	Method	Participant Characteristics					Intervention Component				Outcome Measures (number of measures)	Main Findings	Follow-up (wk)
		Participants (Age Range; Sex-M%; Diagnostic Methods)	Age (Control)	Sample Size (IG/ CG)	IQ (Control)	ADHD Diagnosis (control)	Setting/ Format	Program (Control)	Frequency	Length (mins)			
Cognitive Training													
Ackermann, Switzerland) et al. (2018)	NRS	11–15; M-83%; DSM-4 & CPRS-R	13.4 ± 1.2 (13.3 ± 1.0)	23 (13/ 10)	N/A	• *ADHD-I:* 2; *ADHD-C:* 11; • *(ADHD-I:* 6; *ADHD-C:* 4)	Home/ Individual	CWMT (Medication)	N/A	25 sessions	• WM (2): DSFBT; CBTT • IC (2): SCWT; GNG	• WM: 00 • IC: 00	• 8 wk
Bigorra, Spain) et al. (2016)	RCT	7–12; M-67% K-SADS-PL	8.8 ± 1.8 (9.0 ± 1.7)	110 (60/ 50)	100.6 ± 12.7 (96.6 ± 11.3)	N/A	Home/ Individual	CWMT (MegaMemo)	45-min/ session; 5 times/wk	25 sessions (1125)	• IC: CPT-CE • WM (3): BDST; LNST; BSST • CF (2): WCST; TMT • Planning: ToL	• IC:+ (d=−0.4) • CF:00 • WM(index scores):+ (d=0.81) • Planning:00	• 24 wk
Chacko, USA) et al. (2014)	RCT	7–11; M-78%; DBD & K-SADS-PL	8.4 ± 1.4 (8.4 ± 1.3)	85 (44/ 41)	104.2 ± 20.9 (104.6 ± 13.4)	• *ADHD-I:* 15; *ADHD-C:* 29; • *(ADHD-I:* 17; *ADHD-C:* 24)	Home Individual	CWMT-active (CWMT-placebo)	45-min/ session; 5 times/wk	25 sessions (1125)	• WM: AWMA-digit recall • IC: CPT-CE	• WM:+ (d=1.17) • IC:00	• N/A
Egeland, Norway) et al. (2013)	RCT	10–12; M-73%; ICD-10	10.4 ± 0.7	67 (33/ 34)	94.0 ± 12.0	N/A	School Individual	CWMT (Wait-list control)	45-min/ session; 5 times/wk	24 sessions (1080)	• IC: SCWT; • CF: TMT • WM (2): CAVLT-2; BVRT	• IC:+ (η^2 =0.105) • CF:00 • WM:00	• 32 wk
Green, USA) et al. (2012)	RCT	7–14; M-65%; DSM-4 & CPRS-R	9.9 ± 1.8 (9.6 ± 2.6)	26 (12/ 14)	107.0 ± 12.3 (105.4 ± 11.2)	• *ADHD-HI:2; ADHD-I:* 5; *ADHD-C:* 5 • *(ADHD-I:* 8; *ADHD-C:* 6)	Home Individual	CWMT (WM nonadaptive training)	40-min/ session; 5 times/wk	25 sessions (1000)	• WM(2): DSFBT; LNST	• WM (composite):+ (F=6.67)	• N/A
Kazemi and Mohammadi, Iran) (2019)	NRS	7–12; M-86%; DSM-4	8.9 ± 1.6 (9.4 ± 1.5)	44 (22/ 22)	110.9 ± 11.7 (110.5 ± 9.9)	N/A	Clinical Individual	CWMT	30-min/ session; 3 tiimes/wk	20 sessions (600)	• Planning: ToL	• Planning:+ (η^2 =0.29)	• N/A
Klingberg, Sweden) et al. (2005)	RCT	7–12; M-82%; DSM-4	9.9 ± 1.3 (9.8 ± 1.3)	44 (20/ 24)	N/A	• *ADHD-I:15; ADHD-C:* 5 • *(ADHD-I:* 9; *ADHD-C:* 15)	Home & School/ Individual	CWMT (WM training-low level)	40-min/ session; 5 times/wk	25 sessions (1000)	• IC: SCWT • WM(2): The span-board task; DSFBT • Reasoning: RCPM	• IC:+ (d=0.34) • WM:+ (d=0.59) • Reasoning:+ (d=0.45)	• 36 wk
Klingberg, Sweden) et al. (2002)	NRS	7–15; M-79%; DSM-4	11.0 ± 2.0 (11.4 ± 3.0)	14 (7/7)	N/A	N/A	Clinical Individual	CWMT (WM placebo-low dose)	25-min/ session; 5 times/wk	25 sessions (625)	• IC(2): Stroop; Choice RT task • WM(2): Trained visuo-spatial WM task; The span-board task • Reasoning: RCPM	• IC(Stroop):+ (p = .002) • WM:+ (p = .001) • Reasoning:+ (p = .001)	• N/A

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Table 1 (*continued*)

Study Name (Year, Country/ Region)	Method	Participant Characteristics					Intervention Component				Outcome Measures (number of measures)	Main Findings	Follow-up (wk)
		Participants (Age Range; Sex-M%; Diagnostic Methods)	Age (Control)	Sample Size (IG/ CG)	IQ (Control)	ADHD Diagnosis (control)	Setting/ Format	Program (Control)	Frequency	Length (mins)			
Lee, Hong Kong) et al. (2021)	NRS	6–12; M-81%; DSM-5 & CPRS-R	8.3 ± 1.6 (8.5 ± 1.4)	32 (16/ 16)	N/A	N/A	N/A/ Group	Eye tracking	30-min/ session; 4 times/wk	8 sessions (240)	• IC(2): Flanker Test; Category Fluency Test; • CF(2): CTT; FPT	• IC(Flaker-RT):+ (η^2 =0.40) • CF(FPT):+ (d=0.81)	• N/A
Muris, Netherlands) et al. (2018)	NRS	6–16; M-64%; DSM-4	9.7 ± 1.7 (11.5 ± 2.9)	58 (28/ 30)	103.1 ± 15.8	N/A	Home & School/ Individual	CWMT (Medication)	60-min/ session; 5 times/wk	25 sessions (1500)	• IC: Stroop • WM(2):Digit span; CBTT	• IC:+ (F=23.51) • WM(CBTT):+ (F=7.16)	• 48 wk
Sperafico, Brazil) et al. (2021)	RCT	7–11; M-50%; DSM-4 & K-SADS-PL	9.37 ± 0.89	46 (24/ 22)	92.7 ± 12.3 (92.7 ± 10.3)	• *ADHD-HI:3; ADHD-I:* 8; *ADHD-C:* 13 • *(ADHD-HI:2; ADHD-I:* 9; *ADHD-C:* 11*)*	School/ Group	WM & Numeracy Corner Programme (WM)	60-min/ session; twice/wk	11 sessions (660)	• WM(3): BSST; BDST; RAVLT	• WM(BSST):+ (d=0.17) • WM(BDST):+ (d=0.36) • WM(RAVLT):+ (d=0.72)	• 36 wk
*Steeger, USA) et al. (2016)	RCT	11–15; M-69%; DSM-4	12.0 ± 1.0 (12.7 ± 1.0)	45 (22/ 23)	106.0 ± 11.7 (109.4 ± 12.0)	• *ADHD-I:8; ADHD-C:* 14 • *(ADHD-I:* 9; *ADHD-C:* 12; ADHD-HI: 2*)*	Home/ Individual	CWMT (Full placebo)	40-min/ session; 5 times/wk	25 sessions (1000)	• WM(4): BSST; FSST; BDST; FDST	• WM(BDST)+ (η^2 =0.05) • WM(FDST)+ (η^2 =0.12)	• N/A
Tucha, Germany) et al. (2011)	RCT	N/A; M-69%; DSM-4	10.8 ± 0.4 (11.0 ± 0.6)	32 (16/ 16)	101.6 ± 2.9 (99.7 ± 2.6)	N/A	N/A/ Individual	AixTent (Visual perception)	45-min/ session; twice/wk	8 sessions (360)	• IC: Tonic and phasic alertness • CF: Alternating flexibility	• IC:00 • CF:00	• N/A
van der Donk, Netherlands) et al. (2015)	RCT	8–12; M-72%; DSM-4 & DISC-4	9.8 ± 1.3 (10.0 ± 1.3)	100 (50/ 50)	103.1 ± 15.1 (99.2 ± 12.9)	• *ADHD-I:15; ADHD-C:* 29; No Specified: 6 • *(ADHD-I:* 10; *ADHD-C:* 35; No Specified: 5*)*	School/ Individual	CWMT (Paying Attention in Class)	45-min/ session; 5 times/wk	25 sessions (1125)	• IC: Inhibition Switching Test • WM(2): BSST; BDST • Planning: Six part test	• IC(time):+ (d=−0.02) • WM(BSST):+ (d=0.85) • Planning:+ (d=−0.04)	• 24 wk
van Dongen-Boomsma et al. (2014), Netherlands)	RCT	5–7; M-72%; DSM-4	6.5 ± 0.6 (6.6 ± 0.7)	47 (26/ 21)	99.9 ± 10.2 (96.8 ± 10.7)	• *ADHD-HI:3; ADHD-I:* 2; *ADHD-C:* 21; • *(ADHD-H:7; ADHD-I:* 2; *ADHD-C:* 12*)*	Home/ Individual	CWMT (Placebo)	15-min/ session; 5 times/wk	25 sessions (375)	• WM: DSFBT • IC(2): Stroop; Shape School • Reasoning: RCPM	• WM(BDST):+ (d=0.93) • IC:00 • Reasoning:00	• N/A
EF-specific Curriculum													
Gerber, Germany) et al. (2012)	RCT	5–17; M-86%; DSM-4	12.3 ± 2.3 (10.3 ± 3.5)	37 (18/ 19)	N/A	• N/A	School/ Group	ASCT (Parental Counselling)	90-min/ session; 5 times/wk	12 sessions (1080)	• IC(2): TAP-Alterness; GNG • CF: TMT	• IC:00 • CF(TMT part A):+ (F=5.03)	• 24 wk

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Table 1 (*continued*)

