Effects of Serious Games for Treating Attention Deficit Hyperactivity Disorder: A Meta-Analysis

Sonja Dobrowolski

Faculty of Behavioural, Management, and Social Science

Department of Psychology, University of Twente

PhD Yudit Namer, Dr. Thomas R. Vaessen

July 17th, 2023

Abstract

Non-pharmacological interventions are increasingly being developed and implemented for the treatment of attention deficit hyperactivity disorder (ADHD). Serious games (SG) are one of the most recent non-pharmacological interventions being developed and assessed for efficacy. Previous literature stated that SGs have great potential for treating ADHD and are already used in treatment in combination with Neurofeedback (NF) and electroencephalogram (EEG). With only several experimental studies but no substantial evidence on the effectiveness of SG for reducing ADHD symptoms and improving executive functions (EF) being available yet, the present study conducted a meta-analysis. A systematic literature review was conducted using databases of Scopus, Base, WOS, PsychINFO, Pubmed, Cochrane, ACM, and IEEE. A random effects model was used for the pooled effect sizes, and heterogeneity was examined by Q and I^2 statistics. Publication bias was assessed by funnel plots. In total, eight studies were included, and five different meta-analyses were conducted. The first looked at the effect of SGs on the main ADHD symptoms, and the results showed a small, non-significant positive effect ($g = 0.01$). The second and third meta-analysis looked at one of the main symptoms each (inattention and hyperactivity), and both showed a small, non-significant negative effect ($g = -0.04$; $g = -0.01$). The fourth looked at the effect of SGs on EFs in general, and the last focused on working memory (WM) specifically. The analyses on EF found a small, non-significant positive effect ($g = 0.24$), and the one on WM a large, non-significant positive effect ($g = 0.80$). Therefore, SGs may be effective for ADHD treatment in general but this study found no evidence of its effectiveness as a standalone intervention. Further experimental research is needed to investigate the specific effects of SG on ADHD and its effects when used in combination with NF or EEG.

Keywords: ADHD, serious games, treatment, meta-analysis, effectiveness

Effects of Serious Games for Treating Attention Deficit Hyperactivity Disorder: A Meta-Analysis

Attention deficit hyperactivity disorder (ADHD) is a common neurodevelopmental disorder, usually diagnosed during childhood but can affect individuals throughout their lives. A meta-analysis found a worldwide-pooled prevalence of about 5% for individuals 18 years old or younger (Polanczyk et al., 2014). Furthermore, another meta-analysis found a prevalence of 2.58% for persistent adult ADHD and 6.76% for symptomatic adult ADHD (Song et al., 2021). ADHD can include impaired functioning and neuropsychiatric problems related to a delay in the development of brain areas (American Psychiatric Association, 2013; Flinsenberg, 2020). Impairments in three domains are known as the main symptoms of ADHD, namely inattention, hyperactivity, and impulsivity. These are in line with the three ADHD subtypes (inattentive, hyperactive/impulsive & combined) described in the Diagnostic and Statistical Manual of Mental Disorders, Fifth edition (DSM-5) (American Psychiatric Association, 2013; Faraone et al., 2015). The DSM criteria for each subtype can be found in Appendix A. Other symptoms can be making careless mistakes, being distracted easily, difficulty listening, forgetting and losing things, poor organisational skills, fidgeting, inability to engage in quiet activities, and interrupting others (American Psychiatric Association, 2013). Hyperfocus (HF) is another symptom individuals with ADHD can experience which is relatively new in research.

While ADHD significantly impacts mental wellbeing, academic & professional performance, social relations, and Quality of Life (QoL), few effective treatment options are available (Barkely & Murphy, 2010; DuPaul et al., 2001; Leffa et al., 2022). Currently, clinical guidelines recommend an individualised combination of psychoeducation, pharmacological and non-pharmacological interventions for treating ADHD (Mechler et al., 2022). Psychostimulant

and non-psychostimulant medications are used to treat ADHD and statistics found that 70% of the children experienced improvements in their ADHD symptoms due to the medication (Meijer et al., 2009; National Institute for Health and Care Excellence, 2018). However, these drugs can cause many side effects for children and adults, including sleep disorders, loss of appetite, cardiovascular effects, increased suicidal ideation, depression, dry mouth, seizures, dizziness, mood swings, and growth delay (Cortese, 2020; Meijer et al., 2009). Due to these side effects, risk for tolerance and sensitization effects, and stigma, carers and individuals with ADHD have reservations about ADHD medication (Cortese, 2020; Castells et al., 2020). Moreover, a chart review study identified a need for more effective and safer treatments for ADHD since interventions lack efficacy and often include complications (Schein et al., 2022).

Recently, new non-pharmacological treatment interventions and methods have been developed. These treatments tend to have lower side effects, higher participation rates, and higher motivation (Zheng et al., 2021). Many of the non-pharmacological treatments are shown to be effective, like Neurofeedback (NF) and Serious Games (SG) but there is still a lack of research on their efficacy (Enriquez-Geppert et al., 2019; Zheng et al., 2021). In order to understand the effectiveness and mechanisms of such non-pharmacological treatments it is important to understand the underlying mechanisms of ADHD as described in various scientific theories. One more recent summarising theory will be explained in the following section.

Theoretical Background: The Dual Pathway Model

The dysregulation of thought and action pathway (DTAP) and the motivational style pathway (MSP) are the two separable pathophysiological pathways explaining symptoms of ADHD in the Dual Pathway Model (DPM) (Sonuga-Barke, 2002). DTAP (fronto-dorsal striatal circuit) states that abnormalities in the brain cause reduced inhibitory control, leading to

Executive Dysfunctions (EDF). EDF refers to a range of difficulties in cognitive processes involved in attention, organisation, memory, working memory (WM), and time management, which are also present in ADHD (Sonuga-Barke, 2003). Inhibitory deficits are related to controlling impulsivity, thus making it challenging to resist distractions and emotional, behavioural, and thought regulation. Therefore, inhibitory deficits often negatively impact social engagement and are associated with impairment expressed as EDF.

The MSP (fronto-ventral striatal circuit) states that the reward circuit and environmental factors cause a delay for aversion, which leads to symptoms of ADHD. The reward circuit of individuals with ADHD is altered, which shortens the delay of reward gradient (Sonuga-Barke, 2002). More specifically, the longer individuals with ADHD must wait for a reward after a response, the less effective the rewards become, thus, leading to a preference for immediate rewards. Waiting for a reward (delay) becomes associated with negative emotions (delay aversion). These negative emotions toward delay often arise due to the response being viewed as a failure by the individual, leading to inadequate responses to contextual demands (Sonuga-Barke, 2002). The opposing view of delay can be facilitated by external factors, such as parents responding harshly to perceived impulsiveness towards the child (Sonuga-Barke, 2002; Sonuga-Barke, 2003).

Several studies conducted with 7 months year old infants, 6-year-old children and children visiting school, support the DPM (Dalen et al., 2004; Solanto et al., 2001; Thorell, 2007). While no study was conducted on adults, one cross-sectional study generally supported the ideas behind the DPM since a lower delay tolerance was confirmed (Marx et al., 2010).

Another study has found that individuals with ADHD will wait for a larger reward if the total delay is not reduced by choosing a smaller reward, thus showing an economic factor in the

preference for immediate rewards. The study further found that if delay had to be endured, the participants attention shifted to present stimuli in the environment, to reduce the perception of time and avoid the experience of delay (Sonuga-Barke, 2003). This theory also supports the recent studies which questions the existence of an attentions deficiency and instead suggest a dysfunctional attentional regulation (Hupfeld et al., 2019).

Non-Pharmacological Intervention: Serious Games

Non-pharmacological treatment strategies refer to therapeutic approaches that do not involve the use of medications or drugs and can be psychosocial-, body focused-, cognitive/neuro-cognitive-, and cognitive-behavioural interventions. Generally, non-pharmacological interventions are not recommended for improving core ADHD symptoms as a standalone treatment due to limited evidence of effectiveness (Ogundele & Ayyash, 2023). Treatments like NF and neurocognitive training for example showed mixed results (Cortese et al., 2016; Flisiak-Antonijczuk et al., 2015). Mixed results were often found for studies with an active control condition since a significant improvement was found in both the control and experimental groups. Placebo effects, increased patient knowledge, task demands like practicing sustaining focus, therapeutic relationship or motivation for engagement could be reasons for the improvement in those control condition (Hoxhai et al., 2018; Philipsen et al., 2015; Schonenberg et al., 2017; Vidal et al., 2013).

While some non-pharmacological interventions like NF have been studied more extensively and used in practice, SG still lacks research. SGs are educational applications which intend to teach and practice skills in an entertaining manner (Zheng et al., 2021). SG are very adaptable and offer a wide range of opportunities in individualisation and specialisation to specific ADHD related problems since various technologies can be implemented for the games.

These games are usually based on technology and can be played on consoles, computers, and mobile devices. Often, they are embedded in video games or smart phone applications, like EndeavorRX, (also knowns as AKL-T01) the first Food and Drug Administration (FDA) approved SG for ADHD treatment (Canady, 2020). EndeavorRX is an immersive video game for mobile phones in which children between the age 8-12 can race though worlds, chase creatures and use boosts to solve problems and build their own universe. Within the game sensory stimuli and motor challenges are used to target certain brain areas which are relevant for attention. Furthermore, children are challenged to ignore distractions and multitask by avoiding obstacles and collect targets. The game should be played 25 minutes, 5 days a week for at least four weeks and it is personalised to each patient.

While SGs can have a positive effect on ADHD symptoms and EFs, there is a risk of addiction and harm to eyesight (Zheng et al., 2021). However, individuals with ADHD are already very attracted to videogames, probably due to their reward-sensitive cognitive style and sensation seeking, which is supported by the DPM and HF (Bioulac et al., 2012). Thus, high motivation and engagement can be expected with SG treatments (Prins et al., 2011). Recently studies have included another aspect of ADHD relevant to SGs: hyperfocus (HF). HF is a state of heightened attention which can be experienced by individuals with ADHD, mostly when doing activities of their interest (Hupfeld et a., 2019). This may explain why individuals with ADHD, can game for hours without struggling to focus but cannot sit still in a lecture. This finding supports that the name attention deficit may be misleading since the issue appears to be in regulating attention instead (Hupfeld et a., 2019). Therefore, SGs might overcome the difficulty of engaging individuals with ADHD in learning activities by using a format of their interest.

Furthermore, many SG interventions for ADHD focus on inhibitory control which is in line with the DPM and a core symptom of ADHD (Barkley, 1997; Sonuga-Barke, 2002). In general, SG for ADHD show a great potential for reducing ADHD symptoms and improving EF's due to the matching nature of the games to the learning style of individuals with ADHD. However, the experimental studies published looking at the effectiveness of SGs for ADHD treatment are often not comparable due to differences in outcome measures, lack of quality overall, and many combinations of SGs with other treatments like NF. Results for the efficacy of SG have been mixed but several studies found that SGs were effective for alleviating ADHD symptoms and improving Executive Functions (EF) (Alabdulakareem & Jamjoom, 2020; Zheng et al., 2021). Moreover, SGs may improve memory, participation, attention, social skills, time management, organisation, and emotional regulation (Avila-Pesantez et al., Bul et al., 2015; Hakimirad et al., 2019; Hocine, 2019; Zheng et al., 2021). Further research is needed that assesses the effectiveness of SG interventions as a standalone treatment with standardised outcome measures.

The Current Study

ADHD has a significant effect on the individual's wellbeing, health, and QoL. The most common treatment consisting of medication appears to have significant side effects on the individuals. However, there are new non-pharmacological interventions being developed. Multiple studies have pointed out the lack of quantitative research on the efficacy of these non-pharmacological interventions such as SGs and support the need for meta-analysis (Fabiano et al., 2021; Lakes et al., 2022). Therefore, this study will focus on the effectiveness of SGs for individuals with ADHD. SGs showed great potential for the treatment of ADHD and little quantitative research has been done to prove this potential further. Thus, the research question of

this study is "What is the effect of serious games on the main symptoms of ADHD, EFs and WM?".

Methods

Study Design

The primary goal of a meta-analysis is to provide a more precise and robust estimate of the true effect size by combining the results from multiple independent studies, which have answered the same research question or hypothesis (Borenstein et al., 2021). By aggregating the results of different studies, the statistical power can be improved and significant effects that may have been missed can be detected. Meta-analysis generally includes systematically identifying, selecting, and analysing data from individual studies. More specifically, several steps are involved in a meta-analysis, such as research question and study selection, data extraction, assessment of study quality and risk of bias, effect size calculation, statistical analysis, publication bias assessment and interpretation and reporting (Borenstein et al., 2021). The present meta-analysis adhered to the guidelines set forth by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) for conducting and reporting studies (Page et al., 2021).

