NeuroRegulation



# Effectiveness of Brain-Computer Interface (BCI)-Based Attention Training Game System for Symptom Reduction, Behavioral Enhancement, and Brain Function Modulation in Children With ADHD: A Systematic Review and Single-Arm Meta-Analysis

*Muhammad Zain Raza*, Muhammad Omais, Hafiz Muhammad Ehsan Arshad, Musab Maqsood, and Ali Ahmad Nadeem*

King Edward Medical University, Department of Medicine, Lahore, Pakistan

**Abstract**

**Introduction.** Brain-computer interface (BCI)-based games have been developed as an adjunct to conventional ADHD therapy. This review aims to assess the effectiveness of these systems. **Methodology.** ADHD Rating Scale (ADHD-RS) and Integrated Visual and Auditory Continuous Performance Test (IVA-CPT) scores were analyzed, while other outcomes were assessed qualitatively. **Results.** Eleven studies with a total of 421 subjects were included, which utilized seven unique BCI-based games. There was a significant reduction in parent-reported (*MD* = 2.20; 95% CI: 0.91–3.49) and clinician-reported (*MD* = 1.60; 95% CI: 0.32–2.88) inattention (IA) scores in the intervention group versus control. There was a statistically significant reduction in parent-reported (*MD* = 3.70; 95% CI: 2.11–5.29) and clinician-reported (*MD* = 3.20; 95% CI: 1.82–4.58) IA scores and parent-reported hyperactive/impulsivity (HI) scores (*MD* = 3.88; 95% CI: 1.88–5.87) in a pre–post intervention analysis. IVA-CPT visual and auditory scores showed a statistically significant increase in the response control (*MD* = 12.85; 95% CI: 6.01–19.68) and attention (*MD* = 22.93; 95% CI: 15.44–30.43) quotients. Three studies reported a statistically significant reduction in Child Behavior Checklist (CBCL) scores. One study found a significant change in small-worldness over time (*P* = .045), indicating altered brain network structure after BCI-based attention training. **Conclusion.** BCI-based interventions show promise in controlling inattentive, hyperactive-impulsive, behavioral, and learning disability symptoms of ADHD, but further research is needed on a more holistic approach targeting both inattention and learning symptoms simultaneously.

***Keywords***: attention-deficit/hyperactivity disorder (ADHD); brain-computer interface (BCI); game; neurofeedback

**Citation**: Raza, M. Z., Omais, M., Arshad, M. E., Maqsood, M., & Nadeem, A. A. (2025). Effectiveness of brain-computer interface (BCI)-based attention training game system for symptom reduction, behavioral enhancement, and brain function modulation in children with ADHD: A systematic review and single-arm meta-analysis. *NeuroRegulation, 12*(1), 51–78. https://doi.org/10.15540/nr.12.1.51

***Address correspondence to**: Muhammad Zain Raza, Department of Medicine, King Edward Medical University, H897+X5V, Nila Gumbad Chowk, Neela Gumbad Lahore, Punjab 54000. Email: raza52280@gmail.com



**Edited by**:
Rex L. Cannon, PhD, Currents, Knoxville, Tennessee, USA

**Reviewed by**:
Rex L. Cannon, PhD, Currents, Knoxville, Tennessee, USA
Whitney Norris, University of Arkansas for Medical Sciences, Little Rock, Arkansas, USA

## Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a chronic developmental disorder that begins in childhood and can persist into adulthood (Carlson et al., 1999). It is traditionally categorized into three types: the inattentive type, characterized by easy distraction and difficulties in sustaining attention; the hyperactive/impulsive type, marked by hyperactivity, excessive talking, fidgeting, and a lack of impulse control; and the combined type, which includes symptoms of both inattention and hyperactivity (Carlson et al., 1999). The inattentive type is the most prevalent, while the hyperactive/impulsive type is the least common (Ayano et al., 2020). Therapies for ADHD often focus on managing attentional symptoms, as these are central to the disorder's diagnostic criteria and significantly impact daily functioning. These symptoms include problems with task organization, frequent careless mistakes, and poor school performance. EEG analyses have revealed characteristic brain function disruptions in ADHD patients, such as decreased beta waves (associated with attention), decreased alpha waves (associated with relaxation), and increased theta waves (associated with inattention; Adamou et al., 2020). Furthermore, it is also associated with altered intrinsic brain network organization, including hyperconnectivity within the default mode network (DMN) involved in self-referential mental activity, the ventral attention network (VAN) responsible for orienting attention to salient stimuli, and between the VAN and the dorsal attention network (DAN), which helps in directing attention to task-relevant information (Castellanos & Proal, 2012; Konrad & Eickhoff, 2010; Sidlauskaite et al., 2016).

In typical brain networks, the architecture exhibits a balance of high local clustering of neurons and short path lengths, reflecting an optimal mix of local efficiency (specialized processing within clusters) and global efficiency (integrated processing across distant regions). This configuration is characteristic of a small-world network, which combines strong local connections for efficient segregated processing and long-range connections that enable effective communication across the entire brain. Such a balance supports both simple, localized tasks and complex, distributed cognitive functions. In contrast, brain networks in individuals with ADHD tend to shift toward a nonrandom configuration (Sporns, 2011). These networks are characterized by increased local clustering and longer path lengths, resulting in high local efficiency but reduced global efficiency. This disrupted balance limits the brain's ability to integrate information across distant regions, contributing to impairments in attention, executive function, and other distributed cognitive tasks (Watts & Strogatz, 1998).

Attention training can significantly improve the symptoms by enhancing an individual's ability to focus, sustain attention, and regulate cognitive processes (Jensen et al., 2016). This training typically involves structured exercises and strategies designed to increase attentional control, such as practicing concentration on specific tasks and employing cognitive-behavioral techniques like social planning, self-monitoring, and behavioral activation (Jensen et al., 2016). Alternatively, neurofeedback (NF) therapy has emerged as an innovative method for attention training, which utilizes EEG data to help individuals self-regulate their brain activity (Arns et al., 2009; Enriquez-Geppert et al., 2019). The procedure involves placing electrodes on the scalp to monitor brain wave patterns and providing immediate feedback to participants through visual or auditory signals (Marzbani et al., 2016). Over time, participants train their brains to enhance desirable patterns, such as those associated with attention and executive function, and to reduce those associated with ADHD symptoms (Marzbani et al., 2016). A well-established NF framework involves leveraging adaptive neuroplasticity, which occurs through long-term potentiation (LTP) of neural synapses in brain regions associated with attention, executive function, and working memory, such as the dorsolateral prefrontal cortex, caudate nucleus, and hippocampus (Abarbanel, 1999; Trojan & Pokorný, 1999). Traditional treatments, including medications such as methylphenidate and atomoxetine, enhance LTP by increasing presynaptic levels of norepinephrine (NE; Piña et al., 2020; Rozas et al., 2015). NE acts on beta-adrenergic receptors to improve LTP, particularly in the hippocampus (Piña et al., 2020; Rozas et al., 2015). An alternative to medication, NF, is also proposed for ADHD treatment. Although NF does not directly increase neurotransmitter levels as medications do, it promotes LTP through long-term or repetitive stimulation (Abarbanel, 1999). NF enhances synaptic invaginations and increases the number of postsynaptic receptors (Trojan & Pokorný, 1999). The benefit derived from these approaches lies in the hippocampus's ability to induce LTP in cortical neurons, particularly in the prefrontal cortex (Abarbanel, 1999). This is significant because the hippocampus plays a crucial role in learning and memory, while the prefrontal cortex is essential for executive functions and attention. Consequently, NF training has the potential to enhance neuroplasticity in the prefrontal cortex, which may be particularly beneficial for reducing ADHD symptoms, especially those related to inattention (Abarbanel, 1999).