Study Name (Year, Country/ Region)	Method	Participant Characteristics					Intervention Component				Outcome Measures (number of measures)	Main Findings	Follow-up (wk)
		Participants (Age Range; Sex-M%; Diagnostic Methods)	Age (Control)	Sample Size (IG/ CG)	IQ (Control)	ADHD Diagnosis (control)	Setting/ Format	Program (Control)	Frequency	Length (mins)			
*Hannesdottir, Iceland) et al. (2017)	RCT	8–10; M-67%; DSM-4	9.2 ± 0.5 (8.9 ± 0.5)	30 (16/ 14)	105.8 ± 10.5 (110.6 ± 14.9)	• *ADHD-HI:1; ADHD-I:* 1; *ADHD-C:* 14; • *(ADHD-I:1* • *ADHD-C:*13)	School/ Group	OutSMARTers (Wait-list control)	120-min/ session; twice/wk	10 sessions (1200)	• IC: Stop signal • WM(2): LNST; Letter memory	• IC:+ (F=4.48) • WM:+ (F=10.12)	• 12 wk
*Hannesdottir, Iceland) et al. (2017)	NRS	8–10; M-68%; DSM-4	9.5 ± 0.8 (8.9 ± 0.5)	25 (11/ 14)	109.7 ± 13.2 (110.6 ± 14.9)	• *ADHD-I:* 2; *ADHD-C:* 9; • *(ADHD-I:1* • *ADHD-C:*13)	N/A/ Group	Parent Training	120-min/ session; once/wk	6 sessions (840)	• IC: Stop signal • WM(2): LNST; Letter memory	• IC: 00 • WM: 00	• 12 wk
Janmohammadi, Iran) et al. (2019)	RCT	6–10; M-100%; DSM-4 & K-SADS-PL	7.1 ± 0.8 (7.4 ± 1.0)	39 (20/ 19)	N/A	• N/A	Clinical/ Individual	Eye-tracking (Occupational therapy)	30-min/ session; twice/wk	10 sessions (300)	• IC: CPT-CE	• IC:+ (η^2 =0.39)	• N/A
*Lan, China) et al. (2020)	RCT	9–12; M-63% DSM-4	10.5 ± 1.0 (10.2 ± 1.1)	54 (26/ 28)	N/A	• *ADHD-C:* *26*; • *(ADHD-C:* *28)*	N/A/ Group	Social skill training (Wait-list control)	60-min/ session; once/wk	12 sessions (720)	• IC: CPT-CE • WM: OST • CF: WCST	• IC:00 • WM:00 • CF:00	• 12 wk
Lloyd, UK) et al. (2010)	RCT	9–13; M-90%; DSM-4	N/A	35 (14/ 21)	N/A	• N/A	School/ Individual	emWave (Lego building)	20-min/ session; 5 times/wk	30 sessions (600)	• WM(2): Delayed word recall; Word recognition	• WM:+ (F=11.23)	• 6 wk
Menezes, Brazil) et al. (2015)	NRS	7–17; M-83%	9.6 ± 1.7 (10.3 ± 2.2)	18 (8/10)	N/A	• N/A	School/ Group	PIAFEx	60-min/ session; twice/wk	64 sessions (3840)	• IC: Stroop • CF(2): TMT; WCST • WM(2): Auditory and Visual WM test	• IC:+ (F=4.72) • CF:00 • WM (auditory):+ (F=4.72)	• N/A
Miranda, Spain) et al. (2013)	RCT	7–10; M-86%; DSM-4	N/A	42 (27/ 15)	102.4 ± 7.1 (97.4 ± 10.0)	• N/A	School/ Group	Psychosocial programs for children, parents & teachers	45-min/ session; 16 sessions for children; 120-min/ session; 10 session for parents & teachers	26 sessions (3120)	• IC: Stroop • WM(3): WM Sentences; Inverse Digits test; TSRT • CF: WCST • Planning: ToL	• IC:+ (η^2 =0.20) • WM(TSRT):+ (η^2 =0.40) • CF:00 • Planning:+ (η^2 =0.02	• N/A
Miranda, Spain) et al. (2002)	NRS	8–10; M-84%; DSM-4	N/A	50 (29/ 21)	N/A	• N/A	School/ Group	Teacher training	180-min/ session; twice/month	8 sessions (1440)	• IC: SCWT • WM: Digit span • Planning: ROCFD	• IC:+ (t = −2.25) • WM:00 • Planning:00	• N/A
*Moreno-García et al. (2019, Spain)	RCT	7–14; M-76%; DSM-5	8.1 ± 1.3 (9.2 ± 2.2)	38 (19/ 19)	96.9 ± 14.5 (94.7 ± 12.9)	• *ADHD-I:* 11; *ADHD-H: 3; ADHD-C:* 5; • *(ADHD-I:* 8 *ADHD-H:3;*	School/ Group	Behavioral therapy (Medication)	Children: 50-min/ session; Parent & Teacher: 90-min/ session	30 sessions (15 children/ 10 parent/ 5 teacher) (2100)	• IC: CPT-CE	• IC:00	• N/A

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Table 1 (*continued*)

Study Name (Year, Country/ Region)	Method	Participant Characteristics: Participants (Age Range; Sex-M%; Diagnostic Methods)	Age (Control)	Sample Size (IG/ CG)	IQ (Control)	ADHD Diagnosis (control)	Intervention Component: Setting/ Format	Program (Control)	Frequency	Length (mins)	Outcome Measures (number of measures)	Main Findings	Follow-up (wk)
						• *ADHD-C:* 8)							
Qian, China) et al. (2017)	RCT	6–12; M-79%; DSM-4	8.3 ± 1.3 (7.8 ± 1.2)	68 (38/ 30)	105.7 ± 13.9 (101.8 ± 10.4)	• *ADHD-I:* 17; *ADHD-C:* 21; • *(ADHD-I:* 16 *ADHD-H:1;* • *ADHD-C:* 13)	Clinical/ Group	Executive skills training (Wait-list control)	60-min/ session; once/wk	12 sessions (720)	• IC: SCWT • CF: TMT • Planning: ROCFD	• IC:00 • CF:00 • Planning:+ (F=4.27)	• N/A
Smith, USA) et al. (2019)	RCT	5–9; M-52%; DSM-4 &K-SADS-PL	7.2 ± 1.4 (7.1 ± 1.1)	29 (13/ 16)	107.5 ± 14.7 (99.6 ± 11.5)	• *ADHD-I:* 5; *ADHD-H: 2;* *ADHD-C:* 6; • *(ADHD-I:* 5 *ADHD-H:5;* • *ADHD-C:* 9)	School/ Group	Integrated Brain, Body and Social (TAU)	120-min/ session; 3 times/wk	45 sessions (5400)	• IC: GNG	• IC:00	• N/A
*Steeger, USA) et al. (2016)	RCT	11–15; M-72%; DSM-4	12.6 ± 1.3 (12.7 ± 1.0)	47 (24/ 23)	108.2 ± 14.3 (109.4 ± 12.0)	• *ADHD-I:* 8; *ADHD-C:* 16; • *(ADHD-I:* 9 *ADHD-H:2;* • *ADHD-C:* 12)	School/ Group	Behavioral Parent Training	90-min/ session; once/wk	5 sessions (450)	• WM(4): BSST; FSST; BDST; FDST	• WM:00	• N/A
Tamm, USA) et al. (2013)	RCT	7–15; M-68%; DSM-4 & K-SADS-PL	9.1 ± 1.2 (9.5 ± 1.5)	105 (54/ 51)	107.4 ± 11.5 (105.9 ± 13.3)	• *ADHD-I:* 21; *ADHD-C:* 32; No specified: 1; • *(ADHD-I:* 20; *ADHD-C:* 30; • No specified: 1)	Home/ Individual	Pay Attention (Wait-list control)	30-min/ session; twice/wk	16 sessions (480)	• IC: Color Word Interference • WM(2): DSFBT; LNST • CF: Matrix Reasoning • Planning: Tower test	• IC:00 • WM:00 • CF:00 • Planning (Tower time):+ (d=0.55)	• N/A
Vanzin, Italy) et al. (2020)	NRS	8–13; M-87%; DSM-5	10.3 ± 1.4 (10.9 ± 1.4)	54 (29/ 25)	98.3 ± 11.4 (104.5 ± 13.8)	• N/A	School/ Group	ACT	Children: 90-min/ session; once/wk; Parents: 90-min/ session; once/2-wk	38 sessions (26 children/ 12 parents) (3420)	• IC: ANT-Visual set-shifting	• IC(errors):+ (d=0.08)	• N/A
Wexler, USA) et al. (2021)	RCT	5–9; M-66%;	7.2 ± 1.1 (7.6 ± 1.2)	73 (31/ 42)	104.3 ± 11.9	• *ADHD-C:* *26;*	School/ Group	Integrated three-part intervention	45-min/ session; 3–4 times/wk	60 sessions (2700)	• IC: GNG • WM: List Sorting WM Test	• IC:00 • WM:+ (F=4.83)	• N/A

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Table 1 (*continued*)

Study Name (Year, Country/ Region)	Method	Participant Characteristics					Intervention Component				Outcome Measures (number of measures)	Main Findings	Follow-up (wk)
		Participants (Age Range; Sex-M%; Diagnostic Methods)	Age (Control)	Sample Size (IG/ CG)	IQ (Control)	ADHD Diagnosis (control)	Setting/ Format	Program (Control)	Frequency	Length (mins)			
		DSM-4 & K-SADS-PL			(104.7 ± 14.1)	*ADHD-H: 1; ADHD-at risk: 4* • *(ADHD-C: 23; ADHD-H: 12;* • *ADHD-at risk: 7)*		(Wait-list control)					
Game-based Training													
Azami, Iran) et al. (2016)	RCT	7–12; M-100%	N/A	23 (12/ 11)	N/A	• N/A	Clinical/ Individual	CACR (Placebo CACR)	90-min/ session; 2–3 times/wk	20 sessions (1800)	• IC:CPT-CE • WM(2): Span board; DSFBT • Planning: ToL • Reasoning: RCPM	• IC:00 • WM(BDS):+ (d=−0.72) • Planning:00 • Reasoning:+ (d=1.4)	• 12 wk
Bikic, Denmark) et al. (2017)	RCT	14–17; M-77%; ICD-10	15.6 ± 1.0	17 (9/8)	N/A	• N/A	Home/ Individual	SBT (Tetris)	30-min/ session; 5 times/wk	34 sessions (1020)	• IC: MTS; • WM(2): Spatial Span; Spatial WM • CF: IED • Planning: SOC	• IC:00 • WM:00 • CF:00 • Planning:00	• N/A
Bikic, Denmark) et al. (2018)	RCT	6–13; M-84%; DSM-4 & K-SADS-PL	9.8 ± 2.0 (10.1 ± 1.5)	70 (35/ 35)	96.2 ± 8.5 (95.9 ± 7.4)	• *ADHD-HI:3; ADHD-I*: 12; *ADHD-C*: 20; • *(ADHD-HI:1; ADHD-I:18;* • *ADHD-C:15)*	Home/ Individual	ACTIVATE™ (TAU)	40-min/ session; 6 times/wk	26 sessions (1040)	• IC(2): AST-CE; Stop signal • WM: Spatial WM • CF: IED • Planning: SOC	• IC:00 • WM:00 • CF:00 • Planning:+ (p = .006)	• 12 wk • 24 wk
Dovis, Netherlands) et al. (2015)	RCT	8–12; M-80%; DSM-4 & DISC-4	10.6 ± 1.4 (10.5 ± 1.3)	61 (31/ 30)	101 ± 11.5 (101 ± 11.6)	• N/A	Home/ Individual	Braingame Brain (Placebo)	50-min/ session; 5 times/wk	25 sessions (1250)	• IC(2): STOPIT; SCWT • WM(2): CBTT; DSFBT • CF: TMT • Reasoning: RCPM	• IC(STOPIT):+ (η^2 =0.09) • WM(CBTT):+ (η^2 =0.16) • CF:00 • Reasoning:00	• 12 wk
Estrada-Plana, Spain) et al. (2019)	RCT	8–12; M-63%	9.5 ± 1.2 (9.5 ± 1.1)	27 (13/ 14)	N/A	• *ADHD-I*: 3; *ADHD-C*: 10; • *(ADHD-I*: 5; • *ADHD-C*: 9)	Clinical/ Group	Board games (Wait-list control)	60-min/ session; once/wk	5 sessions (300)	• IC: GNG • WM(4): CBTT; Direct digits; KTT • CF: TMT	• IG:00 • WM(Direct digits):+ (η^2 =0.27) • CF:00	• 4 wk
Johnstone, Australia) et al. (2010)	RCT	7–13; M-86%; DSM-4	10.7 ± 1.5 (10.7 ± 1.3)	29 (15/ 14)	100.5 ± 15.2 (104.1 ± 17.4)	• N/A	Home/ Individual	High-intensity computerised game (Low-intensity)	20-min/ session; 5 times/wk	25 sessions (500)	• IC: GNG	• IC(NG errors):+ (F=3.7)	• N/A

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Table 1 (*continued*)