Search Strategy

Table 1

Summary of search terms

Category	**Included search terms**
Disorder	("ADHD" OR "ADD" OR "attention deficit hyperactivity disorder")
AND	
Intervention type	("serious games" OR "serious gaming" OR "applied games" OR "video games")
AND	
Purpose of the intervention	("treatment" OR "therapy" OR "training" OR "rehabilitation")
Filters	English, peer-reviewed articles

To identify relevant articles, a systematic literature search was conducted across eight databases, namely Scopus, Base, WOS, PsychINFO, Pubmed, Cochrane, ACM and IEEE. The inclusion of an extensive list of databases is grounded on the limited number of experimental studies available on the effectiveness of SGs for ADHD. These databases were chosen based on their area of discipline including neurology, health care, psychology, and technology. The search string used in each database included three search terms with the operators “AND” and “OR” (Table 1). Whenever feasible, the search was refined to include only articles written in English. There was no limitation set on the specific year ranges to avoid the risk of missing relevant studies. For the same reason, previously published reviews and meta-analyses were searched manually.

Eligibility Criteria

The meta-analysis includes studies which met the following inclusion criteria: (1) participants were diagnosed with ADHD (all ages were included for participants); (2) an empirical study was conducted; (3) the effectiveness of a SG was assessed; (3) pre and post

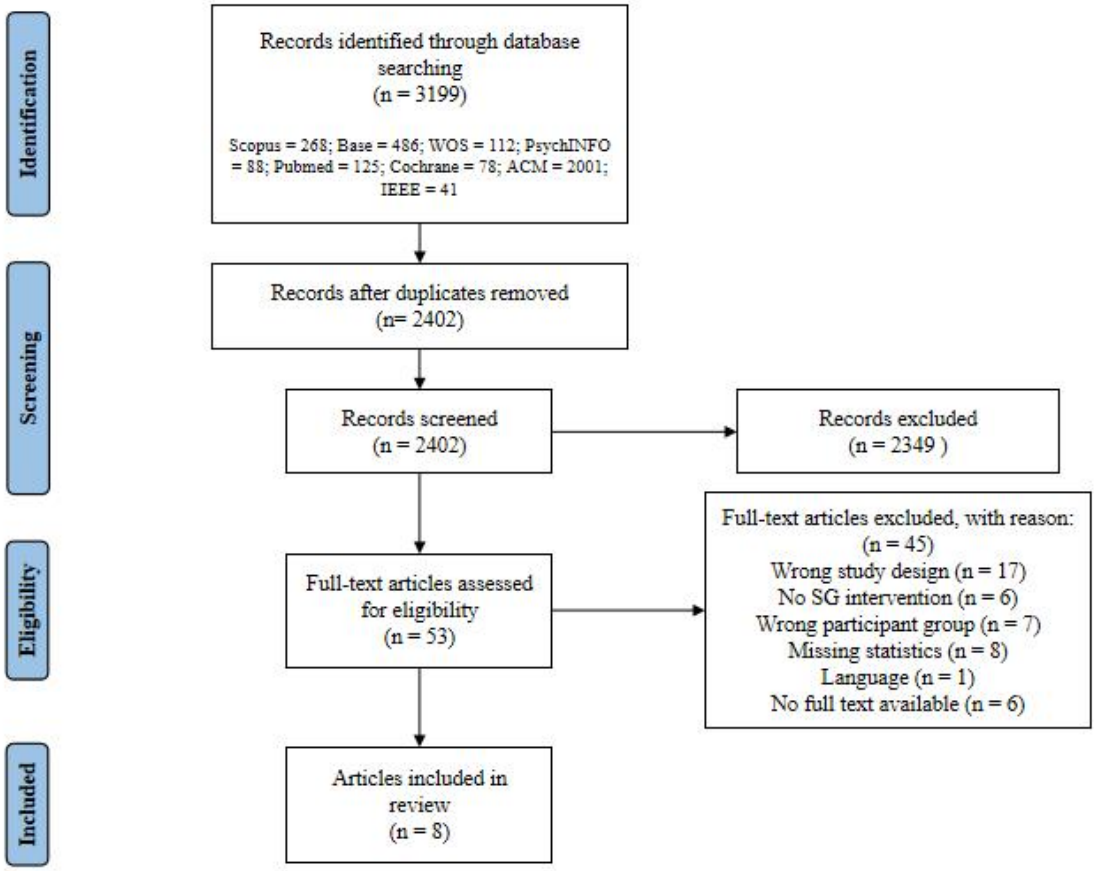
measurements of the effect are reported; (4) a control group was included; and (5) sufficient statistical information are reported to compose an effect size. The studies that did not meet these criteria were excluded, as well as studies meeting the following exclusion criteria: (1) not peer reviewed; (2) not available in English; (3) including Exergames (physical activities combined with technologies, e.g. video games with physical exercise), NF or biofeedback interventions; (4) no measurements on the effect of the intervention of ADHD symptoms or ADHD related symptoms; (5) SG was not a standalone intervention; and (6) no full text available.

Study Selection

The author conducted the systematic literature search in January 2023. Figure 1 illustrates the search strategy and process. As a results of the initial search across the databases, a total of 3199 potential articles were found. After removing duplicates, the titles and abstracts of 2402 articles were screened. Based on the eligibility criteria, relevant keywords during the screen were related to ADHD, SGs, and empirical study. During the full-text review, 53 articles were screened according to the eligibility criteria. Studies were excluded (n = 42) for reasons including language, participant group, not using a control group, not measuring the effects on ADHD symptoms, not reporting sufficient statistical information, including a mixed intervention, using a different study type, no full-text available. Following, a second researcher reviewed the remaining articles (n = 13). After both researchers discussed all articles, five were excluded due to missing statistical measurements and control groups. Consequently, the present meta-analysis includes 8 studies.

Figure 1

Flowchart of the literature search



Data Extraction and Quality Evaluation

For each study, the following data was extracted: (1) study characteristics including author names and year of publication; (2) participants characteristics including sample size, age, gender, and diagnosis; (3) intervention type and design (frequency, duration, and components); (4) study design and methodology; (5) relevant statistical analysis and outcome measures.

Risk of Bias Assessment

The six criteria of the Cochrane risk of bias assessment tool were used to assess the risk of bias of each included study. This tool is designed to assess the internal validity of studies by evaluating potential biases that could affect the reliability and validity of their results (Higgins et

al., 2019). Due to the tool being standardised, it allows comparisons between studies and transparency of the risk of bias assessment. The following criteria were examined by the main researcher based on the tool: (1) random sequence generation (selection bias); (2) allocation concealment (selection bias); (3) blinding of participants and personnel (performance bias); (4) blinding of outcome assessment (detection bias); (5) incomplete outcome data (attrition bias); (6) selective reporting (reporting bias). One of three ratings were assigned to each criterion of the tool, namely low risk of bias, unclear risk of bias, or high risk of bias (Higgins et al., 2019). For example, if a study was double blinded, it was evaluated as low risk of bias for the criterion (3). If a study did not provide sufficient information regarding certain criteria, it was evaluated as unclear risk of bias.

Statistical Analysis

The Comprehensive Meta-Analysis Software (version 4, 2022) was used to conduct the meta-analysis. All relevant effect sizes found in the selected studies were converted into standardised mean difference effect sizes. Due to the small sample size of the study, Hedge's g was used to calculate the corrected effect size, to prevent an upwards bias estimate (Cuijpers, 2016). Hedge's g is a standardised effect size measure used to quantify the magnitude of the treatment effect or the difference between groups (Borenstein et al., 2021). Hedges' g is calculated by taking the difference between the means of two groups (e.g., treatment group and control group) and dividing it by the pooled standard deviation. The resulting standardised mean differences (g) were interpreted as small (<0.2), medium (≥0.5), and large (≥0.8). A positive effect size suggested that SG had a positive effect on the ADHD symptoms of the participants (Borenstein et al., 2021). Since all studies provided multiple effect sizes for various scales, comparable scales were chosen and an average effect size per study was calculated to avoid the

inflation of the estimated population effect size (Rosenthal & Rubin, 1986). Moreover, two studies had multiple control or intervention groups. For these cases, the groups most aligned to the goal of this study and most similar to the other control and intervention groups were chosen. For example, Dovis et al. (2015) had one experimental group, one partially experimental group and one control group. The partially experimental group was excluded from the meta-analysis since it is not comparable to the other studies. Due to expected heterogeneity among the effect sizes of the included studies, the random-effects model was used for calculating the pooled effect size (Borenstein et al., 2021).

Heterogeneity was assessed with Cochran's Q and I^2, which are statistical measures evaluating variability in effect sizes and quantifying the proportion of variation in effect sizes attributed to heterogeneity, respectively (Borenstein et al., 2021). A significant Q statistic ($p < .05$) suggests heterogeneity of intervention effects. Furthermore, I^2 with values $\leq 25\%$ indicate low heterogeneity, with values of 50% indicate moderate heterogeneity, and I^2 values $\geq 75\%$ indicate high heterogeneity (Borenstein et al., 2021).

Potential publication bias was assessed with a funnel plot, which is a graph of the effect size plotted against the study size. If the observed studies are distributed symmetrically around the pooled effect size, there is no indication for a publication bias (Sterne et al., 2005).

Results

Characteristics of Intervention Studies

Population Characteristics

A total of 828 participants were included in the meta-analysis, of which 424 belonged to the experimental groups and 404 to the control groups. The sample size of each study ranged from 16 to 329 (Bikic et al., 2017; Kollins et al., 2020). The studies included in the analysis had

participants with an average age that varied across a range of 9.2 to 15.6 years (Bikic et al., 2017; Medina et al., 2021). All participants of the experimental groups were diagnosed with ADHD. Only one study recruited non-ADHD participants for the control group, all other studies recruited participants with an ADHD diagnosis (Davis et al., 2018). All characteristics of each included study are presented in Table 2.

Table 2

Characteristics of studies included in the meta-analysis

Study (Year, country)	Sample size (Total, EG, CG)	Participants (age, mean (SD))	Intervention (CG)	CG	Design	Length in weeks (frequency)	Session time in min (total dose)	Outcome measurement	Measurement subdomain
A: Bikic et al. (2017, Denmark)	16 EG (n = 9) CG (n = 7)	14-17 15.6 (0.99)	SBT (Tetris)	ADHD Active placebo	Double-blind randomised pilot trial	7 (5 days/week)	30 (1050)	P-ADHD-RS T-ADHD-RS A-ADHD-RS	n/a
B: Bikic et al. (2018, Denmark)	70 EG (n = 35) CG (n = 35)	6-13 EG: 9.77 (1.97) CG: 10.14 (1.52)	TAU & ACTIVATE (TAU)	ADHD TAU	Parallel, two arm, single bling, randomised, controlled trial	8 (6 times/week)	40 (1920)	CANTAB P-BRIEF T-BRIEF P-ADHD-RS P-ADHD-RS-I P-ADHD-RS-H T-ADHD-RS	Impulse inhibition Emotional control Working memory Planning Cognitive flexibility Monitoring Organising materials Initiation Metacognitive index RVP SWM SOC IED SST
C: Bul et al. (2016, Belgium & Netherlands)	170 EG (n = 88) CG (n = 82)	9.85 (1.26) EG: 9.89 (1.28) CG: 9.82 (1.24)	TAU & Plan-It Commander (TAU)	ADHD Both TAU 10 weeks TAU + SG 10 weeks	Crossover open-label trial (10 weeks each)	10/20 (3 times/week)	65 (975/1950)	P-BRIEF T-BRIEF	Planning Working memory
D: Davis et al. (2018, USA)	80 EG (n = 40) CG (n = 40)	8-12 EG: 10.35 (1.24) CG: 10.54 (1.49)	TAU & Project: EVO (Project: EVO)	No ADHD SG	Open-label Proof of concept trial	4 (5 days/week)	30-45 (855)	P-BRIEF CANTAB	Inhibition Working memory Global execution Metacognitive index Behaviour regulation Spatial working memory
E: Dovis et al. (2015, Netherlands)	61 EG (n = 31) CG (n = 30) EGp (n = 28)	8-12 EG: 10.6 (1.4) CG: 10.5 (1.3) EGp: 10.3 (1.3)	BGB training-mode (BGB placebo-mode)	ADHD Placebo	Double-blind, placebo-controlled, multi-arm parallel-	5 (25 sessions)	40 (1000)	P-DBDRS-I P-DBDRS-H P-BRIEF Digit recall	Inhibition Emotional control Working memory Planning

					group			STROOP SSRT	Monitoring Organising materials Initiation Shift
F: Kollins et al. (2020, USA)	329 EG (n = 169) CG (n = 160)	8-12 EG: 9.7 (1.3) CG: 9.6 (1.3)	AKL-T01 (digital word game)	ADHD Active placebo	Randomised, double-blinded, parallel-group, controlled trial	4 (5 session/day; 5 days/week)	5 (25 per 5 sessions) (500)	ADHD-RS ADHD-RS-H ADHD-RS-I	n/a
G: Medina et al. (2021, Spain)	29 EG (n = 15) CG (n = 14)	8-11 EG: 9.2 (1.21) CG: 9.71 (1.33)	KAD_SCL_01 games (sham intervention, videogames)	ADHD Sham treatment	Single-centre, parallel, single-blind, randomised controlled trial	12 (3 sessions/week)	15-20 (720)	EDAH EDAH-I EDAH-H Digit span test CPT-III	Inhibition Flexibility Working memory
H: Weerdmeester et al. (2016, Netherlands)	73 EG (n = 37) CG (n = 36)	6-13; 9.77 (1.74) EG: 9.84 (1.71) CG: 9.69 (1.79)	Dragon & TAU (Angry birds Trilogy & TAU)	ADHD Open label placebo	Randomised controlled trial	3 (6 sessions)	15 (90)	AVL AVL-I AVL-H Go/no-go task	n/a