However, a key drawback of NF therapy lies in the classic correlation-versus-causation problem: NF systems rely on monitoring brain rhythms correlated with attention levels, but these correlations do not necessarily imply direct causation. For example, an increase in certain brain wave activity might be associated with improved attention, but it doesn't confirm that the subject's attention directly caused the change in brain wave patterns (Lim et al., 2010). This ambiguity raises questions about the effectiveness observed with NF in previous studies.

To address this issue, a more innovative design has emerged (i.e., BCI-based gaming systems).

Brain-computer interface (BCI) engineering involves the acquisition, processing, and interpretation of neural signals to enable direct interaction between the brain and external systems. While both BCI and NF use similar electrode-based technology to capture brain signals, BCIs differ fundamentally in purpose and function. In traditional NF, brainwave patterns are merely displayed to the user, who learns to self-regulate brain activity over time; however, the user has no direct control over external systems. In contrast, BCIs enable individuals to actively control external devices or virtual elements by decoding neural signals into commands, creating an interactive feedback loop that goes beyond self-regulation (Mridha et al., 2021). For example, in stroke rehabilitation, BCIs help patients control robotic devices or simulate movement, which aids motor recovery (Sebastián-Romagosa et al., 2023). In epilepsy, BCIs monitor brain activity to predict and manage seizures (Gummadavelli et al., 2018), and in Parkinson's disease, they assist in rehabilitating motor functions (Bronte-Stewart et al., 2020). For mental health, BCIs provide novel interventions by modulating brain activity, such as through BCI music therapy for depression and anxiety (Sun, 2022).

Several studies have indicated that gaming can be helpful in ADHD patients due to its dynamic, engaging environments that stimulate processes such as attention and executive function, which are often impaired in ADHD (Peñuelas-Calvo et al., 2022). Games with adaptive difficulty levels and real-time feedback can enhance neural plasticity by reinforcing attention-related brain networks and improving cognitive control through repetitive, task-oriented practice (Kovacevic et al., 2015). BCI-based gaming is effective because it adapts gameplay based on the users' brain activity, helping to keep them engaged and focused on the in-game tasks. These systems operate on the principle of active and passive BCI technologies. Active BCIs require users to consciously focus their attention or perform specific mental tasks to influence the game or application, while passive BCIs monitor brain activity to detect subconscious changes in mental states, such as attention levels or relaxation, and adapt the game to subtly influence the user to alter these states. Studies have used both active and passive BCI techniques for attention training in children with ADHD (Zander et al., 2010). Both these systems offer distinct yet complementary benefits for ADHD management. While many individual trials have shown promising effects of this type of intervention as the primary treatment, there are few works that comprehensively compile and systematically compare their results, and none of them have focused on treatment outcomes (Cervantes et al., 2023). The objective of this review is to evaluate the impact of BCI-based games on ADHD symptoms, behavioral performance, and brain function, providing a comprehensive assessment of their efficacy in improving behavioral and learning outcomes in affected children.

## Methods

This systematic review was written in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The protocol was registered on the Open Science Framework (OSF) register (Raza et al., 2024).

### Study Outcomes

There were two primary outcomes: (a) improvement in inattentive and hyperactive symptoms of ADHD and (b) improvement in behavior pattern of the child. Improvement in inattentive and hyperactive symptoms was represented by the change in the inattention (IA) and hyperactive-impulsivity (HI) scores measured with the ADHD Rating Scale (ADHD-RS), Integrated Visual and Auditory Continuous Performance Test (IVA-CPT), Clinical Global Impression-Severity (CGI-S) scale, and Children Global Assessment Scale (CGAS). Improvement in the behavior pattern was represented by the change in the scores measured with the Child Behavior Checklist (CBCL; Nøvik, 1999). Refer to Table 1 for details regarding these scales. There was one secondary outcome, brain function modulation, which was represented in this review by the changes in EEG patterns or brain network connectivity observed with functional MRI (fMRI) following the intervention.

### Search Strategy

Four databases (PubMed, Cochrane CENTRAL, ScienceDirect, and IEEE Xplore) and two trial registers (ClinicalTrials.gov and WHO ICTRP) were searched without any date restrictions in July 2024. The search used both controlled vocabulary and text words for the terms "attention deficit hyperactivity disorder (ADHD)" and "brain-computer interface (BCI)". The specific search strategies for individual sources are given in Table 1A.

**Table 1**

*List of All Assessments/Scales Used to Assess Outcomes of ADHD*

| Assessment/Scales | Abbreviation | Explanation |
|---|---|---|
| Diagnostic and Statistical Manual of Mental Disorders | DSM-IV (or V) | Prespecified diagnostic criteria for ADHD |
| ADHD Rating Scale | ADHD-RS | An 18-point questionnaire based on DSM-IV criteria for diagnosing and assessing ADHD severity. It has two subscales, inattention and hyperactive/impulsivity (DuPaul et al., 1998) |
| Inattention score | IA | Inattention score as measured by the ADHD-RS (DuPaul et al., 1998) |
| Hyperactive/impulsivity score | HI | Hyperactivity and impulsivity score as measured by the ADHD-RS (DuPaul et al., 1998) |
| Integrated Visual and Auditory Continuous Performance Test | IVA-CPT | A computerized visual and auditory attention test, wherein responses to objects on a screen requiring impulse control and avoiding errors of omission are scored on visual and auditory primary scales to derive scores (Tinius, 2003) |
| Clinical Global Impression-Severity | CGI-S | A scale assessing the severity of psychiatric symptoms, with higher scores indicating greater symptom severity (Berk et al., 2008) |
| Children Global Assessment Scale | CGAS | A scale that assesses the overall functioning of the child, with higher scores indicating better performance in various domains of life, such as academic performance and social relationships (Shaffer, 1983) |
| Child Behavior Checklist | CBCL | A scale for behavior pattern used in this study to measure improvement in symptoms by evaluating changes in scores. It encompasses two major categories of problems: externalizing and internalizing, as well as several minor categories including social, thought, and attention problems. Externalizing problems include behaviors such as lying, cheating, and aggression toward others, whereas internalizing problems involve issues like anxiety, social withdrawal, depression, and somatic complaints such as headaches and fatigue (Nøvik, 1999) |