Study Name (Year, Country/ Region)	Method	Participant Characteristics: Participants (Age Range; Sex-M%; Diagnostic Methods)	Age (Control)	Sample Size (IG/ CG)	IQ (Control)	ADHD Diagnosis (control)	Intervention Component: Setting/ Format	Program (Control)	Frequency	Length (mins)	Outcome Measures (number of measures)	Main Findings	Follow-up (wk)
Johnstone, Australia) et al. (2017)	RCT	7–13; M-75%; DSM-4	N/A	85 (44/ 41)	N/A	• N/A	Home/ Individual	Focus Pocus (Wait-list control)	20-min/ session; 3–4 times/wk	25 sessions (500)	• IC(2): GNG; Auditory oddball task • WM(2):Countig Span task; DSFBT	• IC:00 • WM:00	• N/A
Jones, USA) et al. (2020)	RCT	7–14; M-69%; DSM-4 & CPRS-R	10.2 ± 2.0 (10.1 ± 2.0)	80 (41/ 39)	N/A	• N/A	Home/ Individual	N-back (General knowledge & trivia program)	15-min/ session; 5 times/wk	20 sessions (300)	• IC: CPT • WM(3): n-Back; Digit span; Following directions • Reasoning: RSPM	• IC:+ (η^2 =0.08) • WM(n-back): + (η^2 =0.13) • Reasoning:00	• 12 wk
Kermani, Iran) et al. (2016)	RCT	8–12; M-58%; DSM-4	9.9 (9.8)	60 (30/ 30)	N/A	• N/A	Home/ Individual	WM Structured games (Wait-list control)	60-min/ session; twice/wk	24 sessions (1440)	• WM(2): Digit span; Symbol search	• WM:+ ($p < .001$)	• 24 wk
*Lan, China) et al. (2020)	RCT	9–13; M-65%; DSM-4	10.9 ± 1.3 (10.2 ± 1.1)	55 (27/ 28)	N/A	• *ADHD-C: 27*; • *(ADHD-C: 28)*	N/A/ Group	Computerized tasks & Group EF games (Wait-list control)	60-min/ session; once/wk	12 sessions (720)	• IC: CPT-CE • WM: OST • CF: WCST	• IC:+ (η^2 =0.22) • WM+ (η^2 =0.13) • CF:00	• 12 wk
Meyer, USA) et al. (2020)	RCT	8–11; M-70%; DSM-4	9.8 ± 1.7 (10.8 ± 0.9)	40 (20/ 20)	N/A	• N/A	Home/ Individual	Computerized IC Games (Adaptive Games)	15-min/ session; 5 times/wk	23 sessions (345)	• IC: Stop Signal Task	• IC(CE):+ (F=11.3)	• N/A
Prins, Netherlands) et al. (2011)	RCT	7–12; M-82%; DSM-4	9.6 ± 1.1 (9.3 ± 1.1)	51 (27/ 24)	N/A	• N/A	Clinical/ Individual	Computerized WM Games (WM training)	35-min/ session; once/wk	3 sessions (105)	• WM: CBTT	• WM:+ (d=0.8)	• N/A
Mindfullness Practice													
Kiani, Iran) et al. (2017)	RCT	13–15; M-0% SNAP-4	13.2 ± 0.4 (13.4 ± 0.7)	30 (15/ 15)	N/A	• N/A	N/A/ Group	Mindfulness meditation (Wait-list control)	90-min/ session; once/wk	8 sessions (720)	• IC: SCWT • WM(2): DSFBT; LNST • Planning: ToL	• IC:+ (η^2 =0.22) • WM:00 • Planning:+ (η^2 =0.15)	• N/A
Neurofeedback Training													
Alegria, UK) et al. (2017)	RCT	12–17; M-100%; DSM-5 & K-SADS-PL	14.1 ± 1.5 (13.6 ± 1.7)	31 (18/ 13)	103.9 ± 16.0 (102.9 ± 12.2)	• N/A	Clinical/ Individual	rtfMRI-NF of rIFG (rtfMRI-NF of lPHG)	8.5-min/ session	14 sessions (119)	• IC(3): GNG; STOPIT; CPT-CE	• IC: 00	• 24 wk
Bakhshayesh, Germany) et al. (2011)	RCT	6–14; M-74%; ICD-10	9.6 ± 2.2 (9.1 ± 1.6)	35 (18/ 17)	N/A	• *ADHD-I:* 4; *ADHD-C:* 14; • *(ADHD-I:* 2; *ADHD-C:* 15*)*	Clinical/ Individual	TBR (Biofeedback)	30-min/ session; 2–3 times/wk	30 sessions (900)	• IC-CPT-CE	• IC:+ (F=11.87)	• N/A
Dobrakowski & Lebecka (2020, Poland)	RCT	6–12; M-77%; DSM-5 & ICD-10	8.8 ± 1.4 (8.6 ± 1.4)	48 (24/ 24)	101.9 ± 13.6 (100.6 ± 6.9)	N/A	Clinical/ Individual	TBR (Wait-list control)	45-min/ session; 1–2 times/wk	12 sessions (540)	• WM: n-Back Task	• WM:+ (d=0.67)	• 48 wk
Drechsler, Switzerland) et al. (2007)	NRS	9–13; M-77%; DSM-4 & ICD-10	10.5 ± 1.3 (11.2 ± 1.0)	30 (17/ 13)	101.0 ± 10.3 (110.0 ± 19.2)	• *ADHD-HI:1; ADHD-I:* 5; *ADHD-C:* 11;	N/A/ Individual	SCP(Group therapy)	45-min/ session; twice/day of 2 wk &	60 sessions (2700)	• IC(2): TAP-Alertness; GNG • CF: TMT	• IC(GNG):+ (η^2 =0.62) • CF:+ (η^2 =0.34)	• N/A

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Table 1 (*continued*)

Study Name (Year, Country/ Region)	Method	Participant Characteristics					Intervention Component				Outcome Measures (number of measures)	Main Findings	Follow-up (wk)
		Participants (Age Range; Sex-M%; Diagnostic Methods)	Age (Control)	Sample Size (IG/ CG)	IQ (Control)	ADHD Diagnosis (control)	Setting/ Format	Program (Control)	Frequency	Length (mins)			
						• *(ADHD-I: 5; ADHD-C: 8)*			1–2 times/wk of 3 wk				
*Geladé, Netherlands) et al. (2017)	RCT	7–13; M-76%; DSM-4	9.9 ± 1.9 (9.1 ± 1.3)	75 (39/ 36)	100.6 ± 13.2 (101.1 ± 14.2)	N/A	N/A/ Individual	TBR (Medication)	45-min/ session; 3 times/wk	30 sessions (1350)	• IC: STOPIT • WM:DSFBT	• IC:00 • WM:00	• N/A
Heinrich, Germany) et al. (2004)	RCT	7–13; M-95%; DSM-4 & ICD-10	11.1 ± 1.7 (10.2 ± 2.1)	22 (13/9)	114.5 ± 18.3 (110.6 ± 11.3)	• *ADHD-I:* 4; *ADHD-C:* 9; • *(ADHD-I:* 2; *ADHD-C:* 7*)*	N/A/ Individual	SCP (Wait-list control)	50-min/ session	25 sessions (1250)	• IC: CPT-CE	• IC:00	• N/A
*Janssen, Netherlands) et al. (2016)	RCT	7–13; M-74%; DSM-4	9.9 ± 1.8 (9.2 ± 1.3)	57 (32/ 25)	99.1 ± 12.3 (100.8 ± 14.3)	N/A	N/A/ Individual	TBR (Medication)	45-min/ session; 3 times/wk	29 sessions (1305)	• IC: Stop-signal task	• IC:00	• N/A
Lévesque, Canada) et al. (2006)	RCT	8–12; M-80%; DSM-4	10.2 ± 1.3 (10.2 ± 0.8)	20 (15/5)	N/A	N/A	N/A/ Individual	SMR+TBR (TAU)	60-min/ session; 3 times/wk	40 sessions (2400)	• IC: Counting Stroop • WM: DFSBT	• IC:+ ($p < .05$) • WM:+ ($p < .05$)	• N/A
Maurizio, Switzerland) et al. (2014)	RCT	8–13; M-88%; DSM-4	10.6 ± 1.3 (10.0 ± 1.2)	25 (13/ 12)	111.1 ± 10.0 (118.1 ± 12.9)	N/A	N/A/ Individual	TBR (Biofeedback)	32-min/ session; 3 times/wk	36 sessions (1152)	• IC: TAP-Alertness • CF: KITAP	• IC(RT):+ (η^2 =0.31) • CF(RT):+ (η^2 =0.19)	• N/A
*Moreno-García et al. (2019, Spain)	RCT	7–14; M-79%; DSM-4	9.2 ± 1.9 (9.2 ± 2.2)	38 (19/ 19)	103.4 ± 13.0 (94.7 ± 12.9)	• *ADHD-HI:4; ADHD-I:* 8; *ADHD-C:* 7; • *(ADHD-HI:3; ADHD-I:*8; *ADHD-C:*8*)*	N/A/ Individual	TBR (Medication)	24-min/ session; 4 times/wk	40 sessions (960)	• IC: CPT-Prudence	• IC:+ (d=0.78)	• N/A
*Rezaei, Iran) et al. (2018)	RCT	7–11; N/A; DSM-5	N/A	14 (7/7)	N/A	N/A	N/A/ Individual	TBR	45-min/ session; 3 times/wk	24 sessions (1080)	• IC: CPT-CE • WM:LNST	• IC:+ (η^2 =0.73) • WM:+ (η^2 =0.89)	• N/A
Shereena, India) et al. (2019)	RCT	6–12; M-93%; ICD-10	8.7 ± 1.8 (9.7 ± 2.4)	30 (15/ 15)	91.5 ± 11.2 (87.2 ± 16.6)	N/A	N/A/ Individual	TBR (Routine clinical management)	20–40 mins/ sessions; 3–4 times/wk	40 sessions (1200)	• IC: GNG • WM(2): N-back; Spatial Span Task • CF: CTT • Planning: Porteus Mace test	• IC:+ (d=0.76) • WM(2-Back): + (d=0.87) • CF:00 • Planning:00	• 24 wk
Wang, China) (2017)	NRS	7–14; M-63%	10.4 ± 2.2 (10.5 ± 2.2)	19 (10/9)	97.33 (97.31)	N/A	School/ Individual	EEG (Alternative training)	35-min/ session; twice/wk	10 sessions (350)	• WM: N-back Test	• WM:+ ($p < .05$)	• N/A
Physical Exercise													
Benzing and Schmidt, Switzerland) (2019)	RCT	8–12; M-84%; ICD-10	10.5 ± 1.3	51 (28/ 23)	N/A	N/A	Home/ Individual	Exergaming-CEPE	30-min/ session, 3 times/wk	24 sessions (720)	• IC: Simon Task • WM: Color Span Backward	• IC:+ (d=0.58) • WM:00	• N/A

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Table 1 (*continued*)