Note. EG = experimental group; CG = control group; SBT = Scientific Brain Training; P-ADHD-RS = parents rated Attention Deficit/Hyperactivity Disorder-Rating Scale; T-ADHD-RS = teachers rated ADHD-RS; A-ADHD-RS = adolescents rated ADHD-RS; TAU = treatment as usual; CANTAB = Cambridge Neuropsychological Test Automated Battery; P-BRIEF = parents rated Behavior Rating Inventory of Executive Function; T-BRIEF = teachers rated BRIEF; P-ADHD-RS-I = P-ADHD-RS-Inattention; P-ADHD-RS-H = P-ADHD-RS-Hyperactivity; RVP = Rapid Visual Processing; SWM = Spatial Working Memory; SOC = Stockings of Cambridge; IED = Intra/extra Dimensional Set Shift; SST = Stop Signal Task; SG = Serious Game; EGp = Experimental Group partially; BGB = Braingame Brian, P-DBDRS-I = parents rated Developmental Behavioural Drift Rating Scale Inattention; P-DBDRS-H = P-DBDRS Hyperactivity; STROOP = Stroop Color-Word Test; SSRT = Stoptask; n/a = not available; EDAH-I = Attention Deficit Hyperactivity Disorder Scale Inattention; EDAH-H = EDAH Hyperactivity; CPT-III = Conners Continuous Performance Test (III); AVL-I = ADHD VragenLijst Inattention; AVL-H = AVL Hyperactivity.

Intervention Characteristics

Interventions used in the studies were video games (n = 4) and minigames embedded in a digital platform (n = 4) which could be played on a computer at home. The SGs target cognitive functions like WM and attention. All SGs were specifically developed for treating individuals with ADHD but they were primarily aimed at children and adolescents. The length of the intervention ranged from three weeks to 12 weeks and the frequency from two times per week to six times per week (Bikic et al., 2018; Medina et al., 2021; Weerdmeester et al., 2016). Each session lasted from 15 minutes to 65 minutes and the total amount of minutes played ranged from 90 minutes to 1920 minutes (Bikic et al., 2018; Weerdmeester et al., 2016).

Methodological Characteristics

In total six studies reported ADHD symptom measures from which eight effect sizes were included in the first analysis of the combined main ADHD symptoms. The second analysis included five effect sizes from five studies for the ADHD inattention symptom and the third analysis included five effect sizes from 5 studies for the ADHD hyperactivity symptoms. Furthermore, 65 EF measure effect sizes from six studies were included in the fourth analysis. Multiple EF measures were found in the articles with the most common ones being WM, impulse inhibition, planning/organising, initiation and constructs from CANTAB. In the fifth analysis five effect size measures of WM from five studies were included.

The study by Davis et al. (2018) divided their participants into three groups namely ADHD, high severity ADHD and non-ADHD. The high severity group consisted of participants which were also part of the ADHD group. Since this study is not interested in the difference within individuals with different severities of ADHD, the high severity ADHD group was not considered in the analysis. Another study had two experimental conditions, a full active and a

partially active condition (Dovis et al., 2015). In the fully active experimental group participants received all modules of the SG in training mode while the partially active group received two modules in training mode and one module in placebo-mode. Training mode entailed automatic adjustments of the difficult levels after each block of tasks and placebo-mode entailed only the first level of each module with no adjustments of the difficult levels. The partially active condition was not considered in this analysis since it was not comparable to the conditions of all other studies. The other six studies have one control and experimental study each.

For the control condition the studies used active placebos (n = 2), placebo (n = 1), open label placebo (n = 1), sham treatment (n = 1) or TAU only (n = 2). The study by Bul et al. (2016) was the only one in which the experimental and control conditions were the same since they recruited non-ADHD individuals for the control condition. Most studies were randomised and double blinded, or at least single blinded (n = 5). The study by Bul et al. (2016) was a crossover open-label trial and the study by Davis et al. (2018) was an open-label proof of concept trial. Since the crossover open-label study from Bul et al. (2016) switched the conditions for both groups after 10 weeks, only the first 10 weeks were considered in this study, to keep the similarity to the other included studies.

Measurement Characteristics

In this section only outcome measures of the included studies relevant to the current study will be described. In total three included studies used the ADHD rating scale to assess the symptoms of ADHD pre- and post-intervention. The ADHD-RS is a commonly used rating scale with 14 items based on the DSM-III criteria for ADHD (Szomlaiski et al., 2009). Furthermore, the Disruptive Behaviour Disorder Rating Scale (DBDRS), Evaluation of Attention Deficit and Hyperactivity (EDAH), and the dutch ADHD “vragenlijst” (AVL) were each used in one study

to assess ADHD symptoms pre- and post-intervention. Only the subscales inattention and hyperactivity were used from the DBDRS, which are based on the DSM-IV (Baeyens et al., 2004).

For the meta-analysis of EFs several outcome measurements were included from the studies. In total four studies reported outcome measures from the Behavior Rating Inventory of Executive Function (BRIEF), which is a parent or teacher completed questionnaire providing information about the extent to which children are impaired by executive dysfunction (Gioia et al., 2000). The BRIEF has multiple subscales, of which all have been included in the meta-analysis. Of the included studies, two have reported all subscales, one reported two, and one study reported three subscales. The included studies furthermore assessed EFs with measurements of CANTAB, Digit Recall, STOOP, stop-signal reaction-time task (SSRT), Digit Span Test, Conners continuous performance test (CPT-III), and the Go/no-go task.

Overall Intervention Effect

ADHD Main Symptoms

There was a small but non-significant positive effect of SG on the ADHD main symptoms as compared to the control groups ($g = 0.01$, $SE = 0.09$, $p = .88$, 95% CI [-0.16, 0.18]) under the random effects model. This suggests that SG interventions were not more beneficial for the main three ADHD symptoms combined compared to the control groups. The results further suggested there was no heterogeneity among the effect sizes ($Q = 1.71$, $df = 4$, $I^2 = 0.00$, $p = .79$). The funnel plot of the study effect size and ADHD combined symptoms was symmetrically distributed, suggesting no publication bias. The results of the effect size analysis, and forest plot are presented in Figure 2 and all funnel plots are Appendix B.

The other two analysis on the effect of SG on ADHD inattention and hyperactivity both found a small but non-significant negative effect (inattention: g = -0.04, SE = 0.08, p = .64, 95% CI [-0.20, 0.12]; hyperactivity: g = -0.01, SE = 0.08, p = .95, 95% CI [-0.17, 0.16]) under the random effects model. This suggests that SG interventions were not more beneficial for either inattention or hyperactivity symptoms of ADHD compared to the control groups. The results suggested no heterogeneity among effect sizes for either analysis (inattention: Q = 2.77, df = 4, I^2 = 0.00, p = .60; hyperactivity: Q = 1.48, df = 4, I^2 = 0.00, p = .83). The funnel plots of the study sizes and the inattention as well as hyperactivity symptoms of ADHD were symmetrically distributed, suggesting no publication bias. The results of the effect size analysis, and forest plots can be found in Appendix C.

Figure 2

Forest plot and post-intervention effects of SGs on combined ADHD symptoms

Model	Study name	Outcome	Statistics for each study						Statistics for each study	Hedges's g and 95% CI
			Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	-1,00 -0,50 0,00 0,50 1,00
	Bikic et al. (2017)	Combined	0,21	0,46	0,21	-0,70	1,12	0,45	0,65	
	Bikic et al. (2018)	Combined	0,04	0,24	0,06	-0,42	0,51	0,19	0,85	
	Kollins et al. (2020)	ADHD	0,03	0,11	0,01	-0,19	0,24	0,24	0,81	
	Medina et al. (2021)	ADHD	0,26	0,36	0,13	-0,45	0,97	0,72	0,47	
	Weerdmeester et al. (2016)	ADHD	-0,22	0,23	0,05	-0,68	0,23	-0,97	0,33	
Random			0,01	0,09	0,01	-0,16	0,18	0,15	0,88	

Executive Functions

There was a small but non-significant positive effect of SG on EFs as compared to the control groups (g = 0.24, SE = 0.20, p = .22, 95% CI [-0.15, 0.62]) under the random effects model. This suggests that SG interventions were not more beneficial for EFs compared to the control groups. The results further suggested heterogeneity exists among the effect sizes (Q = 20.23, df = 5, I^2 = 75.03, p = .001). The funnel plot of the study sizes and EFs was not symmetrically distributed, which may suggest the presence of publication bias. The results of the effect size analysis, and forest plot are presented in Figure 3.

There was a large but non-significant positive effect of SG on WM as compared to the control groups (g = 0.80, SE = 0.47, p = .09, 95% CI [-0.13, 1.70]) under the random effects model. This suggests that SG interventions were not more beneficial for WM compared to the control groups. The results further suggested heterogeneity exists among the effect sizes (Q = 70.89, df = 4, I^2 = 94.36, p < .001). The funnel plot of the study sizes and WM was not symmetrically distributed, which may suggest the presence of publication bias. The results of the effect size analysis, and forest plot are presented in Figure 4.

Figure 3

Forest plot and post-intervention effects of SGs on EFs

Model	Study name	Outcome	Statistics for each study							Hedges's g and 95% CI
			Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	-1,00 -0,50 0,00 0,50 1,00
	Bikic et al. (2018)	Combined	0,08	0,24	0,06	-0,39	0,54	0,33	0,74	
	Bul et al. (2016)	Combined	0,32	0,15	0,02	0,02	0,62	2,07	0,04	
	Davis et al. (2018)	Combined	1,26	0,27	0,07	0,73	1,78	4,70	0,00	
	Dovis et al. (2015)	Combined	-0,20	0,25	0,06	-0,70	0,29	-0,80	0,42	
	Medina et al. (2021)	Combined	-0,21	0,36	0,13	-0,92	0,51	-0,57	0,57	
	Weerdmeester et al. (2016)	Combined	0,11	0,23	0,05	-0,35	0,56	0,46	0,65	
Random			0,24	0,20	0,04	-0,15	0,62	1,22	0,22	

Figure 4

Forest plot and post-intervention effects of SGs on WM

Model	Study name	Outcome	Statistics for each study							Hedges's g and 95% CI
			Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	-1,00 -0,50 0,00 0,50 1,00
	Bikic et al. (2018)	P-BRIEF working memory	0,17	0,24	0,06	-0,29	0,63	0,72	0,47	
	Bul et al. (2016)	P-BRIEF working memory	0,51	0,16	0,02	0,20	0,81	3,26	0,00	
	Davis et al. (2018)	P-BRIEF working memory	3,20	0,34	0,11	2,54	3,86	9,51	0,00	
	Dovis et al. (2015)	P-BRIEF working memory	-0,05	0,25	0,06	-0,54	0,45	-0,19	0,85	
	Medina et al. (2021)	BRIEF working memory	0,25	0,36	0,13	-0,46	0,96	0,68	0,50	
Random			0,80	0,47	0,22	-0,13	1,72	1,69	0,09	

Meta Regression

There was a non-significant small positive slope for the association between frequency of the SG intervention and effect sizes for EFs (β1 = 0.06, z = 0.41, p = .68), which can be seen in Figure 5. The more frequent the SG intervention was used, the more EFs increased. Furthermore, there was a non-significant small negative slope for the association between total dose of the SG intervention and effect sizes for WM (β1 = -0.22, z = -1.27, p = .20), which can be seen in Figure

6. The higher the dose of the SG was, the less WM improved. More meta regressions looking at length in weeks, session time in minutes, total dose in minutes and frequency of intervention in days per week as predictors of the effect size in studies examining EFs and WM, can be found in Appendix D.