## Eligibility Criteria

A study was deemed eligible if it met all of the following inclusion criteria: (a) children aged 12 years or younger diagnosed with ADHD, according to either DSM-IV or DSM-V criteria; (b) patients who received BCI-based attention training game system as the sole intervention; (c) studies must be randomized-controlled trials (RCTs), nonrandomized controlled trials (nRCTs), single-arm experimental trials, or prospective cohort studies; and (d) outcome measures include postinterventional changes in symptoms, behavior, learning disabilities, or brain functions. A study was deemed ineligible if it met at least one of the following exclusion criteria: (a) studies in which most of the participants are taking either stimulant medications, supplements, or both concomitantly or within 1 month prior to starting BCI-based therapy because these substances can significantly improve attention and cognitive control, making it difficult to isolate the true effect of the BCI intervention; (b) patients who have predominantly hyperactive/impulsive symptoms because BCI-based therapy primarily targets attention regulation, and including these patients could introduce heterogeneity in outcomes, making it difficult to assess the true effect of the intervention on attention-related symptoms; (c) studies that include both healthy participants and children with ADHD, but data for ADHD patients is not reported separately; (d) studies that report only the feasibility of BCI-based interventions without any treatment outcomes; and (e) studies that focus solely on nonmedical outcomes of BCI interventions, such as effects on social interactions or economic aspects.

### Study Selection and Data Extraction

First, two authors independently screened the titles and abstracts of the studies identified from the electronic sources based on the inclusion criteria. Second, two authors independently screened the full texts of the studies based on the exclusion criteria. Finally, each included study was independently extracted by two authors for the following data: Study details (author name, year, setting and country, design, and duration), participant details (including age, sex, and treatment plan), and outcomes (primary and secondary). Any conflict between the two independent authors was resolved by the mutual consensus of all authors.

### Risk of Bias Assessment

The risk of bias for RCTs was assessed using RoB 1 developed by Cochrane Collaboration (Higgins et al., 2011). It has seven domains that assess selection, performance, detection, attrition, reporting, and other biases. In each domain, the risk of bias was marked as low, uncertain, or high. The risk of bias for nonrandomized studies was assessed using the methodological index for nonrandomized studies (MINORS) tool developed by Slim et al. (2003). It has a general section with eight criteria for the rating of aims, sampling, planning, endpoints, outcome assessment, follow-up period, attrition, and sample size calculation, respectively. There is an additional section only for comparative studies with four criteria for the rating of control group adequacy, contemporariness of groups, baseline equivalence, and statistical analysis, respectively. On each criterion, the study can be rated 0 (*not reported*), 1 (*inadequately reported*), and 2 (*adequately reported*). The overall maximum score is 16 for noncomparative and 24 for comparative studies.

### Statistical Analysis

The data for all outcomes was summarized qualitatively. To evaluate the improvement in the symptoms of ADHD (represented by changes in ADHD-RS and IVA-CPT scores), a pooled analysis using inverse variance (IV) method and fixed-effects model was conducted. Heterogeneity was assessed by Cochrane Q and I2 tests. All analysis was performed with RevMan Web. No sensitivity analysis and assessment of publication bias was performed.

## Results

### Characteristics and Bias Assessment of Included Studies

A total of 4,103 records were identified through the database search and the manual search. The duplicates were removed, and the remaining 3,260 records underwent title-and-abstract screening. Out of these, 3,236 records were excluded and 26 records were selected for full-text screening. Eleven studies were finally included in the review. The whole screening process is summarized in the PRISMA 2009 flow diagram (Figure 1). Studies excluded in secondary screening along with reasons of exclusion are given in Table 2A.

The included studies, published between 2008 and 2023, reported the data on ADHD patients from three double-arm intervention-control RCTs (Johnstone et al., 2017; Lim et al., 2019; Qian et al., 2018), one double-arm comparative RCT (Lim et al., 2023), one control-matched single-arm trial (Lim et al., 2010), and six single-arm trials (Blandón et al., 2016; Georgiou et al., 2019; Lim et al., 2012; Liu et al., 2013; Park et al., 2019; Yan et al., 2008). One RCT, Johnstone 2017 (Johnstone et al., 2017), had two subgroups with one comprising of ADHD patients with a confirmed diagnosis of ADHD and the other of patients with subclinical symptoms. Only the data from the former group was collected for this review. The characteristics of the included studies are summarized in Table 3A and the patient characteristics are given in Table 2.