Study Name (Year, Country/ Region)	Method	Participant Characteristics: Participants (Age Range; Sex-M%; Diagnostic Methods)	Age (Control)	Sample Size (IG/ CG)	IQ (Control)	ADHD Diagnosis (control)	Intervention Component: Setting/ Format	Program (Control)	Frequency	Length (mins)	Outcome Measures (number of measures)	Main Findings	Follow-up (wk)
			(10.4 ± 1.4)					(Watching video)					
Bustamante, USA) et al. (2016)	RCT	6–12; M-69%: DSM-4	9.4 ± 2.2 (8.7 ± 2.0)	34 (18/ 16)	N/A	N/A	School/ Group	Structured & unstructured play-CEPE (Art project)	90-min/ session, 5 times/wk	50 sessions (4500)	• IC: STOPIT • WM(2): AWMA verbal & visuopatial	• IC:00 • WM(verbal):+ (d=0.26)	• N/A
Chang, Taiwan) et al. (2014)	NRS	5–10; M-85%; DSM-4	8.2 ± 7.7 (8.8 ± 8.3)	27 (14/ 13)	N/A	• *ADHD-I:* 4; *ADHD-H:2; ADHD-C:* 8; • *(ADHD-I:* 3; *ADHD-C:* 10)	School/ Group	Aquatic exercise-AE (Wait-list control)	90-min/ session, twice/wk	16 sessions (1440)	• IC: GNG	• IC(NoGo):+ (η^2 =0.25)	• N/A
Choi, Korea) et al. (2015)	RCT	13–18; M-100%; DSM-4	15.8 ± 1.7 (16.0 ± 1.2)	30 (13/ 17)	94.9 ± 11.8 (95.9 ± 11.2)	N/A	School/ Group	Sports therapy-AE (Behavior control)	90-min/ session, 3 times/wk	18 sessions (1620)	• CF: WCST	• CF:+ (F=5.61)	• N/A
DaSilva, Brazil) et al. (2020)	RCT	11–14, M-70%, DSM-4 &SNAP-4	12.0 ± 2.0 (12.0 ± 1.0)	20 (10/ 10)	N/A	N/A	Community/ Group	Swimming-AE	45-min/ session; twice/wk	16 sessions (720)	• CF: The test of trails	• CF:+ (p = .042)	• N/A
Faramarzi, Iran) et al. (2016)	RCT	M-100%	8.6 ± 1.1 (8.6 ± 0.5)	20 (10/ 10)	N/A	N/A	N/A/ Individual	Sensory integration training-CEPE	45-min/ session; twice/wk	12 sessions (540)	• EF: Conner's Neuropsychology Tes	• EF:+ (F=9.63)	• N/A
*Geladé, Netherlands) et al. (2017)	RCT	7–13; M-75%; DSM-4	9.8 ± 2.0 (9.1 ± 1.3)	73 (37/ 36)	97.6 ± 12.7 (101.1 ± 14.2)	N/A	N/A/ Individual	Physical activity-AE	45-min/ session; 3 times/wk	30 sessions (1350)	• IC: STOPIT • WM:DSFBT	• IC:00 • WM:00	• N/A
*Janssen, Netherlands) et al. (2016)	RCT	7–13; M-78%; DSM-4	9.8 ± 2.0 (9.2 ± 1.3)	49 (24/ 25)	98.3 ± 13.8 (100.8 ± 14.3)	N/A	N/A/ Group	Physical activity-AE (Medication)	45-min/ session; 3 times/wk	27 sessions (1215)	• IC: Stop-signal task	• IC:00	• N/A
Kadri, Tunisia) et al. (2019)	RCT	M-90%	14.5 ± 3.5 (14.2 ± 3.0)	40 (20/ 20)	N/A	N/A	Community/ Group	Taekwondo-CEPE (TAU)	50-min/ session; twice/wk	144 sessions (7200)	• IC: SCWT	• IC:+ (d=2.16)	• N/A
Lee, Korea) et al. (2017)	RCT	6–10; M-100%; DSM-4	8.8 ± 1.0 (8.8 ± 1.0)	12 (6/6)	N/A	N/A	N/A/ Group	Jump rope & ball exercises -CEPE	60-min/ session, 3 times/wk	36 sessions (2160)	• IC: SCWT	• IC:00	• N/A
Memarmoghaddam, Iran) et al. (2016)	RCT	7–11; M-100%; SNAP-4	8.3 ± 1.3 (8.3 ± 1.3)	36 (19/ 17)	N/A	• *ADHD-I:*5; *ADHD-H:6; ADHD-C:* 8; • *(ADHD-I:* 3; *ADHD-H: 5; ADHD-C: 9)*	Community/ Group	AE & goal-directed exercise-CEPE	90-min/ session, 3 times/wk	24 sessions (2160)	• IC(2): GNG; Stroop	• IC(NoGo):+ (η^2 =0.45)	• N/A
Nejati and Derakhshan, Iran) (2021)	RCT	M-87%; DSM-5	9.4 ± 1.4	30 (15/ 15)	N/A	• *ADHD-I:*5; *ADHD-H:2; ADHD-C:* 8;	N/A/ Group	EXCIR-CEPE (AE)	50-min/ session; 3 times/wk	12 sessions (1800)	• IC: GNG • WM: One-back Task • CF: WCST	• IC:+ (η^2 =0.14) • WM:+ (η^2 =0.32)	• 4 wk

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Table 1 (*continued*)

Study Name (Year, Country/ Region)	Method	Participant Characteristics					Intervention Component				Outcome Measures (number of measures)	Main Findings	Follow-up (wk)
		Participants (Age Range; Sex-M%; Diagnostic Methods)	Age (Control)	Sample Size (IG/ CG)	IQ (Control)	ADHD Diagnosis (control)	Setting/ Format	Program (Control)	Frequency	Length (mins)			
						• *(ADHD-I: 6; ADHD-H: 1; ADHD-C: 8)*						• CF:+ (η^2 =0.28)	
Pan, Taiwan) et al. (2016)	RCT	6–12; M-100%; DSM-4	8.9 ± 1.5 (8.9 ± 1.6)	32 (16/ 16)	N/A	N/A	Community/ Individual	Table tennis-CEPE(Wait-list control)	70-min/ session, twice/wk	24 sessions (1680)	• IC: SCWT	• IC:+ (η^2 =0.48)	• 12 wk
Pan, Taiwan) et al. (2019)	NRS	7–12; M-100%; DSM-4	9.1 ± 1.4 (8.9 ± 1.7)	30 (15/ 15)	N/A	N/A	Community/ Individual	Table tennis-CEPE	70-min/ session, twice/wk	24 sessions (1680)	• IC: SCWT • CF: WCST	• IC:+ (d=2.07) • CF:+ (d=1.19)	• N/A
*Rezaei, Iran) et al. (2018)	RCT	7–11; DSM-5	N/A	14 (7/7)	N/A	N/A	N/A/ Group	Yoga-CEPE	45-min/ session; 3 times/wk	24 sessions (1080)	• IC: CPT-CE • WM:LNST	• IC:+ (η^2 =0.89) • WM:+ (η^2 =0.77)	• N/A
Verret, Canada) et al. (2012)	NRS	7–12; M-90%; DSM-4	9.1 ± 1.1	21 (10/ 11)	N/A	N/A	School/ Group	Lunch time PA training-CEPE	45-min/ session, 3 times/wk	30 sessions (1350)	• IC: TEAC-walk/ don't walk	• IC:00	• N/A
Ziereis and Jansen, Germany) (2015)	RCT	7–12; M-74%; ICD-10	9.5 ± 1.4	39 (23/ 16)	N/A	N/A	Community/ Group	Ball skills & games-CEPE (Wait-list control)	60-min/ session; once/wk	12 sessions (720)	• WM(3): DSFBT; LNST; CBTT	• WM(index-score):+ (η^2 =0.38)	• N/A

ACT: Acceptance and commitment therapy; ACST: ADHD Summer Camp Training; AE: aerobic exercise; AEP: Attention Education Program; ANT: Amsterdam neuropsychological task; AWMA: Automated Working Memory Assessment System; BSST: Backward spatial span test; BDST: Backward digit span test; BVRT: Benton Visual Retention Test; CACR: Computer-assisted cognitive rehabilitation; CAVLT-2: Children's Auditory Verbal Learning Test-2; CBTT: Corsi block-tapping task; CE: Commission error; CEPE: cognitively-engaged physical exercises; CF: cognitive flexibility; CG: control group; CPRS-R: Conner's Parent Rating Scale; CPT: Conners' continuous performance test; CTT= Color Trails Test; CWMT: Cognitive Working Memory Training; DBD: Disruptive Behavior Disorder Rating Scales; DISC-4: Diagnostic Interview Schedule for Children IV; DSFBT: Digit span forward and backward test; DSM-4 and-5: Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition and Fifth Edition; EEG: Electroencephalogram; EXCIR: Exercise for Cognitive Improvement and Rehabilitation; FDST: Forward digit span test; FSST: Forward spatial span test; FPT: Five Point Test; GNG: Go-No-Go task; IC: inhibitory control; ICD-10: International Classification of Diseases, Tenth Revision; IED: Intra-Extra Dimensional Set Shift; IG: intervention group; K-ARS-PT: Korean version of the parent and teacher version of DuPaul's ADHD Rating Scale; KITAP: Test for Attentional Performance for Children; K-SADS-PL=Kiddie-Schedule for Affective Disorders and Schizophrenia, Present and Lifetime version; KTT: Keep Track Task; LNST: Letter–number-sequencing task; MTS: Match to Sample Visual Search; NR: no report; lPHG: Left parahippocampal gyrus; N/A: Not available; NRS: Non-randomised comparison studies; OST: Operational Span Test; PIAFEx: The Intervention Program for Self-regulation and Executive Functions; RAVLT: Rey Auditory-Verbal Learning Test; RCT: Randomized Control Trial; RCPM: Raven's Colored Progressive Matrices; RSPM: Raven's Standard Progressive Matrices; ROCFD: Rey-Osterrieth Complex Figure Drawing; rtfMRI-NF: Real-time functional magnetic resonance neurofeedback; rIFG: Right inferior prefrontal gyrus; RT: Reaction time; SBT: Scientific Brain Training; SCP: Slow cortical potential; SMR: Sensory motor waves; SNAP-4: Swanson, Nolan and Pelham Rating Scale, Fourth Edition; SOC: Stockings of Cambridge; STOPIT: Stop-Signal Inhibition Task; SCWT: Stroop Colot and Word Test; SNAP-4: Swanson, Nolan and Pelham Teacher and Parent Rating Scale-Fourth edition; TAU: Treatment as usual; TAP: Test for Attentional Preformance; TBR: Theta/beta ratio; TD: typical developing children; TEAC: Test of Everyday Attention for Children; TMT=Trail Making Test; TOL: Tower of London; TSRT: Temporal Spatial Recall Task; VC: Voluntary Cycling; WCST: Wisconsin Card Sorting Test; WM: working memory.

* studies included in the meta-analysis; + : significant statistical improvement; 00: no statistically significant change

Table 2
Effects of overall and separately for the different categories of interventions on EFs.

Intervention Category	Number of interventions (k)	Average effect size (g)	95% Confidence interval	Test of heterogeneity		
				Q	I^2	P-value
Non-pharmacological Interventions	74	0.672	[0.534, 0.809]	242.160	69.855	< 0.001
Cognitive Training	15	0.724	[0.370, 1.077]	70.644	80.182	< 0.001
AixTent	1	0.163	[− 1.313, 1.640]	0	0	1.0
CWMT	12	0.779	[0.352, 1.207]	66.999	83.582	< 0.001
Eye-tracking	1	0.470	[− 1.012, 1.951]	0	0	1.0
Working memory program	1	1.024	[− 0.421, 2.470]	0	0	1.0
EF-specific Curriculum	16	0.358	[0.214, 0.503]	13.147	0	0.591
Children-oriented	10	0.352	[0.165, 0.540]	8.921	0	0.445
Parents-oriented	2	0.435	[− 0.037, 0.907]	1.970	49.239	0.160
Teachers-oriented	1	0.204	[− 0.368, 0.777]	0	0	1.0
Mixed program	3	0.406	[0.068, 0.743]	1.780	0	0.411
Game-based Training	12	0.532	[0.228, 0.837]	33.692	67.351	< 0.001
Board games	1	-0.443	[− 1.435, 0.549]	0	0	1.0
Computer-based games	9	0.411	[0.155, 0.667]	8.675	7.786	0.370
Mixed games	2	1.394	[0.799, 1.988]	7.279	86.262	0.007
Mindfulness Practice	1	0.266	[− 0.436, 0.967]	0	0	1.0
Neurofeedback Training	13	0.702	[0.367, 1.037]	33.337	64.004	0.001
EEG	1	2.975	[1.589, 4.361]	0	0	1.0
fMRI	1	1.497	[0.537, 2.457]	0	0	1.0
SCP	2	0.426	[− 0.235, 1.087]	0	0	0.987
SMR & TBR	1	0.506	[− 0.617, 1.629]	0	0	1.0
TBR	8	0.504	[0.205, 0.803]	13.448	47.948	0.062
Physical Exercise	17	1.108	[0.734, 1.482]	66.644	75.992	< 0.001
Aerobic exercise	5	1.100	[0.391, 1.808]	22.463	82.193	< 0.001
Cognitively-engaged physical exercises	12	1.119	[0.658, 1.581]	42.873	74.343	< 0.001

Note: CWMT: Cognitive Working Memory Training; EEG: Electroencephalogram; fMRI: Functional magnetic resonance imaging; SCP: Slow cortical potential; SMR: Sensory motor waves; TBR: Theta/beta ratio.