Figure 5

Meta-regression analysis of frequency of intervention in days per week as predictor of the effect size in studies examining EFs

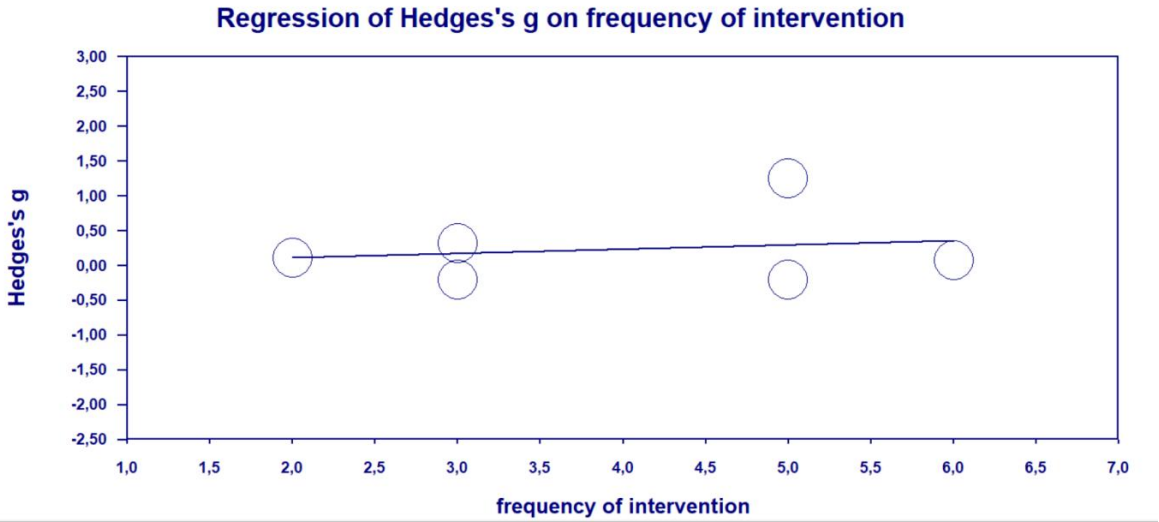
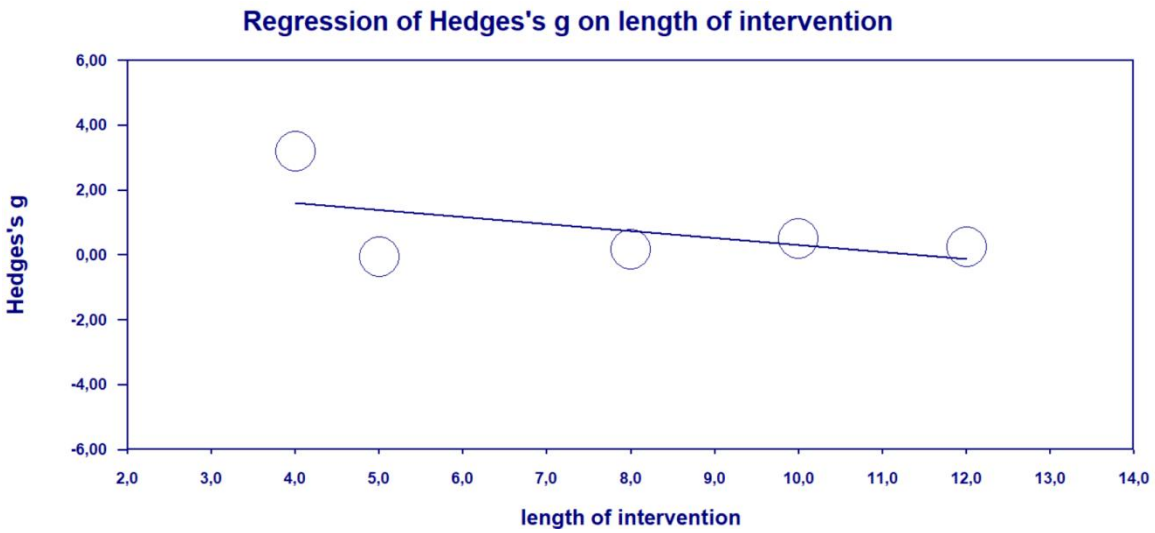


Figure 6

Meta-regression analysis of length of intervention in minutes as predictor of the effect size in studies examining WM



Risk of Bias Assessment

Of the eight included studies, one study had a high risk of bias on criteria (1), five studies had a high risk of bias on criteria (2), two studies had a high risk of bias on criteria (3), five studies had a high risk of bias on criteria (4), two studies had a high risk of bias on criteria (5), and one study had a high risk of bias on criteria (6). Generally, the studies with an open-label design had a higher risk of bias, all other studies showed a low risk of bias in the assessment (Bul et al., 2016; Davis et al., 2018).

Discussion

Summary of the Main Findings

The purpose of this study was to examine the effectiveness of SG interventions on ADHD symptoms and EFs. Results suggest that SGs had no significant effect on ADHD main symptoms, EFs, nor working memory. Further meta-regressions looking at how the intensity of the treatments moderated the SG effects on EFs, and WM showed non-significant results. The

direction of the moderation mostly suggested that longer or more intense treatments with SG interventions rather decrease the effectiveness of such interventions. These results are not in line with the described underlying theory, nor with previous research suggesting a great potential for SGs and indicating significant effects of SGs for the treatment of ADHD (Zheng et al., 2021). However, previous studies have often assessed the effectiveness of SG in combination with NF or EEG only and reported based on those results that SG are effective (Zheng et al., 2021). Meaning they did not examine the effectiveness of SG as a standalone method.

To partly explain the results of the research at hand, the included articles of the meta-analysis were assessed. (A) In the study from Bikic et al. (2017) effects on ADHD symptoms were significant for the experimental and control group. No significant group differences were observed on ADHD or cognitions but a significant effect on sustained attention was found. Thus, the intervention may be beneficial for ADHD symptoms but not more than Tetris. (B) In the second study there were no effects found on any of the measures, most likely due to being underpowered. (C) The SG intervention in the study by Bul et al. (2016) was mainly aimed at improving life- and social skills, which it did. Furthermore, planning/organisation and WM were targeted. The study reported that WM and planning/organising significantly improved due to the SG. Looking at the reported numbers, it is unclear if WM and planning/organising improved since Bul et al. (2016) report that higher scores mean better skills, which is the other way around for scores of the BRIEF according to the manual (Gioia et al., 2000). For example, in Group 1, which was the experimental group for the first 10 weeks, the results of the BRIEF subscale plan/organise significantly worsened after 20 weeks. The mean score went up from 21.32 (4.21) at the baseline measurement to 22.19 (3.70) after 10 weeks and 22.58 (3.63) after 20 weeks (p

= .03). However, Bul et al. (2016) may have used a scoring approach that differed from the official scoring manual without reporting it sufficiently.

Moving on to the next study (D), it was found that WM improved non-significantly for ADHD but both WM and inhibition improved significantly for the high severity ADHD group (Davis et al., 2018). Suggesting that this SG might be effective for that specific subgroup, which was not investigated in the current study. (E) The study by Dovis et al. (2015) both the control and experimental group improved on all BRIEF measures. Furthermore, it was reported that only the fully active group improved on WM, inhibitory control and interference control. (F) Medina et al. (2021) found their SG to be effective for inhibitory control, cognitive flexibility, WM, and behavioural and executive functioning behaviour. All ADHD main symptoms, measured by the EDAH improved for both the experimental and control group. These results were significant for all four measures of the experimental and for two of the control group. Improvements on the CPT-III measures only occurred in the experimental group but were not significant. (G) In the study by Kollins et al. (2020), attention and cognitive control were targeted, and it was found that the SG may improve attention. Lastly (H), Weerdmeester et al. (2016) assessed the effectiveness of a SG specifically targeting the main ADHD symptoms and results showed that these symptoms improved significantly.

Looking at the studies with more promising results, they all had a shorter length of treatment (3-4 weeks), adaptive and personalised difficulty levels, reward systems and focused on a few specific cognitions or symptoms (Davis et al., 2018; Kollins et al., 2020; Weerdmeester et al., 2016). More specifically, the interventions were aimed at improving attention, cognitive control, or inhibition. Other studies in the meta-analysis did not all include adaptive difficulty levels and not all included rewards in their games. Furthermore, all the other studies focused on

various cognitions and symptoms. The study by Bul et al. (2016) stood out since the intervention focused on improving behavioural strategies to provide a more sustainable treatment effect due to the applicability in daily life. However, ADHD symptoms itself did not improve in this study.

Another relevant aspect are the control conditions from all studies. Many different kinds like active control, placebo and sham were used but no pattern in terms of effectiveness is visible. Still, Bikic et al. (2017) mentioned the relevance for choosing a cognitive non-challenging control group and Weerdmeester et al. (2016) pointed out that mediators and moderators should be investigated when using an active control group. As mentioned, mixed results were often found when using an active control condition since significant effects were found in both the control and experimental groups. In total three studies have found effects for the control and experimental, meaning these results might be caused by placebo effects, increased patient knowledge, task demands, therapeutic relationships, or motivation for engagement (Bikic et al. 2017; Dovis et al., 2015; Medina et al., 2021).

Examining the results of each included study suggest that SG developed with a specific symptom, cognition, EF, or behaviour in mind may be more effective. Furthermore, shorter interventions, with adaptive difficulty levels and reward systems could be more beneficial for treating ADHD. These findings are in line with the DPM and the general symptoms of ADHD. Individuals with ADHD can hyperfocus on games if they are of their interest and if rewards within the game are given with little delay (Prins et al., 2011; Bioulac et al., 2012). This is due to their delay aversion (DPM) and their hyperactivity and attention dysregulation. Therefore, short interventions with adaptive difficult levels should improve engagement and motivation within the tasks. Furthermore, supported by the DPM, many SG interventions focus on inhibitory control, which is highly relevant for ADHD treatment. Still, the results of the meta-analyses at

hand show that SG as a standalone treatment are not beneficial for the main ADHD symptoms, EFs or WM.

Strengths and Limitations

There were several limitations for the study at hand. Firstly, only eight studies were included in the study and only five or six were included per meta-analysis. This increases the likelihood of biases being present, such as publication bias which were found for two meta-analyses. Furthermore, the systematic literature review was carried out mainly by one person, which can also increase the likelihood of biases such as interpretation bias or confirmation bias but also increases the likelihood of mistakes. Still, the final selection of the studies was discussed with a second researcher. Moreover, the studies included while being similar in the intervention used and the general set up of the research were also dissimilar regarding their outcome measurements and methods. This may have had an influence on the results as well. Furthermore, none of the included studies had adult participants, even though adults were not excluded in the systematic literature. This confirms the pattern of focus on children and adolescents, which is apparent although many studies have shown that ADHD and consequences of ADHD can persist into adulthood (Price et al., 2019).

Still, this was the first meta-analysis conducted on the effectiveness of SG as a standalone treatment method for ADHD. Additionally, besides assessing the effectiveness of SG on the main ADHD symptoms, the study also looked at the specific symptoms including hyperactivity and inattention, as well as EFs and working memory. Another strength of this study is the specific consideration of the outcomes of each study included to explain the overall outcome which is not in line with the general standpoint of current literature.

Recommendations

Based on the findings of this study, it would be recommended to conduct more experimental studies on SG as a standalone treatment option and reporting all results from the most common measurements of ADHD symptoms and EFs. Mixed methods approach can be used to qualitatively examine the individuals experience of the treatment, to further improve the effectiveness of non-pharmacological interventions. A specific focus should be laid on the control group, to either ensure their cognitive non-challenging nature or at least control for mediation and moderation effects. Considering the findings of Davis et al. (2018) it may be interesting to differentiate between the severity of ADHD since the SG had more significant effects on the high severity group. Furthermore, it may be relevant to differentiate between the subtypes, to further adjust the SG to the individuals. Moreover, it would be relevant to further assess the effects of SG in combination with NF or EEG since these combinations seem to be effective. By doing this, the specific factors in which SG benefit treatment should be investigated to further understand the mechanism of SG. Lastly, based on the findings of this meta-analysis it is recommended to examine why shorter treatments with SGs may be more effective than longer and more intense treatments.

For future developments of SG, it is recommended to define clearly what symptoms, cognitions, behaviours, or EF constructs the SG is supposed to improve to increase their effectiveness. Moreover, the participants interest in the game itself appeared to be relevant. As it is done in NF, SGs could be based on games the participants already play, instead of developing entirely new games. This way engagement, motivation and interest may be increased. Furthermore, it may be interesting to develop SGs specific to the subtypes of ADHD since the symptoms differ in nature and could require different game aspects. For the hyperactive subtype

more engaging games might be necessary since distractions are more difficult to avoid. As mentioned earlier, only children and adolescents were included in the articles found in the systematic literature review. Since adults also suffer from ADHD or the consequences of ADHD, it is also recommended to develop and evaluate the effectiveness of SGs for adults.