**Figure 1.** *PRISMA flowchart for the Screening Process.*

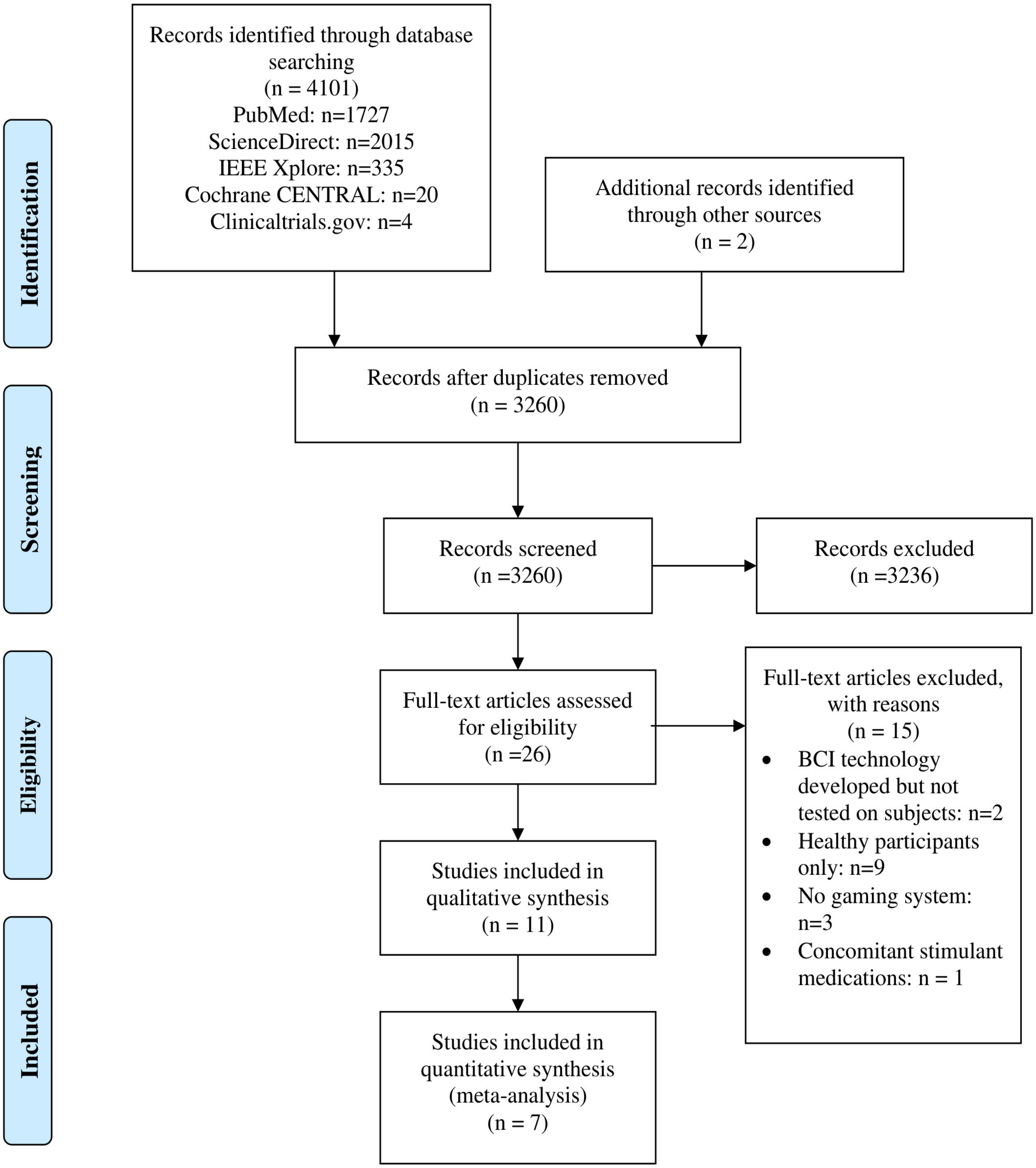


**Table 2**
*Patient Characteristics and BCI Games Used in the Eleven Included Studies*

| Study ID | Total number of participants | Type of BCI | Age range/ Mean age | Gender distribution | Comorbidities | Groups | |
|---|---|---|---|---|---|---|---|
| | | | | | | BCI | Non-BCI |
| Blandón et al. (2016) | 9 children | Active | 5–12 | N/A | None | 9 | - |
| Georgiou et al. (2019) | 53 children | Active | 9.98 ± 1.85 | 40 males<br>13 females | None | 53 | - |
| Johnstone et al (2017) | 44 children | Active | 9.81 / 7.3–12.8 | 31 males<br>13 females | None | 22 | 22 |
| Lim et al. (2010) | 16 children | Active | 8.9 ± 1.4 | 13 males<br>3 females | None | 8 | 8 |
| Lim et al. (2012) | 20 children | Active | 7.8 ± 1.4 / 6-11 | 16 males<br>4 females | None | 20 | - |
| Lim et al. (2019) | 163 children | Active | 8.6 ± 1.54 / 6–12 | 138 males<br>25 females | None | 81 | 82 |
| Lim et al. (2023) | 20 children (10 home-based and 10 in clinic) | Active | 9.93 ± 1.69 / 6–12 | 16 males<br>4 females | Tourette syndrome, dyslexia | 20 | - |
| Liu et al. (2013) | 13 children | Active | 6–13 years | 19 males<br>3 females | None | 13 | |
| Park et al. (2019) | 5 children | Passive | 6–8 | All males | None | 5 | - |
| Qian et al. (2018) | 66 children | Active | 9.00 ± 1.50 | All males | None | 44 | 22 |
| Yan et al. (2008) | 12 children | Active | 8–12 years | 10 males<br>2 females | None | 12 | - |

## Available BCI-Based Equipment

All of the included studies utilized seven unique BCI-based intervention programs, which are summarized in Table 3. Based on the specific mode of interaction of the interface, the BCI equipment was classified into three categories (i.e., active, reactive, and passive). Only one of the included studies, Park et al. (2019) utilized passive BCI mode of interaction. The remaining eight studies utilized active BCI mode of interaction.

1. Lim et al. (2010) developed a puzzle game where users' attention levels were used to solve increasingly complex puzzles. EEG signals were collected via electrodes placed at Fp1, Fp2, and Pz, covering frequencies from 4 Hz to 36 Hz, including theta, alpha, beta 1, and beta 2 waves. These signals were processed through spatial filters, and machine learning was applied to classify the EEG data into attention or nonattention states, providing a quantifiable attention score. Calibration of the BCI system was achieved using EEG data collected during a concentration task involving the game.
2. Subsequent studies by Lim (2012, 2019, 2023) and Qian et al. (2018) involved a 3D computerized graphic game named *CogoLand*. In this game, participants controlled an avatar based on EEG signals detected by electrodes placed at Fp1 and Fp2. The frequency bands (4–36 Hz) and signal processing techniques were consistent with those used in the previous puzzle game. The EEG data were computed into a BCI ADHD Severity Measure (BASM) score via a built-in regression function and presented to the user on screen. BCI calibration was done using EEG waves recorded during a color Stroop test.
3. Blandón et al. (2016) created a virtual reality (VR) adventure game called *Harvest Challenge*, where players interacted with virtual objects by modulating their attention levels. This study utilized two toolboxes: HCI-signal processing toolbox for

processing physiological and biomechanical signals, including electromyographic (EMG) signals, and NeuroRead for EEG signal processing and visualization from low-cost BCI systems. The frequency bands recorded ranged from 0.5 Hz to 35 Hz, covering alpha, beta, delta, theta, and gamma waves. These attention levels were mapped from 0 to 100 percent, providing visually explicit physiological feedback.

4. Johnstone et al. (2017) developed *Focus Pocus*, a game consisting of 14 mini-games, including 6 NF games. Out of these, two games focused on attention, two on relaxation, and two on zen feedback. A portable EEG device collected waves in delta, theta, alpha, and beta frequency bands. Proprietary algorithms calculated values representing two independent psychological states: "attention" and "relaxation," with scores presented between 0 and 100.
5. Georgiou et al. (2019) utilized the *FocusLocus* game system, where players expand a reef colony by employing tactics and strategic planning skills such as goal setting, planning, sequencing, and time management. EEG waves were collected and clustered into five frequency bands corresponding to brainwaves: (a) delta waves (0.5 Hz to 3 Hz), (b) theta waves (4 Hz to 7 Hz), (c) alpha waves (8 Hz to 13 Hz), (d) beta waves (14 Hz to 30 Hz), and (e) gamma waves (31 Hz to 50 Hz).
6. Park et al. (2019) developed a passive mode BCI game with an immersive fairy tale experience. Users followed the storyline and read dialogues on the screen while the BCI system monitored their brain and motion activity. The game adapted its gameplay by prolonging time or incorporating encouraging words from game characters if the user's attention level dropped.
7. Yan et al. (2008) and Liu et al. (2013) developed a series of games that integrate NF and VR technologies, allowing patients' attention levels to influence gameplay. For instance, Yan et al. (2008) described a game where a player's attention controls the movement of a spaceship. The spaceship accelerates when the EEG-based BCI detects an increase in the player's attention level.