3.2. Study characteristics

Among the 67 studies (please refer to Table 1), there were six non-pharmacological intervention categories, 74 interventions, 173 core EF effect sizes (24 for CF, 72 for IC, and 77 for WM), and 18 higher-level EF effect sizes (12 for planning and 6 for reasoning). Seven studies (Geladé et al., 2017; Hannesdottir et al., 2017; Janssen et al., 2016; Lan et al., 2020; Moreno-García et al., 2019; Rezaei et al., 2018; Steeger et al., 2016) included more than one type of treatment method, and they were included as independent interventions (Table 1). All studies were published between 2002 and 2022; 43 studies were conducted in Europe, 19 in Asia, 11 in North America, 3 in South America, 2 in Australia, and 1 in Africa. Fifty-three and 14 studies adopted an RCT and NRS design, respectively. The total sample included 3147 children and adolescents with ADHD (75.98% boys aged 5–18 years). Forty-eight effect sizes utilized cognitive training in 15 interventions (Ackermann et al., 2018; Bigorra et al., 2016; Chacko et al., 2014; Egeland et al., 2013; Green et al., 2012; Kazemi and Mohammadi, 2019; Klingberg et al., 2005, 2002; Lee et al., 2021; Muris et al., 2018; Sperafico et al., 2021; Steeger et al., 2016; Tucha et al., 2011; van der Donk et al., 2015; Van Dongen-Boomsma et al., 2014); 45 used EF-specific curriculum in 16 interventions (Gerber et al., 2012; Hannesdottir et al., 2017; Janmohammadi et al., 2019; Lan et al., 2020; Lloyd et al., 2010; Menezes et al., 2015; Miranda et al., 2013, 2002; Moreno-García et al., 2019; Qian et al., 2017; Smith et al., 2019; Steeger et al., 2016; Tamm et al., 2013; Vanzin et al., 2020; Wexler et al., 2021); 44 tested game-based training in 12 interventions (Azami et al., 2016; Bikic et al., 2018, 2017; Dovis et al., 2015; Estrada-Plana et al., 2019; Johnstone et al., 2017, 2010; Jones et al., 2020; Kermani et al., 2016; Lan et al., 2020; Meyer et al., 2020; Prins et al., 2011); 24 used neurofeedback training in 13 studies (Alegria et al., 2017; Bakhshayesh et al., 2011; Dobrakowski and Łebecka, 2020; Drechsler et al., 2007; Geladé et al., 2017; Heinrich et al., 2004; Janssen et al., 2016; Lévesque et al., 2006; Maurizio et al., 2014; Moreno-García et al., 2019; Rezaei et al., 2018; Shereena et al., 2019; Wang, 2017); 26 measured physical exercise in 17 studies (Benzing and Schmidt, 2019; Bustamante et al., 2016; Chang et al., 2014; Choi et al., 2015; Faramarzi et al., 2016; Geladé et al., 2017; Janssen et al., 2016; Kadri et al., 2019; Lee et al., 2017; Memarmoghaddam et al., 2016; Nejati and Derakhshan, 2021; Pan et al., 2019, 2016; Rezaei et al., 2018; Silva et al., 2020; Verret et al., 2012; Ziereis and Jansen, 2015); only one study (Kiani et al., 2017) focused on mindfulness practices. Intervention frequency ranged from 1 to 5 times per week, sessions lasted 8.5–120 min, number of intervention sessions ranged from 3 to 64, and total duration ranged from 105 to 7200 min. Non-pharmacological intervention effects on core EFs, CF, IC, and WM were assessed by 173, 24, 72, and 77 effect sizes respectively. Although studies of higher-level EFs were limited, 6 effect sizes reported reasoning and 12 reported planning.

3.3. Meta-analysis of non-pharmacological intervention effects

Non-pharmacological interventions moderately to largely and significantly affected (combined) overall EFs ($g = 0.673$, 95% CI [0.534–0.809]), with large heterogeneity ($Q = 242.16$, $I^2 = 69.855$, $p < .001$) (Table 2). We found moderate to large significant effects on core EFs ($g = 0.557$, $k = 173$, 95% CI [0.467–0.648]), with large heterogeneity ($Q = 648.433$, $I^2 = 73.475$, $p < .001$) (Table 3). The effects for the three subtypes of core EFs were: moderately significant on CF ($g = 0.322$, $k = 24$, 95% CI [0.199–0.445]) with medium heterogeneity ($Q = 40.821$, $I^2 = 43.656$, $p = .012$); small to moderately significant on IC ($g = 0.478$, $k = 72$, 95% CI [0.405–0.551]) with large heterogeneity ($Q = 260.238$, $I^2 = 72.717$, $p < .001$); and small to moderately significant on WM ($g = 0.479$, $k = 77$, 95% CI [0.411–0.547]) with large heterogeneity ($Q = 342.031$, $I^2 = 77.780$, $p < .001$). Eighteen effect sizes had a small to moderate effect on higher-level EFs ($g = 0.444$, $k = 18$, 95% CI [0.169–0.720]) with medium heterogeneity ($Q = 43.189$, $I^2 = 60.639$, $p < .001$). Planning was moderately significantly affected ($g = 0.439$, $k = 12$, 95% CI [0.106–0.772]); and reasoning was non-significantly affected ($g = 0.450$, $k = 6$, 95% CI [−0.042 to 0.958]).

3.4. Meta-analysis of intervention type effects

3.4.1. Cognitive training

Cognitive training significantly affected overall EFs ($g = 0.724$, 95%

Table 3
Effects of overall and separately for the different categories of interventions on domain-specific EFs.

Intervention Category	Number of contrasts (k)	Average effect size (g)	95% Confidence interval	Test of heterogeneity		
				Q	I^2	P-value
Non-pharmacological Interventions						
Core executive functions	173	0.557	[0.467, 0.648]	648.433	73.475	< 0.001
Cognitive flexibility	24	0.322	[0.199, 0.445]	40.821	43.656	0.012
Inhibitory control	72	0.478	[0.405, 0.551]	260.238	72.717	< 0.001
Working memory	77	0.479	[0.411, 0.547]	342.031	77.780	< 0.001
Higher-level executive functions	18	0.444	[0.169, 0.720]	43.189	60.639	< 0.001
Planning	12	0.439	[0.106, 0.772]	18.919	41.858	0.063
Reasoning	6	0.450	[− 0.042, 0.958]	23.093	78.348	< 0.001
Cognitive Training						
Core executive functions	42	0.689	[0.468, 0.909]	226.837	81.925	< 0.001
Cognitive flexibility	6	0.180	[− 0.386, 0.745]	1.174	0	0.947
Inhibitory control	15	0.602	[0.231, 0.973]	84.555	83.443	< 0.001
Working memory	21	0.907	[0.593, 1.220]	120.260	83.369	< 0.001
Higher-level executive functions	6	0.574	[− 0.019, 1.166]	30.285	83.490	< 0.001
Planning	3	0.385	[− 0.396, 1.167]	10.554	81.049	0.005
Reasoning	3	0.824	[− 0.080, 1.728]	19.610	89.801	< 0.001
EF-specific Curriculum						
Core executive functions	41	0.337	[0.235, 0.438]	47.066	15.013	0.206
Cognitive flexibility	7	0.322	[0.080, 0.564]	4.701	0	0.583
Inhibitory control	15	0.437	[0.269, 0.605]	23.954	41.553	0.046
Working memory	19	0.263	[0.114, 0.412]	15.642	0	0.618
Higher-level executive functions	4	0.532	[0.246, 0.818]	5.888	49.050	0.117
Planning	4	0.532	[0.247, 0.817]	5.888	49.050	0.117
Game-based Training						
Core executive functions	38	0.378	[0.180, 0.576]	178.525	79.275	< 0.001
Cognitive flexibility	5	0.183	[− 0.378, 0.743]	1.191	0	0.880
Inhibitory control	13	0.270	[− 0.073, 0.614]	48.156	75.081	< 0.001
Working memory	20	0.504	[0.219, 0.790]	125.625	84.876	< 0.001
Higher-level executive functions	6	0.342	[− 0.160, 0.844]	4.283	0	0.509
Planning	3	0.400	[− 0.353, 1.153]	0.163	0	0.922
Reasoning	3	0.293	[− 0.420, 1.006]	3.169	36.896	0.205
Mindfulness Practice						
Core executive functions	3	0.216	[− 0.188, 0.620]	0.879	0	0.644
Inhibitory control	1	0.483	[− 0.224, 1.190]	0	0	1.0
Working memory	2	0.086	[− 0.407, 0.579]	0.064	0	0.801
Higher-level executive functions	1	0.407	[− 0.297, 1.111]	0	0	1.0
Planning	1	0.407	[− 0.297, 1.111]	0	0	1.0
Neurofeedback Training						
Core executive functions	23	0.724	[0.469, 0.978]	61.009	63.940	< 0.001
Cognitive flexibility	2	0.406	[− 0.483, 1.295]	0.218	0	0.640
Inhibitory control	14	0.740	[0.402, 1.078]	32.320	59.777	0.002
Working memory	7	0.815	[0.319, 1.311]	27.548	78.219	< 0.001
Higher-level executive functions	1	0.296	[− 0.881, 1.473]	0	0	1.0
Planning	1	0.296	[− 0.938. 1.531]	0	0	1.0
Physical Exercise						
Core executive functions	26	0.910	[0.637, 1.183]	95.015	73.688	< 0.001
Cognitive flexibility	4	1.377	[0.638, 2.116]	14.604	79.547	0.002
Inhibitory control	14	0.900	[0.526, 1.274]	49.461	73.717	< 0.001
Working memory	8	0.729	[0.241, 1.217]	24.293	71.185	0.001

CI [0.370–1.007]) with large heterogeneity ($Q = 70.644$, $I^2 = 80.182$, $p < .001$; Fig. 2). Cognitive Working Memory Training (CWMT) moderately to largely affected overall EFs ($g = 0.779$, 95% CI [0.352–1.207]; Table 2). The effect was: moderately significant on core EFs ($g = 0.689$, $k = 42$, 95% CI [0.468–0.909]); non-significant on CF ($g = 0.180$, $k = 6$, 95% CI [−0.386 to 0.745]); moderately to largely significant on IC ($g = 0.602$, $k = 15$, 95% CI [0.231–0.973]); largely significant on WM ($g = 0.907$, $k = 21$, 95% CI [0.593–1.220]). Higher-level EFs were non-significantly affected (overall: $g = 0.574$, $k = 6$, 95% CI [−0.019 to 1.166]; planning: $g = 0.385$, $k = 3$, 95% CI [−0.396 to 1.167]; reasoning: $g = 0.824$, $k = 3$, 95% CI [−0.080 to 1.728]) (Table 3).

3.4.2. *EF-specific curriculum*

The average significant effect of EF-specific curriculum on overall EFs was small to moderate ($g = 0.358$, $k = 16$, 95% CI [0.214–0.503]), with small heterogeneity ($Q = 13.147$, $I^2 = 0$, $p = .591$; Fig. 3). Children-oriented curriculum moderately affected overall EFs ($g = 0.352$, 95% CI [0.165–0.540]; Table 2). Regarding core EFs, they were small to moderately significantly affected ($g = 0.337$, $k = 41$, 95% CI [0.235–0.438]) with small heterogeneity ($Q = 47.066$, $I^2 = 15$, $p = .206$), with CF ($g = 0.322$, $k = 7$, 95% CI [0.080–0.564]), IC ($g = 0.437$, $k = 15$, 95% CI [0.269–0.605]) and WM ($g = 0.263$, $k = 19$, 95% CI [0.114–0.412]) being small to moderately significantly affected. Regarding higher-level EFs, planning was moderately to largely significantly affected ($g = 0.532$, $k = 4$, 95% CI [0.247–0.817]) with medium heterogeneity ($Q = 5.888$, $I^2 = 49$, $p = .117$) (Table 3).