In terms of the publication bias found in the last two meta-analyses it is recommended to publish high-quality studies regardless of their results. Furthermore, it would be advised to publish all results and report as many statistics as possible, preferable in a standardised form. A substantial number of studies were omitted due to missing statistics or low quality of the studies. This would allow other researchers to conduct more elaborate meta-analysis which will further support the exploration of the effectiveness of SGs.

Conclusion

This first meta-analysis on the effectiveness of SGs for ADHD main symptoms, EFs and WM provided no evidence for such effectiveness. Based on the findings or previous research, the studies included in this study and the results of the current study, it is recommended to conduct further experimental studies for SG as a standalone treatment. Furthermore, the role SG play in treatment methods in combination with NF or BIC should be investigated. Moreover, new SGs should focus on specific ADHD symptoms, cognitions, behaviours or EFs; consider shorter treatment lengths, include more personalisation, and consider adults as the treatment group. Even though the results of the study at hand are not reflecting a great potential for SGs as a treatment for ADHD, there are other studies which have shown ways in which SGs can be implemented in a beneficial manner. Thus, the results of this study do not show that SGs are not effective for ADHD in general, it is simply giving an indication that it might not be beneficial for ADHD as a standalone treatment for the main ADHD symptoms and EFs.

References

Alabdulakareem, E., & Jamjoom, M. (2020). Computer-assisted learning for improving ADHD individuals' executive functions through gamified interventions: A review. *Entertainment Computing*, *33*, 100341. https://doi.org/10.1016/j.entcom.2020.100341

American Psychiatric Association, D. S., & American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders: DSM-5* (Vol. 5). Washington, DC: American psychiatric association.

Avila-Pesantez, D., Rivera, L. A., Vaca-Cardenas, L., Aguayo, S., & Zuñiga, L. (2018, April). Towards the improvement of ADHD children through augmented reality serious games: Preliminary results. *IEEE Global Engineering Education Conference (EDUCON)* (pp. 843-848). IEEE. https://doi.org/10.1109/EDUCON.2018.8363318

Baeyens, D., Roeyers, H., Hoebeke, P., Verte, S., Van Hoecke, E., & Walle, J. V. (2004). Attention deficit/hyperactivity disorder in children with nocturnal enuresis. *The Journal of urology*, *171*(6 Part 2), 2576-2579. https://doi.org/10.1097/01.ju.0000108665.22072.b2

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: constructing a unifying theory of ADHD. *Psychological bulletin*, *121*(1), 65.

Bikic, A., Christensen, T. Ø., Leckman, J. F., Bilenberg, N., & Dalsgaard, S. (2017). A double-blind randomized pilot trial comparing computerized cognitive exercises to Tetris in adolescents with attention-deficit/hyperactivity disorder. *Nordic journal of psychiatry*, *71*(6), 455-464. https://doi.org/10.1080/08039488.2017.1328070

Bikic, A., Leckman, J. F., Christensen, T. Ø., Bilenberg, N., & Dalsgaard, S. (2018). Attention

and executive functions computer training for attention-deficit/hyperactivity disorder (ADHD): results from a randomized, controlled trial. *European child & adolescent psychiatry*, *27*, 1563-1574. https://doi.org/10.1007/s00787-018-1151-y

Bioulac, S., Lallemand, S., Fabrigoule, C., Thoumy, A. L., Philip, P., & Bouvard, M. P. (2014). Video game performances are preserved in ADHD children compared with controls. *Journal of attention disorders*, *18*(6), 542-550. https://doi.org/10.1177/1087054712443702

Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2021). Introduction to meta-analysis. *John Wiley & Sons.*

Bul, K. C., Franken, I. H., Van der Oord, S., Kato, P. M., Danckaerts, M., Vreeke, L. J., ... & Maras, A. (2015). Development and user satisfaction of "Plan-It Commander," a serious game for children with ADHD. *Games for health journal*, *4*(6), 502-512. https://doi.org/10.1089/g4h.2015.0021

Bul, K. C., Kato, P. M., Van der Oord, S., Danckaerts, M., Vreeke, L. J., Willems, A., ... & Maras, A. (2016). Behavioral outcome effects of serious gaming as an adjunct to treatment for children with attention-deficit/hyperactivity disorder: a randomized controlled trial. *Journal of medical Internet research*, *18*(2), e26. https://doi.org/10.2196/jmir.5173

Canady, V. A. (2020). FDA approves first video game Rx treatment for children with ADHD. *Mental Health Weekly*, *30*(26), 1-7. https://doi.org/10.1002/mhw.32423

Castells, X., Ramon, M., Cunill, R., Olivé, C., & Serrano, D. (2021). Relationship between

treatment duration and efficacy of pharmacological treatment for ADHD: a meta-analysis and meta-regression of 87 randomized controlled clinical trials. *Journal of attention disorders*, *25*(10), 1352-1361. https://doi.org/10.1177/1087054720903372

Cortese, S. (2020). Pharmacologic treatment of attention deficit–hyperactivity disorder. *New England Journal of Medicine*, *383*(11), 1050-1056. https://doi.org/10.1056/NEJMra1917069

Cortese, S., Ferrin, M., Brandeis, D., Holtmann, M., Aggensteiner, P., Daley, D., ... & Zuddas, A. (2016). Neurofeedback for attention-deficit/hyperactivity disorder: meta-analysis of clinical and neuropsychological outcomes from randomized controlled trials. *Journal of the American Academy of Child & Adolescent Psychiatry*, *55*(6), 444-455. https://doi.org/10.1016/j.jaac.2016.03.007

Cuijpers, P. (2016). *Meta-analyses in mental health research: A practical guide* (Vol. 15). Amsterdam: Vrije Universiteit.

Dalen, L., Sonuga-Barke, E. J., Hall, M., & Remington, B. (2004). Inhibitory deficits, delay aversion and preschool AD/HD: implications for the dual pathway model. *Neural plasticity, 11*(1-2), 1-11. https://doi.org/10.1155/NP.2004.1

Davis, N. O., Bower, J., & Kollins, S. H. (2018). Proof-of-concept study of an at-home, engaging, digital intervention for pediatric ADHD. *PloS one*, *13*(1), e0189749. https://doi.org/10.1371/journal.pone.0189749

Dovis, S., Van der Oord, S., Wiers, R. W., & Prins, P. J. (2015). Improving executive functioning in children with ADHD: training multiple executive functions within the context of a computer game. A randomized double-blind placebo controlled trial. *PloS one*, *10*(4), e0121651. https://doi.org/10.1371/journal.pone.0121651

DuPaul, G. J., McGoey, K. E., Eckert, T. L., & VanBrakle, J. (2001). Preschool children with attention-deficit/hyperactivity disorder: Impairments in behavioral, social, and school functioning. *Journal of the American Academy of Child & Adolescent Psychiatry*, *40*(5), 508-515. https://doi.org/10.1097/00004583-200105000-00009

DuPaul, G. J., Schaughency, E. A., Weyandt, L. L., Tripp, G., Kiesner, J., Ota, K., & Stanish, H. (2001). Self-report of ADHD symptoms in university students: Cross-gender and cross-national prevalence. *Journal of learning disabilities*, 34(4), 370-379. https://doi.org/10.1177%2F002221940103400412

Eckert, T. L., DuPaul, G. J., & Vilardo, B. (2012). The effects of school-based interventions for attention deficit hyperactivity disorder: a meta-analysis 1996–2010. *Sch Psychol Rev*, *41*, 387-412. https://doi.org/10.1080/02796015.2012.12087496

Enriquez-Geppert, S., Smit, D., Pimenta, M. G., & Arns, M. (2019). Neurofeedback as a treatment intervention in ADHD: Current evidence and practice. *Current psychiatry reports*, *21*, 1-7. https://doi.org/10.1007/s11920-019-1021-4

Fabiano, G. A., Schatz, N. K., Aloe, A. M., Pelham Jr, W. E., Smyth, A. C., Zhao, X., ... & Coxe, S. (2021). Comprehensive meta-analysis of attention-deficit/hyperactivity disorder psychosocial treatments investigated within between group studies. *Review of Educational Research*, *91*(5), 718-760. https://doi.org/10.3102/00346543211025092

Faraone, S. V., Asherson, P., Banaschewski, T., Biederman, J., Buitelaar, J. K., Ramos Quiroga, J. A., ... & Franke, B. (2015). Attention-deficit/hyperactivity disorder. *Nature Reviews Disease Primers*, *1*, e15020. https://doi.org/10.1038/nrdp.2015.20

Flinsenberg, D. (2020). *Autonomy through technology: engaging executive functions in ADHD with an extended mind approach* (Master thesis, University of Twente).

Flisiak-Antonijczuk, H., Adamowska, S., Chładzińska-Kiejna, S., Kalinowski, R., & Adamowski, T. (2015). Treatment of ADHD: comparison of EEG-biofeedback and methylphenidate. *Archives of Psychiatry & Psychotherapy*, *17*(4). https://doi.org/10.12740/APP/60511

Gioia, G. A., Isquith, P. K., Guy, S. C., & Kenworthy, L. (2000). *Behavior rating inventory of executive function: BRIEF*. Odessa, FL: Psychological Assessment Resources.

Hakimirad, E., Kashani-Vahid, L., Hosseini, M. S., Irani, A., & Moradi, H. (2019, December). Effectiveness of EmoGalaxy video game on social skills of children with ADHD. In *2019 International Serious Games Symposium (ISGS)* (pp. 7-12). IEEE. https://doi.org/10.1109/ISGS49501.2019.9046992

Higgins, J. P., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (Eds.). (2019). Cochrane handbook for systematic reviews of interventions. *John Wiley & Sons.*

Hocine, N. (2019, June). Personalized serious games for self-regulated attention training. *Adjunct Publication of the 27th Conference on User Modeling, Adaptation and Personalization* (pp. 251-255). https://doi.org/10.1145/3314183.3323458

Hupfeld, K. E., Abagis, T. R., & Shah, P. (2019). Living "in the zone": hyperfocus in adult ADHD. *ADHD Attention Deficit and Hyperactivity Disorders*, *11*(2), 191-208. https://doi.org/10.1007/s12402-018-0272-y

Kollins, S. H., DeLoss, D. J., Cañadas, E., Lutz, J., Findling, R. L., Keefe, R. S., ... & Faraone, S. V. (2020). A novel digital intervention for actively reducing severity of paediatric ADHD (STARS-ADHD): a randomised controlled trial. *The Lancet Digital Health*, *2*(4), e168-e178. https://doi.org/10.1016/S2589-7500(20)30017-0

Lakes, K. D., Cibrian, F. L., Schuck, S. E., Nelson, M., & Hayes, G. R. (2022). Digital health interventions for youth with ADHD: a mapping review. *Computers in Human Behavior Reports*, *6*, 100174. https://doi.org/10.1016/j.chbr.2022.100174

Leffa, D. T., Caye, A., & Rohde, L. A. (2022). ADHD in children and adults: diagnosis and prognosis. *Behavioral Neuroscience of Attention-Deficit Hyperactivity Disorder*, 1-18.

Marx, I., Hübner, T., Herpertz, S. C., Berger, C., Reuter, E., Kircher, T., ... & Konrad, K. (2010). Cross-sectional evaluation of cognitive functioning in children, adolescents and young adults with ADHD. *Journal of neural transmission*, *117*(3), 403-419. https://doi.org/10.1007/s00702-009-0345-3

Mechler, K., Banaschewski, T., Hohmann, S., & Häge, A. (2022). Evidence-based pharmacological treatment options for ADHD in children and adolescents. *Pharmacology & Therapeutics*, *230*, 107940. https://doi.org/10.1016/j.pharmthera.2021.107940

Medina, R., Bouhaben, J., de Ramón, I., Cuesta, P., Antón-Toro, L., Pacios, J., ... & Maestú, F. (2021). Electrophysiological brain changes associated with cognitive improvement in a pediatric attention deficit hyperactivity disorder digital artificial intelligence-driven intervention: Randomized controlled trial. *Journal of medical Internet research*, *23*(11), e25466. https://doi.org/10.2196/25466

Meijer, W. M., Faber, A., van den Ban, E., & Tobi, H. (2009). Current issues around the pharmacotherapy of ADHD in children and adults. *Pharmacy world & science*, *31*, 509-516. https://doi.org/10.1007/s11096-009-9302-3

National Institute for Health and Care Excellence, 2018 NICE guideline - Attention deficit hyperactivity disorder: Diagnosis and management Retrieved June 12, 2023, from

https://www.nice.org.uk/guidance/ng87/resources/attention-deficit-hyperactivity-disorder-diagnosis-and-management-pdf-1837699732933 (2018)

Ogundele, M. O., & Ayyash, H. F. (2023). ADHD in children and adolescents: Review of current practice of non-pharmacological and behavioural management. *AIMS Public Health*, *10*(1), 35. https://doi.org/10.3934%2Fpublichealth.2023004

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *International journal of surgery*, *88*, 105906.