**Table 3**

*Specification of the Seven BCI-Based Games*

| Name of the game | BCI mode (active/ passive) | Control interface | Gameplay | Mechanism of levels | Duration per session |
|---|---|---|---|---|---|
| Puzzle Game (Cogoland initial version) | Active | EEG (alpha, beta 1, and beta 2 waves) | Puzzle game / a series of games with increasing difficulty. | N/A | Two 30-min sessions/week for 10 weeks |
| Cogoland | Active | The EEG data was collected via a headband with two dry EEG sensors (4–36 Hz). | Adventure game with different levels. The player has to cover as much distance as possible in the first level and then collect fruits in the subsequent levels. | There were three levels in the game and each level required additional attention to play. | Three 30-min sessions/week for 8 weeks |
| Harvest Challenge | Active | NeuroRead v1.1 was utilized, which is a toolbox for EEG processing (alpha, beta, delta & theta waves) and visualization. | The game starts in an ecological farm and the first task is to collect the equipment needed for a safe ride in the canopy. Next, the player is given the task to repair the pathway and collect as many carrots as possible. | Three levels in total:<br>1. Equipment for the Canopy<br>2. Repairing the pathway<br>3. Harvesting the carrots<br>The previous level has to be cleared first in order to reach the next level. | 30 min/session, total two sessions |

**Table 3**
*Specification of the Seven BCI-Based Games*

| Name of the game | BCI mode (active/ passive) | Control interface | Gameplay | Mechanism of levels | Duration per session |
|---|---|---|---|---|---|
| Focus Pocus | Active | The portable, dry sensor "Mindwave" EEG device was used. The EEG waves were alpha, beta, delta & theta waves. | The player is a "wizard in training" working to improve important wizard skills such as broomstick racing, transformation, potion making, etc. | In each training session, two NF games were driven by Attention, two by Relaxation, and two by Zen feedback. | 3-4 sessions/week, total of 25 sessions over 6–8 weeks |
| FocusLocus | Active | EEG was recorded via a wearable headset equipment. The recorded waves were alpha, beta, gamma, delta, and theta. | Well-established paradigms of Real-Time Strategy (RTS) and Management Simulation (MS) game genres. | The game includes rewards and punishments that will be offered to the player on the basis of their performance. | No more than 30 min/session. |
| Fairy-Tale game | Passive | The control interface "Adaptive Behavior Training Game Platform (ABTGP)" collects brainwaves as EEG. | The player acts as a third character in the story of a fisherman and a genie. The player is given tasks and if his attention drops, the fisherman encourages him to carry out tasks. | No levels, increased concentration required to perform subsequent tasks. | 37-min runtime, sessions performed over 5 weeks, including one 20-min adaptation test and four 40-min full tests |
| Virtual Environment (VE) games | Active | EEG signals (0.1–70 Hz) collected via electrodes placed on scalp | Three spaceships move on computer screen. The middle spaceship speeds up in response to an inspirational signal from EEG | N/A | 25- to 35-min sessions performed twice per week with total 20 training sessions |

## Symptom Reduction

***ADHD-RS Scores.*** Five of the included studies reported ADHD-RS IA and HI scores (except for Johnstone et al. (2017), which reported a modified scale consisting of questions from both these sheets) reported by a parent, teacher or a clinician. The summary of these scores is given in Table 4A. The pooled analysis using IV method and the fixed-effects model using two of the included intervention-control RCTs, Lim et al. (2010 & 2019), showed a statistically significant mean difference between intervention and control groups in parent-reported (*MD* = 2.2; 95% CI: 0.91–3.49; *P* = .0008) as well as clinician-reported (*MD* = 1.6; 95% CI: 0.32–2.88; *P* = .001) IA scores. The pooled scores and the analyses are presented in Figure 2.

Furthermore, the pooled pre- and postintervention values from five of the included trials (Lim et al., 2010, 2012, 2019, 2023; Qian et al., 2018), using IV method and the fixed-effects model, showed statistically significant improvements in the parent-reported (*MD* = 3.7; 95% CI: 2.11–5.29; *P* < .00001) and the clinician-reported (*MD* = 3.20; 95% CI: 1.82–4.58; *P* < .00001) ADHD-RS IA scores. The analyses are presented in Figure 3. Similarly, the pooled pre- and postintervention values for parent-reported ADHD-RS HI score with the same methods showed a statistically significant difference (*MD* = 3.88; 95% CI: 1.88–5.87; *P* < .0001). The analysis is presented in Figure 4.

***Integrated Visual and Auditory Continuous Performance Test (IVA-CPT) Scores.*** Two studies, Yan et al. (2008) and Liu et al. (2013), utilized the IVA-CPT to assess changes in response control and attention quotients, along with their auditory and visual components (see Table 5A).

**Figure 2.** *Forest Plot of Pooled MD for ADHD-RS IA Scores.*

| | Intervention | | | Control/ waitlist | | | | Mean difference |
|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Fixed, 95% CI** |
| **1.1.1 Parent-reported** | | | | | | | | |
| Lim 2010 | 3 | 4.8 | 8 | 0.8 | 1.3 | 8 | 13.9% | 2.20 [-1.25 , 5.65] |
| Lim 2019 | 4 | 4.8 | 81 | 1.8 | 4.21 | 82 | 86.1% | 2.20 [0.81 , 3.59] |
| **Subtotal (95% CI)** | | | **89** | | | **90** | **100.0%** | **2.20 [0.91 , 3.49]** |
| Heterogeneity: Chi² = 0.00, df = 1 (P = 1.00); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 3.35 (P = 0.0008) | | | | | | | | |
| **1.1.2 Teacher-reported** | | | | | | | | |
| Lim 2010 | 6 | 5.9 | 5 | 0.8 | 5.6 | 6 | 100.0% | 5.20 [-1.64 , 12.04] |
| **Subtotal (95% CI)** | | | **5** | | | **6** | **100.0%** | **5.20 [-1.64 , 12.04]** |
| Heterogeneity: Not applicable | | | | | | | | |
| Test for overall effect: Z = 1.49 (P = 0.14) | | | | | | | | |
| **1.1.3 Clinician-reported** | | | | | | | | |
| Lim 2019 | 3.5 | 3.87 | 81 | 1.9 | 4.42 | 81 | 100.0% | 1.60 [0.32 , 2.88] |
| **Subtotal (95% CI)** | | | **81** | | | **81** | **100.0%** | **1.60 [0.32 , 2.88]** |
| Heterogeneity: Not applicable | | | | | | | | |
| Test for overall effect: Z = 2.45 (P = 0.01) | | | | | | | | |