3.4.3. *Game-based training*

Game-based training moderately to largely significantly affected overall EFs ($g = 0.532$, $k = 12$, 95% CI [0.228–0.837]) with medium heterogeneity ($Q = 33.692$, $I^2 = 67$, $p < .001$; Fig. 4). WM was significantly affected ($g = 0.504$, $k = 20$, 95% CI [0.219–0.790]) with large heterogeneity ($Q = 125.625$, $I^2 = 84$ $p < .001$), and non-significant for IC and CF (Table 2). Regarding higher-level EFs, there were six contrasts, which had a small but non-significant effect ($g = 0.342$, $k = 6$, 95% CI [−0.160 to 0.844]), including on planning ($g = 0.400$, $k = 3$, 95% CI [−0.353 to 1.153]) and reasoning ($g = 0.293$, $k = 3$, 95% CI [−0.420 to

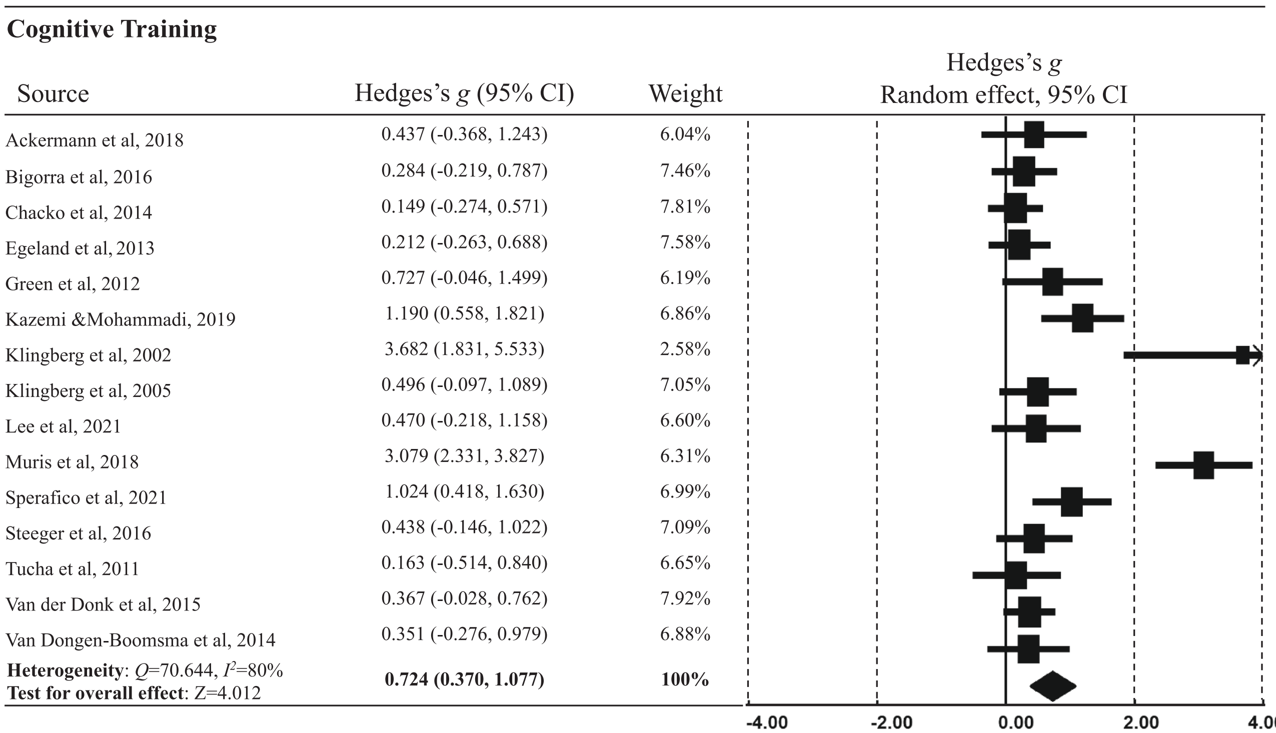

Fig. 2. Forest plot of effect of cognitive training on overall EFs.

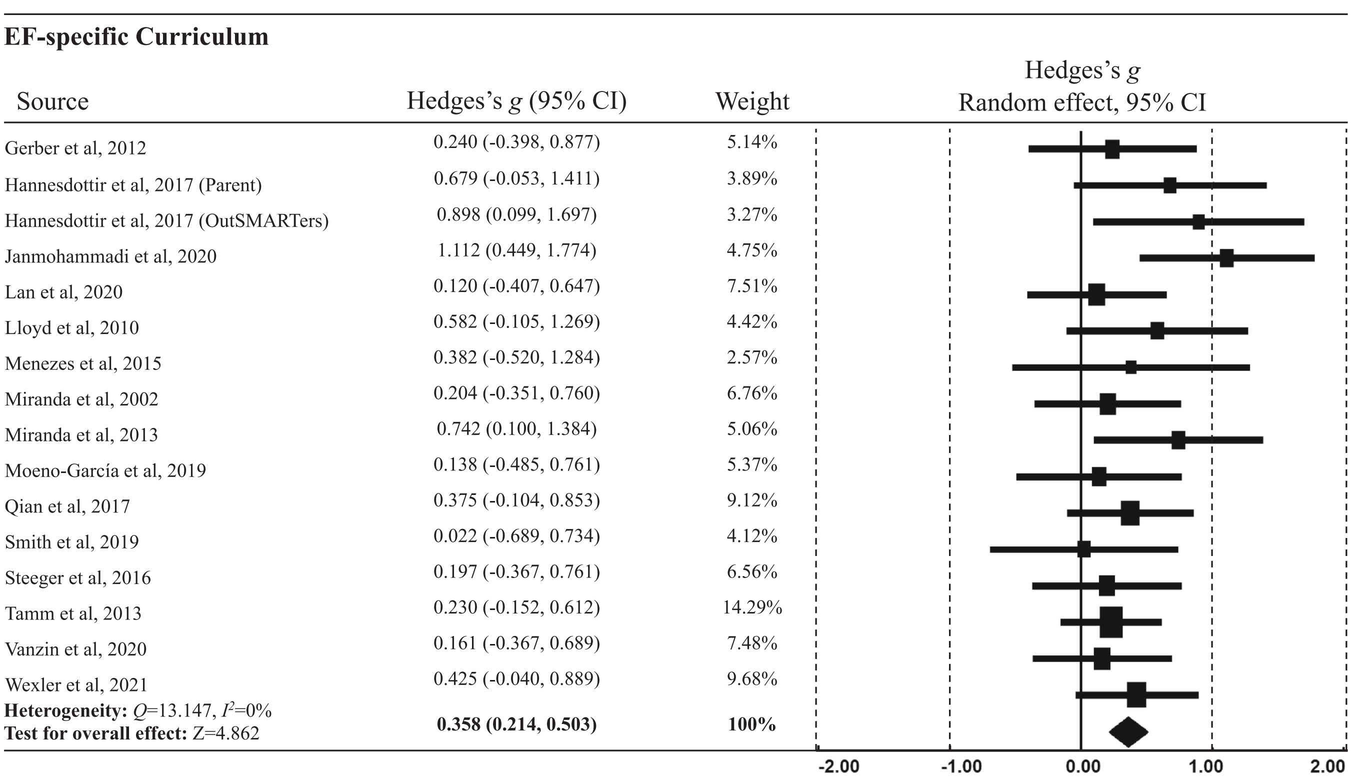

Fig. 3. Forest plot of the effect of EF-specific curriculum on overall EFs.

1.006]) (Table 3).

3.4.4. Mindfulness practice

Mindfulness intervention had no effect on overall EFs (g = 0.266, 95% CI [−0.436 to 0.967]); the three core EFs effect sizes had non-significant effects (g = 0.216, 95% CI [−0.188 to 0.620]) (Table 3).

3.4.5. Neurofeedback training

Neurofeedback training largely significantly affected overall EFs (g = 0.702, k = 13, 95% CI [0.367–1.037]) with medium heterogeneity (Q =

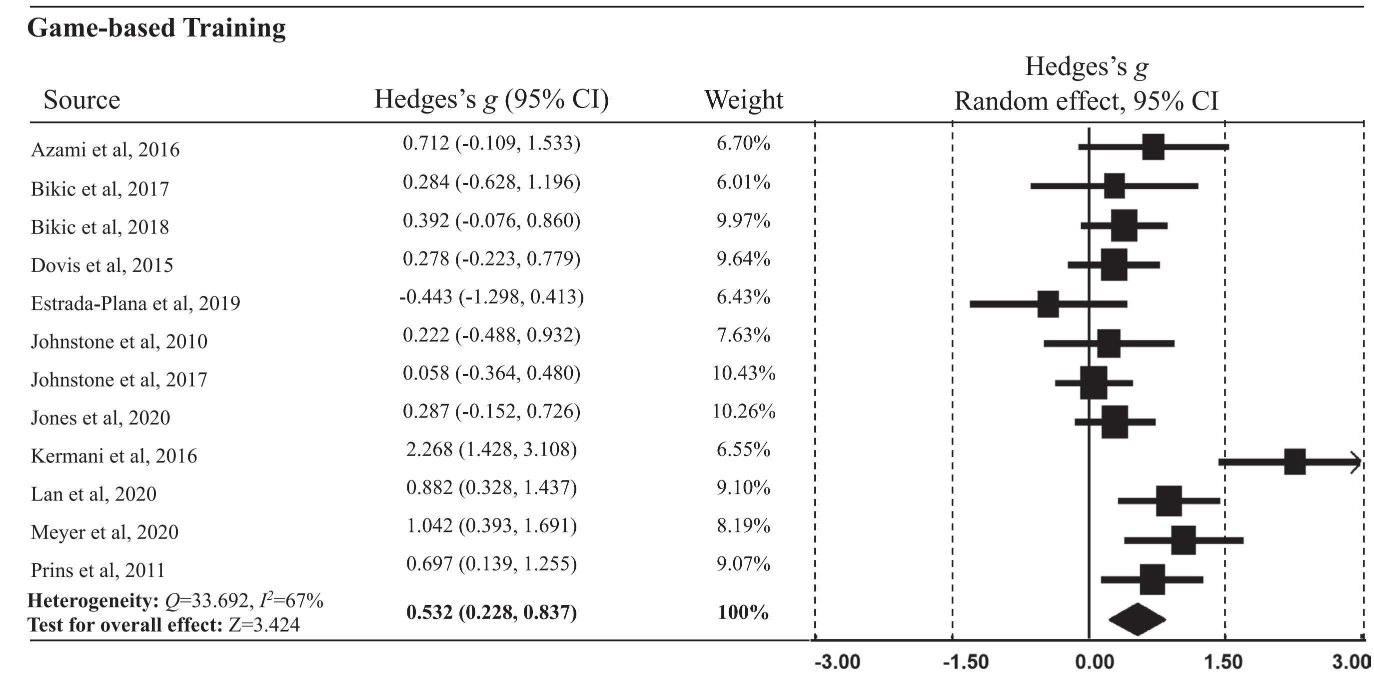

Fig. 4. Forest plot of effect of game-based training on overall EFs.