Philipsen, A., Jans, T., Graf, E., Matthies, S., Borel, P., Colla, M., ... & van Elst, L. T. (2015). Effects of group psychotherapy, individual counseling, methylphenidate, and placebo in the treatment of adult attention-deficit/hyperactivity disorder: a randomized clinical trial. *JAMA psychiatry*, *72*(12), 1199-1210. https://doi.org/10.1001/jamapsychiatry.2015.2146

Price, A., Janssens, A., Woodley, A. L., Allwood, M., & Ford, T. (2019). Experiences of healthcare transitions for young people with attention deficit hyperactivity disorder: a systematic review of qualitative research. *Child and Adolescent Mental Health*, *24*(2), 113-122. https://doi.org/10.1111/camh.12297

Prins, P. J., Dovis, S., Ponsioen, A., Ten Brink, E., & Van Der Oord, S. (2011). Does computerized working memory training with game elements enhance motivation and training efficacy in children with ADHD?. *Cyberpsychology, behavior, and social networking*, *14*(3), 115-122. https://doi.org/10.1089/cyber.2009.0206

Polanczyk, G. V., Willcutt, E. G., Salum, G. A., Kieling, C., & Rohde, L. A. (2014). ADHD

prevalence estimates across three decades: an updated systematic review and meta-regression analysis. *International journal of epidemiology*, *43*(2), 434-442. https://doi.org/10.1093/ije/dyt261

Rosenthal, R., & Rubin, D. B. (1986). Meta-analytic procedures for combining studies with multiple effect sizes. *Psychological Bulletin, 99*(3), 400–406. https://doi.org/10.1037/0033-2909.99.3.400

Schein, J., Childress, A., Cloutier, M., Desai, U., Chin, A., Simes, M., ... & Adams, J. (2022). Reasons for treatment changes in adults with attention-deficit/hyperactivity disorder: a chart review study. *BMC psychiatry*, *22*(1), 1-11. https://doi.org/10.1186/s12888-022-04016-9

Schonenberg, M., Wiedemann, E., Schneidt, A., Scheeff, J., Logemann, A., Keune, P. M., & Hautzinger, M. (2017). Neurofeedback, sham neurofeedback, and cognitive-behavioural group therapy in adults with attention-deficit hyperactivity disorder: A triple-blind, randomised, controlled trial. *The Lancet. Psychiatry, 4*(9), 673–684. https://doi.org/10.1016/S2215-0366(17)30291-2

Solanto, M. V., Abikoff, H., Sonuga-Barke, E., Schachar, R., Logan, G. D., Wigal, T., ... & Turkel, E. (2001). The ecological validity of delay aversion and response inhibition as measures of impulsivity in AD/HD: a supplement to the NIMH multimodal treatment study of AD/HD. *Journal of abnormal child psychology, 29*(3), 215-228. https://doi.org/10.1023/A:101032971481

Song, P., Zha, M., Yang, Q., Zhang, Y., Li, X., & Rudan, I. (2021). The prevalence of adult attention-deficit hyperactivity disorder: A global systematic review and meta-analysis. *Journal of global health*, *11*. https://doi.org/10.7189%2Fjogh.11.04009.

Sonuga-Barke, E. J. (2002). Psychological heterogeneity in AD/HD—a dual pathway model of behaviour and cognition. *Behavioural brain research*, *130*(1-2), 29-36. https://doi.org/10.1016/S0166-4328(01)00432-6

Sonuga-Barke, E. J. (2003). The dual pathway model of AD/HD: an elaboration of neuro developmental characteristics. *Neuroscience & Biobehavioral Reviews*, *27*(7), 593-604. https://doi.org/10.1016/j.neubiorev.2003.08.005

Sonuga-Barke E.J., Brandeis D, Cortese S, S., Daley, D., Ferrin, M., Holtmann, M., ... & Sergeant, J. (2013). Non-pharmacological interventions for attention-deficit/hyperactivity disorder: systematic review and meta-analyses of randomised controlled trials of dietary and psychological treatments. *American Journal of Psychiatry,170*, 275–289. https://doi.org/10.1176/appi.ajp.2012.12070991

Sterne, J. A., Becker, B. J., & Egger, M. (2005). The funnel plot. *Publication bias in meta-analysis: Prevention, assessment and adjustments*, 73-98. https://doi.org/10.1002/0470870168 .

Szomlaiski, N., Dyrborg, J., Rasmussen, H., Schumann, T., Koch, S. V., & Bilenberg, N. (2009). Validity and clinical feasibility of the ADHD rating scale (ADHD-RS) A Danish Nationwide Multicenter Study. *Acta paediatrica*, *98*(2), 397-402. https://doi.org/10.1111/j.1651-2227.2008.01025.x

Thorell, L. B. (2007). Do delay aversion and executive function deficits make distinct contributions to the functional impact of ADHD symptoms? A study of early academic skill deficits. *Journal of child Psychology and Psychiatry, 48*(11), 1061-1070. https://doi.org/10.1111/j.1469-7610.2007.01777.x

Vidal, R., Bosch, R., Nogueira, M., Gomez-Barros, N., Valero, S., Palomar, G., & Ramos-

Quiroga, J. A. (2013). Psychoeducation for adults with attention deficit hyperactivity disorder *vs*. Cognitive behavioral group therapy: A randomized controlled pilot study. *Journal of Nervous and Mental Disease, 201*(10), 894–900. https://doi.org/10.1097/NMD.0b013e3182a5c2c5

Weerdmeester, J., Cima, M., Granic, I., Hashemian, Y., & Gotsis, M. (2016). A feasibility study on the effectiveness of a full-body videogame intervention for decreasing attention deficit hyperactivity disorder symptoms. *Games for health journal*, *5*(4), 258-269. https://doi.org/10.1089/g4h.2015.0103

Zheng, Y., Li, R., Li, S., Zhang, Y., Yang, S., & Ning, H. (2021). A review on serious games for ADHD. *arXiv preprint arXiv:2105.02970*. https://doi.org/10.48550/arXiv.2105.02970

Appendix A

Diagnostic Criteria for ADHD (DSM)

Diagnostic Criteria for ADHD

1. A recurring pattern of distress that interferes with functioning in social, personal or academic/occupational areas. Specific symptomological presentation (subtype) is determined by the presence symptoms (that have been persistent for at least six months) and is classified as follows:
    - **a. Inattentive subtype:**
      The symptoms are not solely a manifestation of oppositional behaviour, defiance, hostility, or failure to understand tasks or instructions. For older adolescents and adults (age 17 and older), at least five symptoms are required.
        - **i.** Often makes careless mistakes or demonstrates poor attention to detail
        - **ii.** Often faces challenges remaining focused on tasks; difficulty in sustaining attention for extended periods of time.
        - **iii.** Often does not appear to listen when spoken or seems distracted when there are no other stimuli present.
        - **iv.** Often demonstrates lack of follow through, easily side-tracked of fails to complete work or classroom assignments.
        - **v.** Often has difficulty with organization; demonstrates poor time management.
        - **vi.** A pattern of dislike or avoidance for activities that require sustained mental effort.
        - **vii.** Frequently loses things or forgets items that are necessary for the completion of tasks or activities.
        - **viii.** Is often easily distracted by the outside environment
        - **ix.** Frequently forgets routine task or activities
    - **b. Hyperactive and impulsive subtype:**
        - **i.** Excessive fidgeting, squirming or movement, particularly when seated.
        - **ii.** Difficulty remaining seated when being seated is expected.
        - **iii.** Frequently runs about or climbs in inappropriate situations.
        - **iv.** Often unable to engage in quiet activities.
        - **v.** Feels uncomfortable being still for extended time, appears restless and may be difficult to keep up with.
        - **vi.** Often talks excessively
        - **vii.** Frequently interrupts others in conversation or blurts out answers to a question
        - **viii.** Shows difficulty in waiting his or her turn
        - **ix.** Frequently intrudes on the activities of others
    - **c.** Six or more symptoms were present prior to age 12 years (five or more symptoms if being evaluated over the age of 17).
    - **d.** Symptoms are present in three or more settings.
    - **e.** Clear evidence that the symptoms are impairing in social, interpersonal and/or academic/professional settings.

f. The symptoms cannot be better explained by another medical condition or mental disorder

When diagnosing ADHD, it is usual to specify presentation classifications as follows:

- **Combined presentation**: If criterion for both the inattention subtype (1a) and the hyperactive-impulsive subtype (1b) are met.
- **Predominantly inattentive presentation**: If only the criterion for the inattention subtype (1a) are met.
- **Predominantly hyperactive/impulsive presentation**: If only the criterion for the hyperactive-impulsive subtype (1b) are met.

Condition may also be specified as being in partial remission

- **In partial remission**: Full criteria were previously met, however fewer than the full criteria are currently present despite continued impairment in personal, social or academic/occupational functioning.

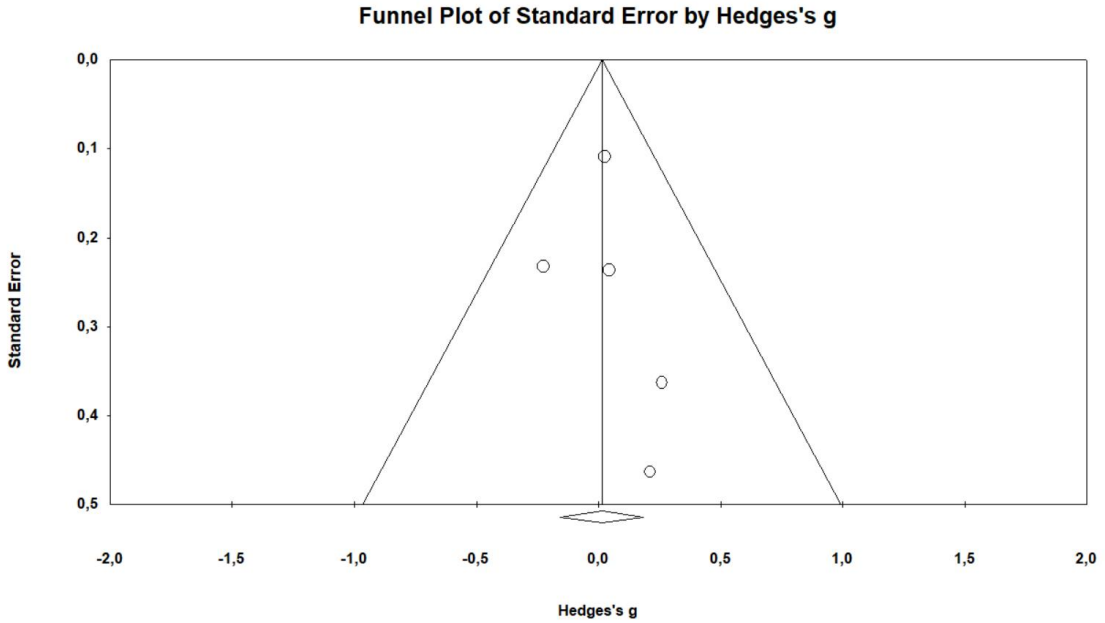
It is also common to specify symptom severity:

- **Mild**: Few or no symptoms in excess of those required to make the diagnosis are present, and/or symptoms result only in minor impairments.
- **Moderate**: Symptoms or functional impairment are currently present and can be classified as are neither “mild” nor “severe”.
- **Severe**: The presence of many symptoms in excess of those required in making the diagnosis or the symptoms result in significant impairment or performance.