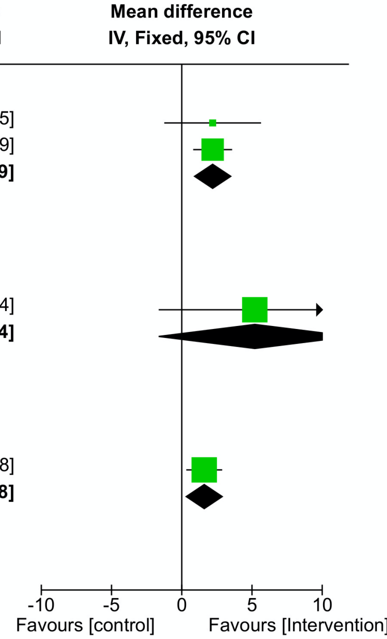



**Figure 3.** *Forest Plot of Pooled MD for Pre- and Postintervention ADHD-RS IA Scores.*

| | Pre-intervention | | | Post-intervention | | | | Mean difference |
|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Fixed, 95% CI** |
| **2.1.1 Parent-reported** | | | | | | | | |
| Lim 2010 | 18 | 6.1 | 8 | 15 | 5.9 | 8 | 7.3% | 3.00 [-2.88 , 8.88] |
| Lim 2012 | 17.7 | 5 | 20 | 12.6 | 3.4 | 20 | 36.0% | 5.10 [2.45 , 7.75] |
| Qian 2018 | 16.27 | 4.25 | 18 | 13.16 | 4.07 | 18 | 34.2% | 3.11 [0.39 , 5.83] |
| Lim 2023 | 15.9 | 6.97 | 10 | 14.1 | 6.31 | 10 | 7.4% | 1.80 [-4.03 , 7.63] |
| Lim 2023 | 17.7 | 4.32 | 10 | 14.7 | 4.97 | 10 | 15.2% | 3.00 [-1.08 , 7.08] |
| **Subtotal (95% CI)** | | | **66** | | | **66** | **100.0%** | **3.70 [2.11 , 5.29]** |
| Heterogeneity: Chi² = 1.83, df = 4 (P = 0.77); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 4.57 (P < 0.00001) | | | | | | | | |
| **2.1.2 Teacher-reported** | | | | | | | | |
| Lim 2010 | 6 | 5.9 | 5 | 0.8 | 5.6 | 5 | 100.0% | 5.20 [-1.93 , 12.33] |
| **Subtotal (95% CI)** | | | **5** | | | **5** | **100.0%** | **5.20 [-1.93 , 12.33]** |
| Heterogeneity: Not applicable | | | | | | | | |
| Test for overall effect: Z = 1.43 (P = 0.15) | | | | | | | | |
| **2.1.3 Clinician-reported** | | | | | | | | |
| Lim 2019 | 18.9 | 4.25 | 78 | 15.6 | 5.26 | 78 | 84.3% | 3.30 [1.80 , 4.80] |
| Lim 2023 | 17.9 | 5.61 | 10 | 14.7 | 4.97 | 10 | 8.8% | 3.20 [-1.45 , 7.85] |
| Lim 2023 | 16.1 | 5.69 | 10 | 14.1 | 6.3 | 10 | 6.9% | 2.00 [-3.26 , 7.26] |
| **Subtotal (95% CI)** | | | **98** | | | **98** | **100.0%** | **3.20 [1.82 , 4.58]** |
| Heterogeneity: Chi² = 0.22, df = 2 (P = 0.90); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 4.55 (P < 0.00001) | | | | | | | | |

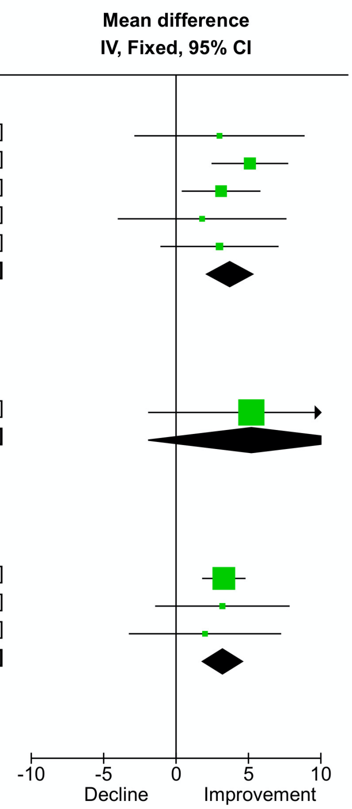
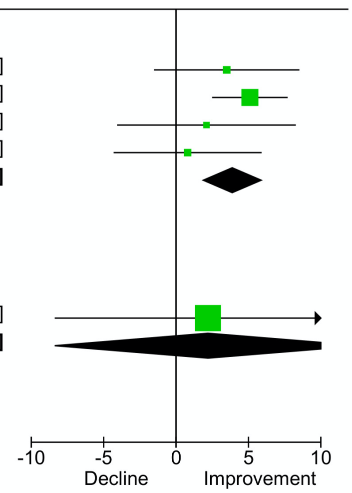


**Figure 4.** *Forest Plot of Pooled MD for Pre- and Postintervention ADHD-RS HI Scores.*

| Study or Subgroup | Pre-intervention Mean | SD | Total | Post-intervention Mean | SD | Total | Weight | Mean difference IV, Fixed, 95% CI |
|---|---|---|---|---|---|---|---|---|
| **2.2.1 Parent-reported** | | | | | | | | |
| Lim 2010 | 14.9 | 5.6 | 8 | 11.4 | 4.6 | 8 | 15.8% | 3.50 [-1.52 , 8.52] |
| Lim 2012 | 15.6 | 3.9 | 19 | 10.5 | 4.3 | 19 | 58.5% | 5.10 [2.49 , 7.71] |
| Lim 2023 | 11.8 | 8.44 | 10 | 9.7 | 5.29 | 10 | 10.5% | 2.10 [-4.07 , 8.27] |
| Lim 2023 | 12.2 | 5.37 | 10 | 11.4 | 6.26 | 10 | 15.3% | 0.80 [-4.31 , 5.91] |
| **Subtotal (95% CI)** | | | **47** | | | **47** | **100.0%** | **3.88 [1.88 , 5.87]** |
| Heterogeneity: Chi² = 2.58, df = 3 (P = 0.46); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 3.81 (P = 0.0001) | | | | | | | | |
| **2.2.2 Teacher-reported** | | | | | | | | |
| Lim 2010 | 16.8 | 9.3 | 5 | 14.6 | 7.7 | 5 | 100.0% | 2.20 [-8.38 , 12.78] |
| **Subtotal (95% CI)** | | | **5** | | | **5** | **100.0%** | **2.20 [-8.38 , 12.78]** |
| Heterogeneity: Not applicable | | | | | | | | |
| Test for overall effect: Z = 0.41 (P = 0.68) | | | | | | | | |




A pooled analysis of pre- and postintervention values from these studies, using the IV method and a fixed-effects model, revealed statistically significant increases. Specifically, the overall auditory RCQ increased (*MD* = 12.18, 95% CI: 4.93–19.42; *P* = .001), as did the visual RCQ (*MD* = 10.68, 95% CI: 2.15–19.20; *P* = .01) and the overall RCQ (*MD* = 12.85, 95% CI: 6.01–19.68; *P* = .0002). Similarly, for the attention quotient, there were significant increases in auditory AQ (*MD* = 17.29, 95% CI: 8.76-25.81; *P* < .001), visual AQ (*MD* = 22.48, 95% CI: 13.33–31.73; *P* < .00001), and overall AQ (*MD* = 22.93, 95% CI: 15.44–30.43; *P* < .00001). The analyses are given in Figure 5 and Figure 6.