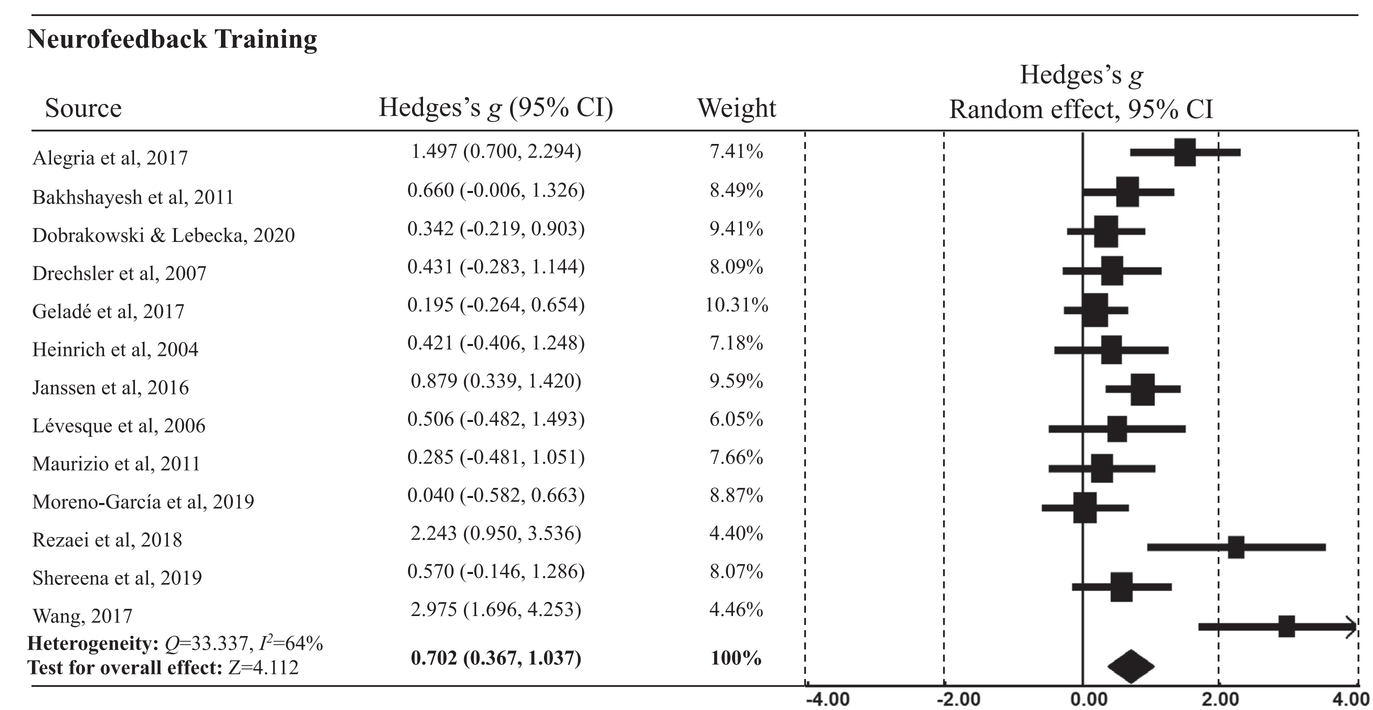

Fig. 5. Forest plot of effect of neurofeedback training on overall EFs.

33.337, I^2 = 64, $p < .001$; Fig. 5). Twenty-three effect sizes largely affected core EFs ($g = 0.724$, $k = 23$, 95% CI [0.469–0.978]), including IC ($g = 0.740$, $k = 14$, 95% CI [0.402–1.078]) and WM ($g = 0.815$, $k = 7$, 95% CI [0.319–1.311]). Only two contrasts assessed CF skills, showing non-significant effects ($g = 0.406$, $k = 2$, 95% CI [−0.483 to 1.295]). One on planning was non-significant ($g = 0.296$, 95% CI [−0.938 to 1.531]) (Table 3).

3.4.6. *Physical exercise*

Physical exercise significantly largely affected overall EFs ($g = 1.108$, $k = 17$, 95% CI [0.734–1.482]) with large heterogeneity ($Q = 66.644$, $I^2 = 76$, $p < .001$; Fig. 6). Both aerobic exercise ($g = 1.100$, $k = 5$, 95% CI [0.391–1.808]) and cognitively-engaged physical exercises ($g = 1.119$, $k = 12$, 95% CI [0.658–1.581]) produced significantly large effects on overall EFs (Table 2). Twenty-six effect sizes significantly largely affected core EFs ($g = 0.910$, $k = 26$, 95% CI [0.637–1.183]); four effect sizes significantly largely affected CF ($g = 1.377$, $k = 4$, 95% CI [0.638–2.116]); eight largely affected WM ($g = 0.729$, $k = 8$, 95% CI [0.241–1.217]); 14 largely significantly affected IC ($g = 0.900$, $k = 14$, 95% CI [0.526–1.274]). Few studies tested such intervention effects on

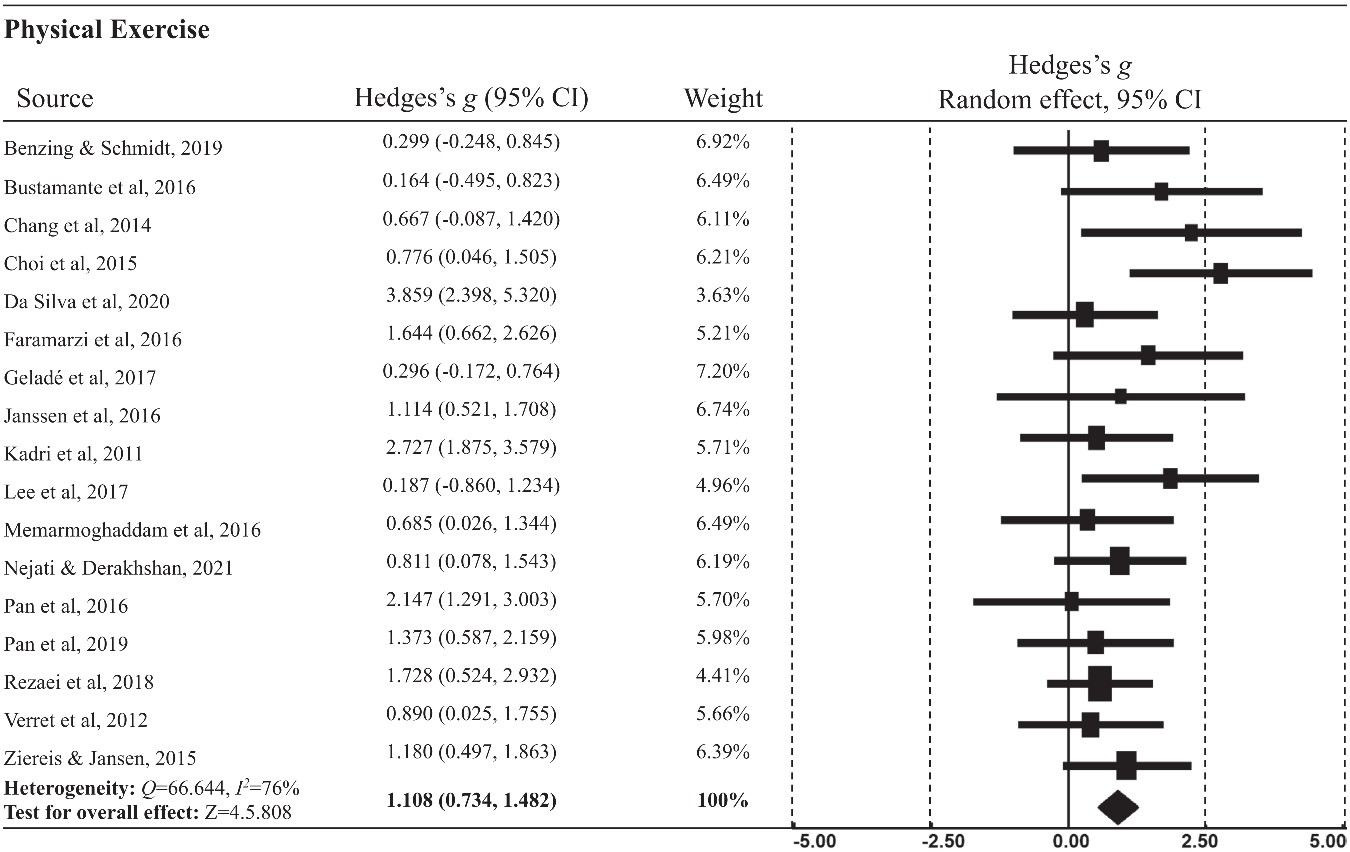

Fig. 6. Forest plot of effect of physical exercise on overall EFs.

Table 4
Moderator analysis of non-pharmacological interventions on overall EFs.

Categorical moderator	Level	Number of studies (k)	Average effect size (g)	95% Confidence interval	Test of heterogeneity		
					Q	I^2	P-value
Design	NRS	14	0.995	[0.665, 1.325]	73.057	82.206	< 0.001
	RCT	60	0.604	[0.455, 0.752]	158.596	62.799	< 0.001
Frequency	1–2 times/week	29	0.827	[0.603, 1.051]	123.186	77.270	< 0.001
	3–4 times/week	21	0.585	[0.323, 0.846]	35.672	43.934	0.017
	≥ 5 times/week	20	0.552	[0.292, 0.813]	69.338	72.598	< 0.001
	N/A	4	0.679	[0.075, 1.282]	7.297	58.888	0.063
Intervention format	Group	29	0.652	[0.428, 0.875]	80.968	65.418	< 0.001
	Individual	45	0.686	[0.510, 0.862]	160.865	72.648	< 0.001
Modality	Clinical	10	0.775	[0.420, 1.131]	27.816	67.645	0.001
	Community	6	1.752	[1.261, 2.243]	26.638	81.230	< 0.001
	Home	19	0.547	[0.307, 0.786]	78.827	77.165	< 0.001
	School	18	0.507	[0.251, 0.762]	28.369	40.075	0.041
	N/A	21	0.596	[0.350, 0.842]	34.111	41.368	0.025
Session length, min	≤ 40 mins/session	21	0.653	[0.390, 0.916]	54.285	63.157	< 0.001
	41–60 mins/session	36	0.742	[0.541, 0.943]	155.766	77.530	< 0.001
	> 60 mins/session	15	0.576	[0.265, 0.888]	29.003	51.730	0.010
	N/A	2	0.437	[– 0.390, 1.265]	1.751	42.894	0.186
Continuous moderator	Level	Number of studies (k)	β	95% Confidence interval	Q	d.f.	P-value
Age	5–18	68	0.0530	[– 0.0345, 0.1406]	1.41	1	0.2352
Sessions	3–144	74	0.0054	[– 0.0027, 0.0134]	1.69	1	0.1939
Duration (mins)	105–7200	74	0.0000	[– 0.0001, 0.0001]	0.08	1	0.7713

higher-level EFs (Table 3).

3.5. Moderator analysis

Regarding non-pharmacological intervention effects on overall EFs, the meta-regressions showed that age, intervention duration, and intervention sessions were not related to effect changes; subgroup analyses showed that effects were not moderated by research design, frequency, intervention format, intervention modality, or session length (Table 4).

3.6. Sensitivity analysis

Six studies (Kadri et al., 2019; Kermani et al., 2016; Muris et al.,

Table 5
Methodological quality assessment for included studies.

Study (Year, Country/ Region)	Eligibility Criteria	Random Allocation	Concealed Allocation	Similar at Baseline	Subject Blinded	Therapist Blinded	Assessor Blinded	Dropout Rate	Intention-to-treat Analysis	Between-group Comparison	Points Measures	Total Score	Overall Study Quality
Ackermann, Switzerland) et al. (2018)	1	0	0	1	0	0	0	1	1	1	1	5	fair
Alegria, UK) et al. (2017)	1	1	1	1	1	0	0	1	1	1	1	8	good
Azami, Iran) et al. (2016)	1	1	1	1	0	0	0	1	1	1	1	7	good
Bakhshayesh, Germany) et al. (2011)	1	1	0	1	1	0	0	1	1	1	1	7	good
Benzing and Schmidt, Switzerland) (2019)	1	1	1	1	1	0	0	1	1	1	1	8	good
Bigorra, Spain) et al. (2016)	1	1	1	1	1	0	1	1	1	1	1	9	excellent
Bikic, Denmark) et al. (2017)	1	1	1	1	1	0	1	1	1	1	1	9	excellent
Bikic, Denmark) et al. (2018)	1	1	1	1	1	0	1	1	1	1	1	9	excellent
Bustamante, USA) et al. (2016)	1	1	1	1	0	0	1	1	1	1	1	8	good
Chacko, USA) et al. (2014)	1	1	1	1	1	0	1	1	1	1	1	9	excellent
Chang, Taiwan) et al. (2014)	1	0	0	1	0	0	0	1	1	1	1	5	fair
Choi, Korea) et al. (2015)	1	1	0	1	0	0	0	1	1	1	1	6	good
DaSilva, Brazil) et al. (2020)	1	1	0	1	0	0	0	1	1	1	1	6	good
Dobrakowski & Lebecka (2020, Poland)	1	1	0	1	0	0	0	1	1	1	1	6	good
Dovis, Netherlands) et al. (2015)	1	1	1	1	1	0	1	1	1	1	1	9	excellent
Drechsler, Switzerland) et al. (2007)	1	0	0	1	0	0	0	1	1	1	1	5	fair
Egeland, Norway) et al. (2013)	1	1	1	1	0	0	1	1	1	1	1	8	good
Estrada-Plana, Spain) et al. (2019)	1	1	0	1	0	0	0	1	1	1	1	6	good
Faramarzi, Iran) et al. (2016)	1	1	0	1	0	0	0	0	1	1	1	5	fair
Geladé, Netherlands) et al. (2017)	1	1	1	1	0	0	0	1	1	1	1	7	good
Gerber, Germany) et al. (2012)	1	1	0	1	0	0	0	1	1	1	1	6	good
Green, USA) et al. (2012)	1	1	1	1	1	1	0	1	1	1	1	9	excellent
Hannesdottir, Iceland) et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	6	good
Heinrich, Germany) et al. (2004)	1	1	0	1	0	0	0	1	1	1	1	6	good
Janmohammadi, Iran) et al. (2019)	1	1	0	1	0	0	1	1	1	1	1	7	good
Janssen, Netherlands) et al. (2016)	1	1	1	1	0	0	0	1	1	1	1	7	good
Johnstone, Australia) et al. (2010)	1	1	1	1	1	0	0	1	1	1	1	8	good
Johnstone, Australia) et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	6	good
Jones, USA) et al. (2020)	1	1	1	1	0	0	0	1	1	1	1	7	good
Kadri, Tunisia) et al. (2019)	1	1	0	1	0	0	0	1	1	1	1	6	good
Kazemi and Mohammadi, Iran) (2019)	1	0	0	1	0	0	0	0	1	1	1	4	fair
Kermani, Iran) et al. (2016)	1	1	0	1	0	0	0	0	1	1	1	5	fair
Kiani, Iran) et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	6	good