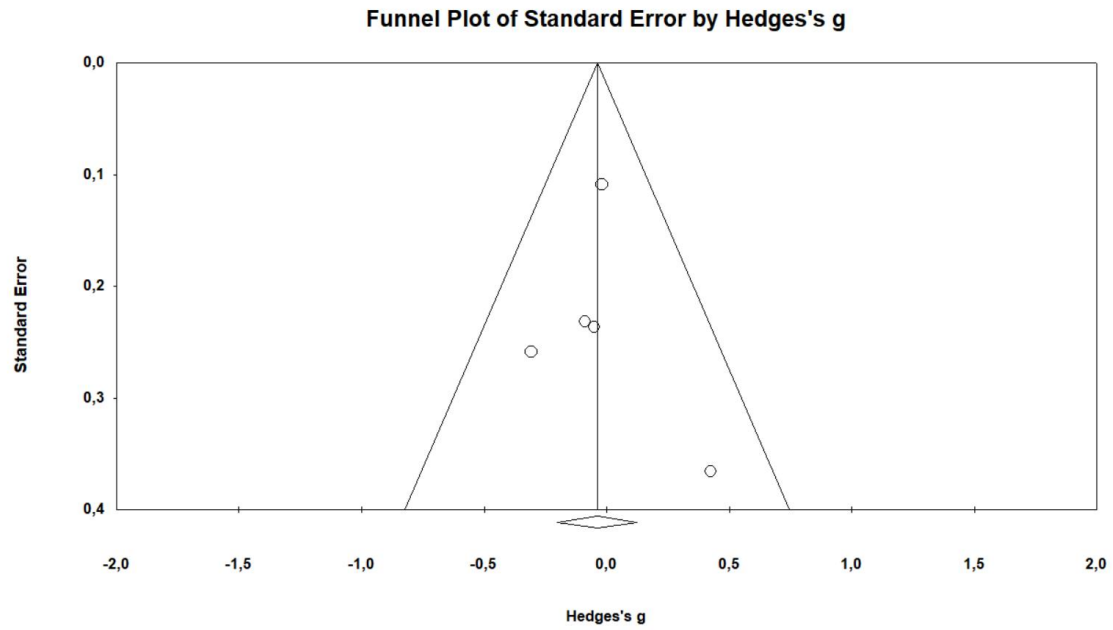
Appendix B

Funnel Plots

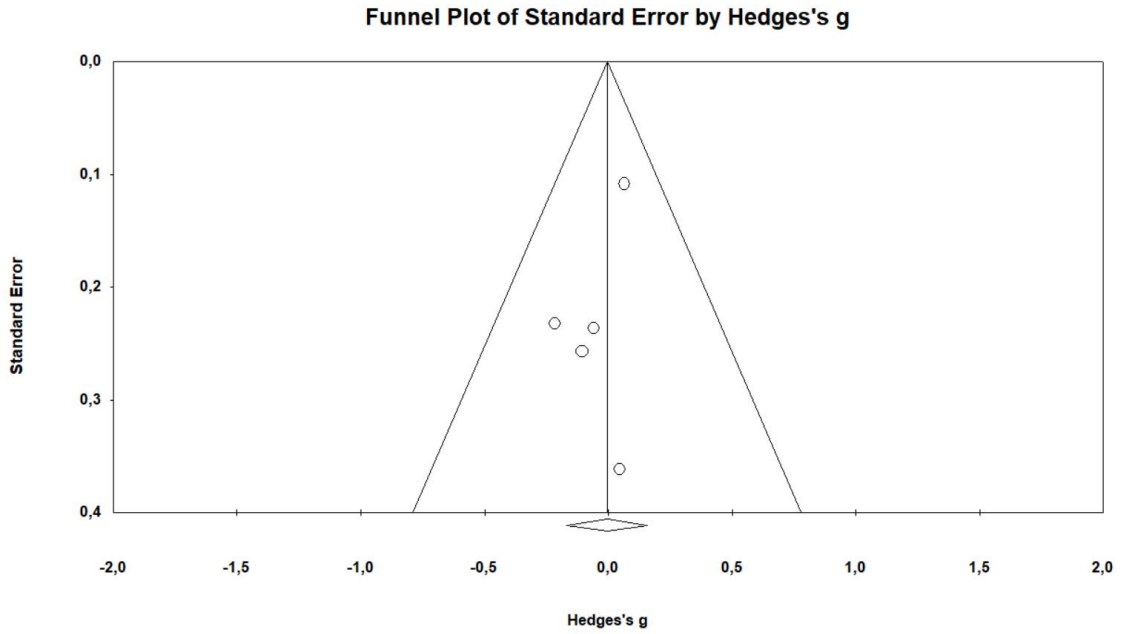
Funnel Plot for ADHD Combined Main Symptoms



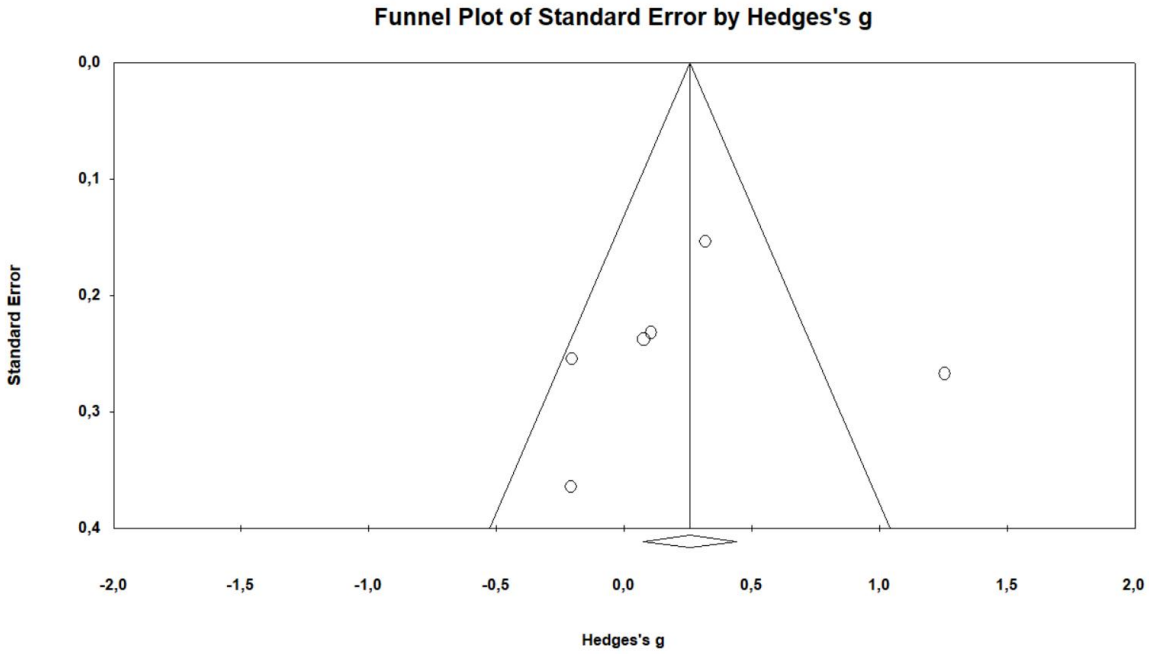
Funnel Plot for ADHD Inattention Symptoms



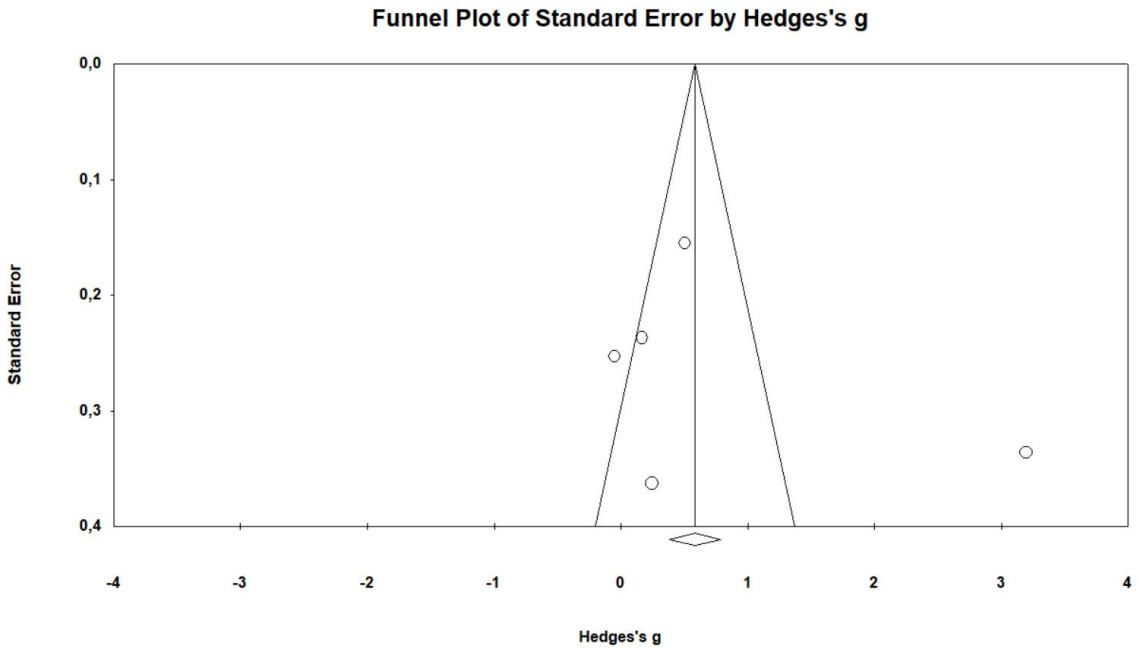
Funnel Plot for ADHD Hyperactivity Symptoms



Funnel Plot for EF



Funnel Plot for WM



Appendix C

Forest Plots and Post-Intervention Effects

Forest Plot and Post-Intervention Effects of SGs on ADHD-I

Model	Study name	Outcome	Statistics for each study						Statistics for each study	Hedges's g and 95% CI
			Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	-1,00 -0,50 0,00 0,50 1,00
	Bikic et al. (2018)	ADHD I	-0,05	0,24	0,06	-0,51	0,41	-0,21	0,83	
	Dovis et al. (2015)	ADHD I	-0,31	0,26	0,07	-0,81	0,20	-1,19	0,23	
	Kollins et al. (2020)	ADHD I	-0,02	0,11	0,01	-0,23	0,19	-0,18	0,86	
	Medina et al. (2021)	ADHD I	0,43	0,37	0,13	-0,29	1,14	1,16	0,24	
	Weerdmeester et al. (2016)	ADHD I	-0,09	0,23	0,05	-0,54	0,37	-0,38	0,70	
Random			-0,04	0,08	0,01	-0,20	0,12	-0,47	0,64	

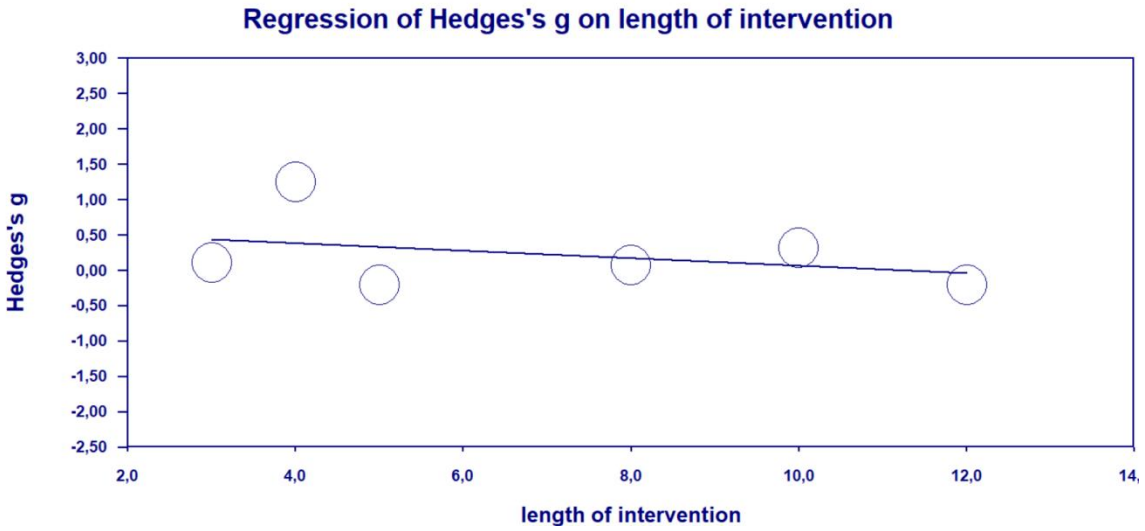
Forest Plot and Post-Intervention Effects of SGs on ADHD-H

Model	Study name	Outcome	Statistics for each study						Statistics for each study	Hedges's g and 95% CI
			Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	-1,00 -0,50 0,00 0,50 1,00
	Bikic et al. (2018)	ADHD H	-0,06	0,24	0,06	-0,52	0,40	-0,25	0,80	
	Dovis et al. (2015)	ADHD H	-0,11	0,26	0,07	-0,61	0,40	-0,41	0,68	
	Kollins et al. (2020)	ADHD H	0,07	0,11	0,01	-0,15	0,28	0,60	0,55	
	Medina et al. (2021)	ADHD H	0,05	0,36	0,13	-0,66	0,76	0,13	0,90	
	Weerdmeester et al. (2016)	ADHD H	-0,22	0,23	0,05	-0,67	0,24	-0,93	0,35	
Random			-0,01	0,08	0,01	-0,17	0,16	-0,06	0,95	