**Figure 5.** *Forest Plot of Pooled MD for Pre- and Postintervention Response Control Quotient Scores.*

| Study or Subgroup | post-intervention Mean | SD | Total | pre-intervention Mean | SD | Total | Weight | Mean difference IV, Fixed, 95% CI |
|---|---|---|---|---|---|---|---|---|
| **2.3.1 Auditory score** | | | | | | | | |
| Liu 2013 | 98.571 | 7.208 | 13 | 86.357 | 17.372 | 13 | 50.2% | 12.21 [1.99 , 22.44] |
| Yan 2008 | 97.286 | 10.095 | 12 | 85.143 | 15.082 | 12 | 49.8% | 12.14 [1.87 , 22.41] |
| **Subtotal (95% CI)** | | | **25** | | | **25** | **100.0%** | **12.18 [4.93 , 19.42]** |
| Heterogeneity: Chi² = 0.00, df = 1 (P = 0.99); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 3.29 (P = 0.0010) | | | | | | | | |
| **2.3.2 Visual score** | | | | | | | | |
| Liu 2013 | 96.714 | 10.179 | 13 | 83.929 | 17.394 | 13 | 60.6% | 12.78 [1.83 , 23.74] |
| Yan 2008 | 94.571 | 13.636 | 12 | 87.143 | 19.777 | 12 | 39.4% | 7.43 [-6.16 , 21.02] |
| **Subtotal (95% CI)** | | | **25** | | | **25** | **100.0%** | **10.68 [2.15 , 19.20]** |
| Heterogeneity: Chi² = 0.36, df = 1 (P = 0.55); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 2.45 (P = 0.01) | | | | | | | | |
| **2.3.3 Overall** | | | | | | | | |
| Liu 2013 | 97.286 | 6.9 | 13 | 83.216 | 16.172 | 13 | 51.1% | 14.07 [4.51 , 23.63] |
| Yan 2008 | 95.857 | 9.685 | 12 | 84.29 | 14.291 | 12 | 48.9% | 11.57 [1.80 , 21.33] |
| **Subtotal (95% CI)** | | | **25** | | | **25** | **100.0%** | **12.85 [6.01 , 19.68]** |
| Heterogeneity: Chi² = 0.13, df = 1 (P = 0.72); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 3.69 (P = 0.0002) | | | | | | | | |

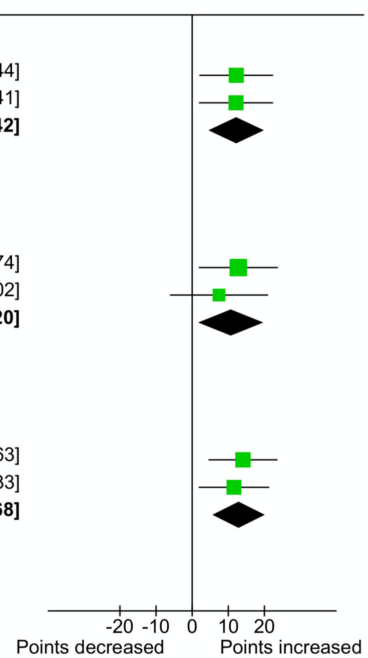
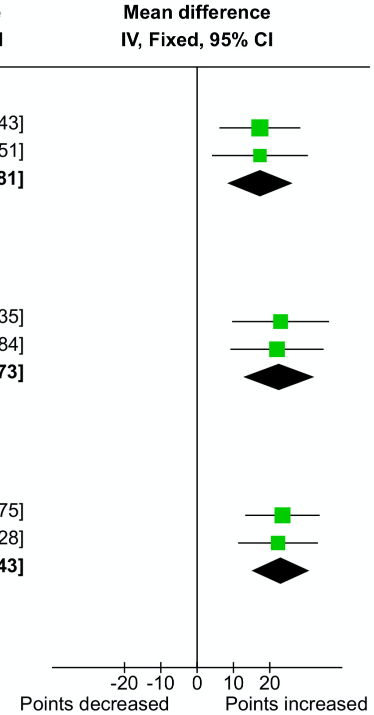


**Figure 6.** *Forest Plot of Pooled MD for Pre- and Postintervention Attention Quotient Scores.*

| | post-intervention | | | pre-intervention | | | | Mean difference |
|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Fixed, 95% CI** |
| **2.4.1 Auditory score** | | | | | | | | |
| Liu 2013 | 91.857 | 9.115 | 13 | 74.571 | 18.364 | 13 | 58.5% | 17.29 [6.14 , 28.43] |
| Yan 2008 | 96.572 | 16.257 | 12 | 79.286 | 16.799 | 12 | 41.5% | 17.29 [4.06 , 30.51] |
| **Subtotal (95% CI)** | | | **25** | | | **25** | **100.0%** | **17.29 [8.76 , 25.81]** |
| Heterogeneity: Chi² = 0.00, df = 1 (P = 1.00); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 3.98 (P < 0.0001) | | | | | | | | |
| **2.4.2 Visual score** | | | | | | | | |
| Liu 2013 | 95.143 | 11.408 | 13 | 72.143 | 21.746 | 13 | 48.0% | 23.00 [9.65 , 36.35] |
| Yan 2008 | 90.857 | 11.098 | 12 | 68.857 | 19.786 | 12 | 52.0% | 22.00 [9.16 , 34.84] |
| **Subtotal (95% CI)** | | | **25** | | | **25** | **100.0%** | **22.48 [13.23 , 31.73]** |
| Heterogeneity: Chi² = 0.01, df = 1 (P = 0.92); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 4.76 (P < 0.00001) | | | | | | | | |
| **2.4.3 Overall** | | | | | | | | |
| Liu 2013 | 94.071 | 8.325 | 13 | 70.572 | 16.928 | 13 | 53.5% | 23.50 [13.24 , 33.75] |
| Yan 2008 | 93.429 | 12.012 | 12 | 71.143 | 15.279 | 12 | 46.5% | 22.29 [11.29 , 33.28] |
| **Subtotal (95% CI)** | | | **25** | | | **25** | **100.0%** | **22.93 [15.44 , 30.43]** |
| Heterogeneity: Chi² = 0.03, df = 1 (P = 0.87); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 5.99 (P < 0.00001) | | | | | | | | |




***Clinical Global Impression-Severity (CGAS) and Children Global Assessment Scale (CGI-S) Scores.*** Only two RCTs, Lim et al. (2019) and Lim et al. (2023), reported clinician-assessed CGAS and CGI-S scores. Lim et al. (2019) reported a statistically significant mean difference (*MD* = 3.3; 95% CI: 2.4–4.2; *P* < .0001) and (*MD* = 4.5; 95% CI: 3.5–5.4; *P* < .0001) between the intervention and the waitlist at the 20th and 24th week of intervention compared to mean change at 8th week of waitlist, respectively. Similar results were reported for the clinician-rated CGI-S scores for the two groups. On the other hand, Lim et al. (2023) reported the group differences in CGAS and CGI-S scores between the children receiving home-based and clinic-based intervention. However, no significant differences were observed in those scores. The results from these studies are summarized in Table 4.

## Behavioral Enhancement

***Child Behavior Checklist (CBCL) Scores.*** Three of the included studies, Qian et al. (2018), Lim et al. (2019), and Lim et al. (2023), reported behavioral enhancement in the form of improvements on various versions of parent-reported CBCL scales. Two of the studies reported the mean values and measures of variance for intervention and waitlist groups, while one RCT, Lim et al. (2023), compared home-based intervention against clinic-based intervention. The reported findings from these three are summarized in Table 5.