(*continued on next page*)

Table 5 (*continued*)

Study (Year, Country/Region)	Eligibility Criteria	Random Allocation	Concealed Allocation	Similar at Baseline	Subject Blinded	Therapist Blinded	Assessor Blinded	Dropout Rate	Intention-to-treat Analysis	Between-group Comparison	Points Measures	Total Score	Overall Study Quality
Klingberg, Sweden) et al. (2005)	1	1	1	1	1	1	1	1	1	1	1	10	excellent
Klingberg, Sweden) et al. (2002)	1	0	0	1	0	0	0	1	1	1	1	5	fair
Lan, China) et al. (2020)	1	1	0	1	1	1	1	1	1	1	1	9	excellent
Lee, Korea) et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	6	good
Lee, Hong Kong) et al. (2021)	1	0	0	1	0	0	0	1	1	1	1	5	fair
Lévesque, Canada) et al. (2006)	1	1	0	1	0	0	0	0	1	1	1	5	fair
Lloyd, UK) et al. (2010)	1	1	0	1	1	0	1	1	1	1	1	8	good
Maurizio, Switzerland) et al. (2014)	1	1	0	1	1	0	0	1	1	1	1	7	good
Memarmoghaddam, Iran) et al. (2016)	1	1	0	1	0	0	0	1	1	1	1	6	good
Menezes, Brazil) et al. (2015)	1	0	0	1	0	0	0	1	1	1	1	5	fair
Meyer, USA) et al. (2020)	1	1	0	1	1	0	0	1	1	1	1	7	good
Miranda, Spain) et al. (2013)	1	1	0	1	0	0	0	1	1	1	1	6	good
Miranda, Spain) et al. (2002)	1	0	0	1	0	0	0	1	1	1	1	5	fair
Moreno-García et al. (2019, Spain)	1	1	0	1	0	0	0	1	1	1	1	6	good
Muris, Netherlands) et al. (2018)	1	1	0	1	0	0	0	1	1	1	1	6	good
Nejati and Derakhshan, Iran) (2021)	1	1	0	1	0	0	0	1	1	1	1	6	good
Pan, Taiwan) et al. (2016)	1	1	0	1	0	0	0	1	1	1	1	6	good
Pan, Taiwan) et al. (2019)	1	0	0	1	0	0	0	1	1	1	1	5	fair
Prins, Netherlands) et al. (2011)	1	1	0	1	0	0	0	1	1	1	1	6	good
Qian, China) et al. (2017)	1	1	1	1	0	0	0	1	1	1	1	7	good
Rezaei, Iran) et al. (2018)	1	1	0	1	0	0	0	1	1	1	1	6	good
Shereena et al. (2018, India)	1	1	0	1	0	0	0	1	1	1	1	6	good
Smith, USA) et al. (2019)	1	1	0	1	0	0	0	1	1	1	1	6	good
Sperafico, Brazil) et al. (2021)	1	1	0	1	0	0	0	1	1	1	1	6	good
Steeger, USA) et al. (2016)	1	1	0	1	1	0	1	1	1	1	1	8	good
Tamm, USA) et al. (2013)	1	1	0	1	0	0	0	1	1	1	1	6	good
Tucha, Germany) et al. (2011)	1	1	0	1	0	0	0	1	1	1	1	6	good
van der Donk, Netherlands) et al. (2015)	1	1	1	1	1	0	1	1	1	1	1	9	excellent
van Dongen-Boomsma et al. (2014, Netherlands)	1	1	0	1	1	1	1	1	1	1	1	9	excellent
Vanzin, Italy) et al. (2020)	1	0	0	1	0	0	0	1	1	1	1	5	fair
Verret, Canada) et al. (2012)	1	0	0	1	0	0	0	1	1	1	1	5	fair
Wang, China) (2017)	1	0	0	1	0	0	0	1	1	1	1	5	fair
Wexler, USA) et al. (2021)	1	1	0	1	0	0	0	1	1	1	1	6	good
Ziereis and Jansen, Germany) (2015)	1	1	0	1	0	0	0	1	1	1	1	6	good

* Yes= 1; No= 0. < 4 are considered ‘poor’, 4–5 are considered ‘fair’, 6–8 are considered ‘good’ and 9–10 are considered ‘excellent’. $M_{\text{Total score}} = 6.57$.

2018; Pan et al., 2016; Silva et al., 2020; Wang, 2017) were identified as outliers ($z = 6.272$, $z = 5.293$, $z = 8.069$, $z = 4.915$, $z = 5.176$, $z = 4.560$, respectively). Thus, we performed a “one study removed” test. The single effect size scores showed changes of − 0.031(Kadri et al., 2019), − 0.023 (Kermani et al., 2016), − 0.045 (Muris et al., 2018), − 0.002 (Pan et al., 2016), − 0.025 (Silva et al., 2020), and − 0.021 (Wang, 2017), respectively, but remained significant ($p < .01$) and within the 95% confidence interval. Therefore, we kept the six outliers in the meta-analysis.

3.7. Publication bias

Regarding publication bias, the results were *g* publication-bias-adjusted = 0.792, 95%CI [0.654–0.931]; eleven studies were needed to balance the plot (Fig. S1). Therefore, there is a potential publication bias (Duval and Tweedie, 2000) in our included studies.

3.8. Quality assessment

The studies were generally of fairly high quality (mean quality score, 6.57) because they were RCTs (Table 5). All studies had clear inclusion criteria, and participants had a formal diagnosis. An intention-to-treat analysis (based on baseline assessments) indicated that participants received appropriate training. However, it is difficult to maintain a double-blind participant and therapist status in physical exercise training trials (Sherrington et al., 2010).

4. Discussion

We investigated the effects of non-pharmacological interventions on EFs in children and adolescents with ADHD based on 74 independent interventions in 67 studies. Results indicated that non-pharmacological interventions had positive moderate to large effects on overall EFs; small to moderate effects on CF, IC, WM, and planning; non-existent on reasoning skills. Further, few non-pharmacological intervention modifiers of overall EFs were observed.

Our findings have extended those of a 2020 systematic review including 19 articles (Lambez et al., 2020) that assigned non-pharmacological interventions to four categories (neurofeedback, cognitive-behavioural therapy, cognitive training, and physical exercises). It should be noted that Lambez et al.’s study did not examine non-pharmacological interventions’ overall effects and specific EF domains. It only included few studies and covered children, adolescents, and adults (Lambez et al., 2020), failing to provide robust evidence of non-pharmacological interventions’ overall effect on EFs and precise effect size for children and adolescents with ADHD. The current study delivers robust evidence from 74 independent non-pharmacological interventions with 3147 children and adolescents with ADHD, confirming a moderate to large training effect ($g = 0.672$). More importantly, recent literature on non-pharmacological approaches to EFs and the impact of comorbidities in children with ADHD also supported our results (Liu et al., 2023; Nejati et al., 2023; Roy et al., 2022).

Consistent with a previous review (Lambez et al., 2020), physical exercise was the most effective non-pharmacological intervention for improving overall EFs in children and adolescents with ADHD (g=1.108), especially for IC (g=0.900) and CF (g=1.377). A recent review on exercise interventions (Liang et al., 2021) strongly supports our findings. While research showed that cognitively-engaged physical exercises produced more exercise-induced improvements than aerobic exercise in healthy children (Diamond and Ling, 2016), our findings suggest that both aerobic and cognitively-engaged physical exercises are beneficial for overall EFs in children and adolescents with ADHD. This may be because low EFs performers (vs. high) can experience a greater exercise-induced reward (Pontifex et al., 2019). Therefore, children and adolescents with ADHD and EF impairments may improve EFs through any exercise intervention type (Sibley and Etnier, 2003).

Cognitive training was the most effective intervention for WM (g=0.907), especially CWMT (g=0.779). Consistent with a systematic review of 22 studies (Veloso et al., 2020), in which 13 reported performance-based EF improvements, including WM (Veloso et al., 2020). Despite these similarities, the previous review included pre-schoolers and subjective EF measurements, potentially inflating the true effect size of cognitive training in children and adolescents with ADHD. Furthermore, several RCTs on CWMT reported positive WM effects in children and adolescents with ADHD (Bigorra et al., 2016; Chacko et al., 2014; Van Dongen-Boomsma et al., 2014). CWMT has been used with different ages and populations and has shown effectiveness in healthy populations (g=1.18) (Melby-Lervåg and Hulme, 2013). Our study confirmed that CWMT moderately to largely affected WM (g=0.779) in children and adolescents with ADHD. Therefore, CWMT interventions might be key to improving WM performance in ADHD populations.

Regarding higher-level EFs, only EF-specific curricula significantly affected planning (g=0.532). Our study also confirmed that child-oriented programs showed significant effects on overall EFs (g = 0.352, 95% CI [0.165–0.540]), while parent- or teacher-oriented programs did not. These results concord with previous reviews (Diamond and Lee, 2011; Takacs and Kassai, 2019), and indicate that EF training could be incorporated into school curriculum to allow children to practice learned EF skills interwoven into all academic activities.

This study has a number of limitations. First, we included only one study that assessed mindfulness practices, hindering our ability to evaluate its true effects. Second, most participants in the meta-analysis were boys (75.98%), so sex could not be assessed as a moderator variable. Third, our meta-analysis showed high heterogeneity; despite limiting the sample to studies with neurocognitive EF tests and excluding other measurement approaches (e.g., parent-/teacher-reported questionnaires). Fourth, higher-level EFs (e.g., planning and reasoning) were assessed with only 18 effect sizes, and other higher-level EFs (e.g., problem-solving skills) could not be identified. Finally, our study focused on intervention effects on EFs. Researchers could further evaluate transfer effects of EF improvement to related health indicators, such as social relationships, behavioral problems, and academic achievement, and explore the potential mechanisms underlying the effects of different categories on EFs in children and adolescents with ADHD (e.g., behavioural mechanism of sleep) (Liang et al., 2022; Qiu and Liang, 2023).

5. Conclusion

A moderate to large positive effect of non-pharmacological interventions on overall EFs in children and adolescents with ADHD was observed. The study underpins the importance of non-pharmacological treatments for improving core EFs in this clinical population.

Declaration of Competing Interest

There are no conflicts of interest from funding sources or from manufacturer/commercial products. All authors have no financial disclosures.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ajp.2023.103692.

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