Appendix D

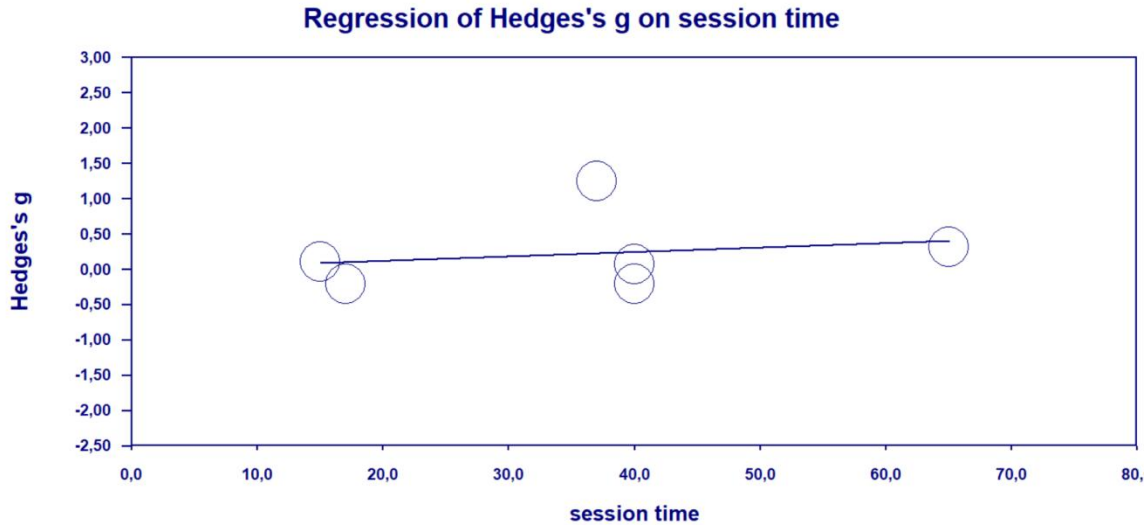
Meta Regression

Meta-Regression Analysis of Length of Intervention in Weeks as Predictor of the Effect Size in Studies Examining EFs



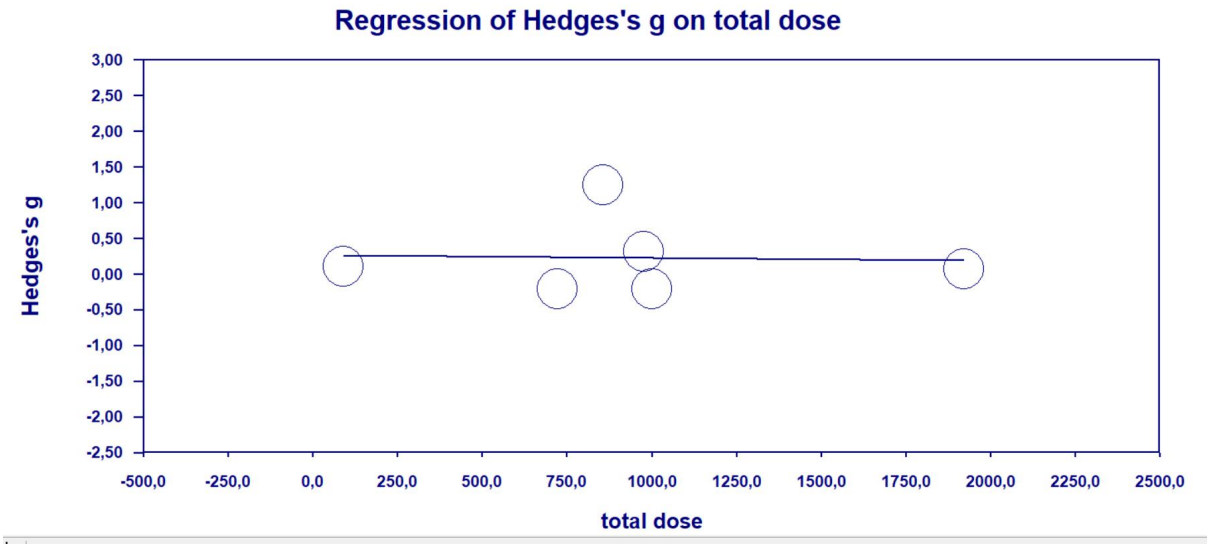
Note. β1 = -0.05, z = -0.77, p = .44.

Meta-Regression Analysis of Session Time in Minutes as Predictor of the Effect Size in Studies Examining EFs



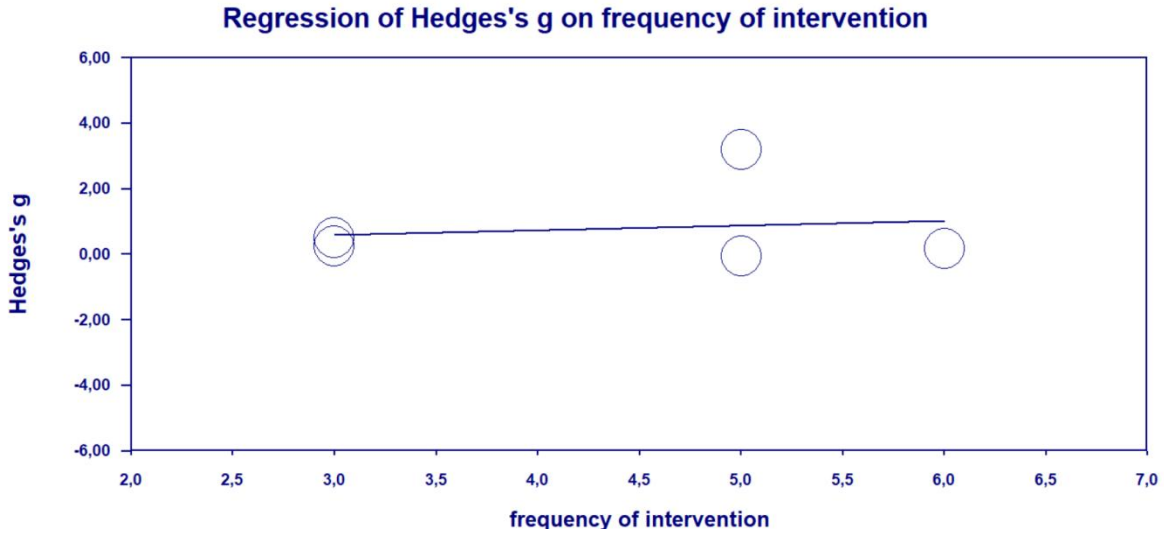
Note. β1 = 0.01, z = 0.47, p = .64.

Meta-Regression Analysis of Total Dose in Minutes as Predictor of the Effect Size in Studies Examining EFs



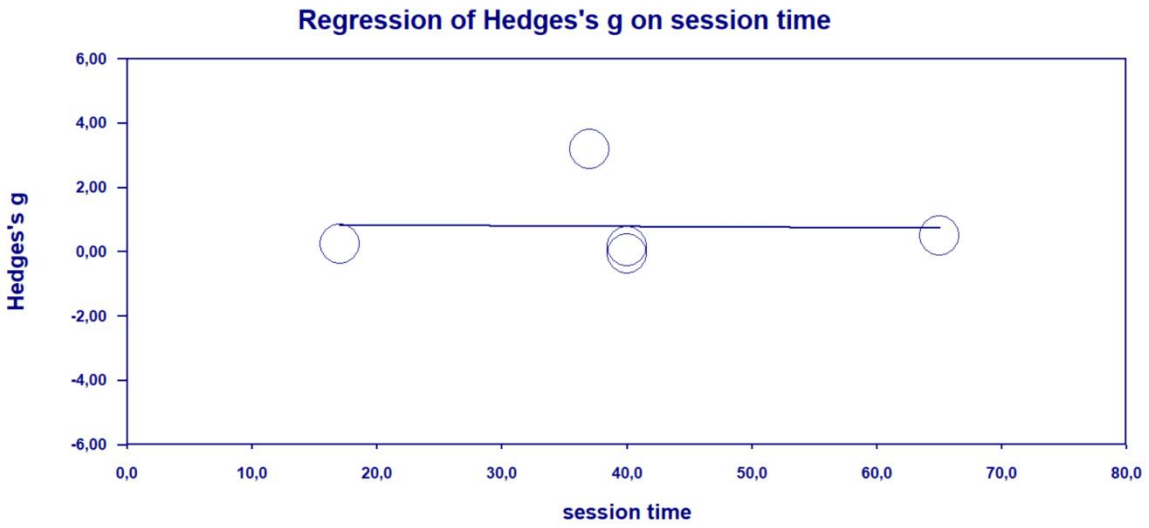
Note. β1 = -0.00, z = -0.10, p = .92.

Meta-Regression Analysis of Frequency of Intervention in Days Weeks as Predictor of the Effect Size in Studies Examining WM



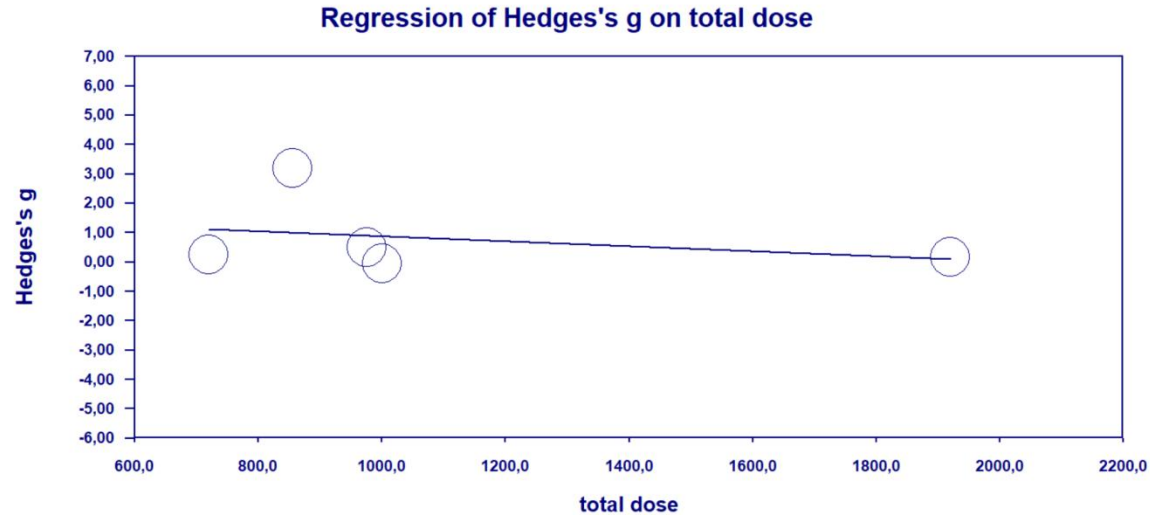
Note. β1 = 0.15, z = 0.29, p = .77.

Meta-Regression Analysis of Session Time in Minutes as Predictor of the Effect Size in Studies Examining WM



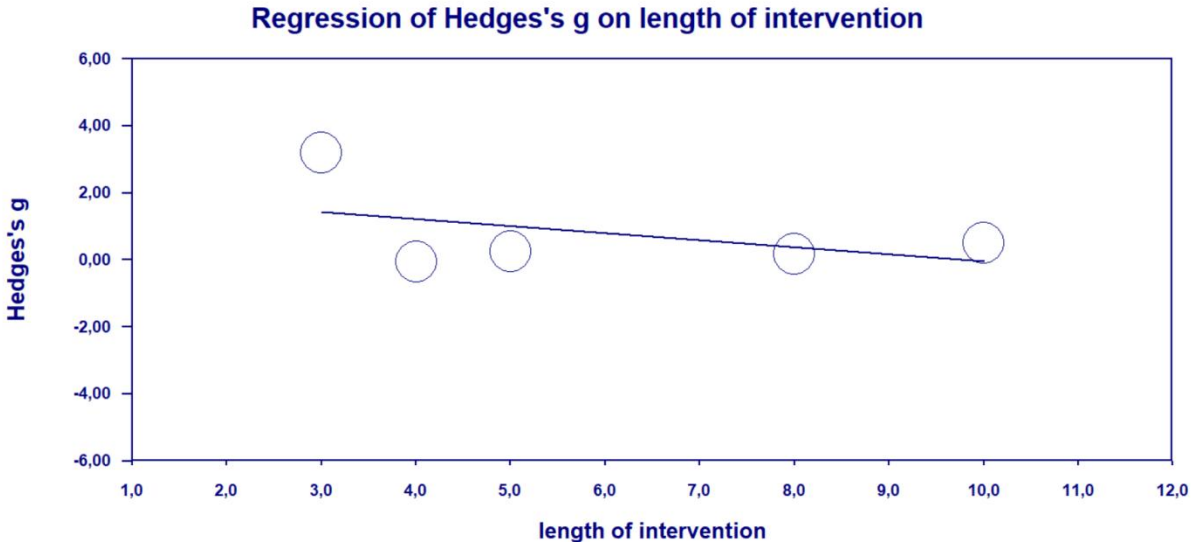
Note. β1 = -0.002, z = -0.05, p = .96.

Meta-Regression Analysis of Total Dose in Minutes as Predictor of the Effect Size in Studies Examining WM



Note. β1 = -0.001, z = -0.69, p = .49

Meta-Regression Analysis of Length of Intervention in Weeks as Predictor of the Effect Size in Studies Examining WM



Note. β1 = -0.21, z = -1.0, p = .32