***Reading Disability.*** Only one study, Park et al. (2019), reported improvement in reading comprehension (reciting, vocabulary understanding, sentence completion, vocabulary selection, sentence structure, short passage reading comprehension) on the Korean National Intelligence for Special Education–Basic Academic Achievement Test (KNISE-BAAT) scale, showing a statistically significant improvement in reciting short passage comprehension (*P* = .021) and general reading comprehension (Park et al., 2019).

## Brain Function Modulation

Only one study, Qian et al. (2018), reported the analysis of functional and structural MRI images pre- and postinterventions. Global efficiency and clustering coefficient did not show any significant effect of the BCI-based training over time (*P* > .05). In contrast, the small-worldness measure showed a significant time and group interaction (*P* = .045). After the BCI-based training, the small-worldness of the intervention group remained almost the same while that of the control group decreased significantly. Moreover, the reduction of small-worldness was correlated with less behavioral improvement (CBCL internalizing problems) over time across all ADHD patients (*r* = −0.384, *P* = .040).

**Table 4**
*CGAS and CGI-S Scores for the Intervention and Control Groups*

| Study ID | Assessor | Test | Time of assessment | Intervention group<br>Mean change from baseline (*SD*) | Control group<br>Mean change from baseline (*SD*) | Group Difference reported<br>*MD* (*SD*); *P* value |
|---|---|---|---|---|---|---|
| Lim et al. (2019) | Clinician | CGAS | at Week 8 | 2.8 (4.75) | 1.8 (4.92) | 1.03 (−2.6–0.5)<br>*P* = .1817 |
| | | | at Week 20 | 3.2 (6.03) | N/A | 3.3 (2.4–4.2)<br>*P* < .0001 |
| | | | at Week 24 | 4.3 (5.87) | N/A | 4.5 (3.5–5.4)<br>*P* < .0001 |
| | Clinician | CGI-S | at Week 8 | Median Change = 0.0; Range = (−5.0, 1.0) | Median Change = 0.0; Range = (−1.0, 2.0) | Median D (Range) = 0.0; *P* = .2026 |
| | | | at Week 20 | Median Change = 0.0; Range = (−2.0, 5.0) | | Median D (Range) = 0.0 (−2.0, 5.0); *P* < .0001 |
| | | | at Week 24 | Median Change = 0.0; Range = (−2.0, 5.0) | | Median D (Range) = 0.0 (−2.0, 5.0); *P* < .0001 |
| Lim et al. (2023) [The intervention is clinic and the control is home] | Clinician | CGAS | At week 8 | 3.70 (7.88) | 5.56 (3.68) | *P* = .68 |
| | Clinician | CGI-S | At week 8 | −0.06 (0.70) | −0.50 (0.53) | *P* = .28 |

## Adverse Effects

Two of the included studies, Lim et al. (2019) and Lim et al. (2023), reported treatment-associated adverse events. Lim et al. (2019) stated that a total of 6.4% (11/172) participants reported at least one adverse event, and headache was the most common complaint, followed by dizziness (6 and 4, respectively). Only one participant reported two different adverse events on one occasion, i.e., headache and trouble paying attention or concentrating. Lim et al. (2023) stated that only 2 out of 20 participants reported to have experienced a side effect. None of these adverse events required medical treatment or were rated to be severe.

## Risk of Bias Assessment

The risk of bias of nonrandomized studies assessed with MINORS is given in Table 6A. The only comparative study, Lim et al. (2010), scored 19 which indicates high risk of bias (ideal score = 24). Four noncomparative ones scored 11 or above, and two, Blandón et al. (2016) and Liu et al. (2013), scored 7 points, indicating high risk of bias in all these studies. The risk of bias for only single arm studies using is presented in Figure 7. The risk of bias of RCTs assessed with RoB 1 is given in Figure 8. All studies but Johnstone et al. (2017) had a low risk of bias in majority of the domains.

**Table 5**
*CBCL Scores for Intervention and Control Groups*

| Study ID | Assessor | CBCL type | Time of assessment | Intervention group | | Control group | |
|---|---|---|---|---|---|---|---|
| | | | | Mean (*SD*) | Mean Difference (*SD*) | Mean (*SD*) | Mean Difference (*SD*) |
| Qian et al. (2018) | Parents | Internalizing problems | Baseline | 7.88 (5.08) | | 12.36 (9.65) | |
| | | | At week 8 | 5.38 (4.17) | | 10.54 (7.84) | |
| Lim et al. (2019) | Parent | Internalizing problems | Baseline | 61.2 (10.1) | | 60.9 (10.59) | |
| | | | At week 8 | N/A | Baseline/week 8 = 4.0 (4.80) | | Baseline/week 8 = 1.8 (4.21) |
| | | | At week 20 | N/A | Baseline/week 20 = 4.1 (5.59) | | |
| | | | At week 24 | N/A | Baseline/week 24 = 5.3 (6.17) | | |
| | | Externalizing problems | Baseline | 62.5 (9.45) | | 64.6 (9.19) | |
| | | | At week 8 | N/A | Baseline/week 8 = 3.3 (6.54) | | Baseline/week 8 = 2.5 (6.51) |
| | | | At week 20 | N/A | Baseline/week 20 = 3.7 (8.20) | | |
| | | | At week 24 | N/A | Baseline/week 24 = 4.7 (8.70) | | |
| Lim et al. (2023) [The intervention is clinic and the control is home] | Parent | Attention problems | Baseline | 67.3 (10.0) | | 75.8 (12.9) | |
| | | | At week 8 | N/A | Baseline/ week 8 = −3.70 (8.11) | N/A | Baseline/week 8 = −5.00 (7.82) |
| | | Internalizing problems | Baseline | 54.3 (10.9) | | 62.0 (7.56) | |
| | | | At week 8 | N/A | Baseline/ week 8 = −3.10 (7.88) | N/A | Baseline/week 8 = −1.5 (7.09) |
| | | Externalizing problems | Baseline | 57.6 (12.1) | | 60.1 (10.10) | |
| | | | At week 8 | N/A | Baseline/ week 8 = −3.60 (6.22) | N/A | Baseline/week 8 = −2.70 (5.79) |
| | | Total problems | Baseline | 60.7 (9.42) | | 66.1 (6.44) | |
| | | | At week 8 | N/A | Baseline/ week 8 = −3.8 (4.19) | N/A | Baseline/week 8 = −3.00 (5.06) |
| | | ADH Problems | Baseline | 64.9 (8.21) | | 67.4 (8.98) | |
| | | | At week 8 | N/A | Baseline/ week 8 = −2.30 (5.46) | N/A | Baseline/week 8 = −1.90 (6.21) |

**Figure 7.** *Risk of Bias Assessment of Single Arm Studies by MINOR Scale. (0 = Not Reported, 1 = Reported but Inadequate, 2 = Adequately Reported).*

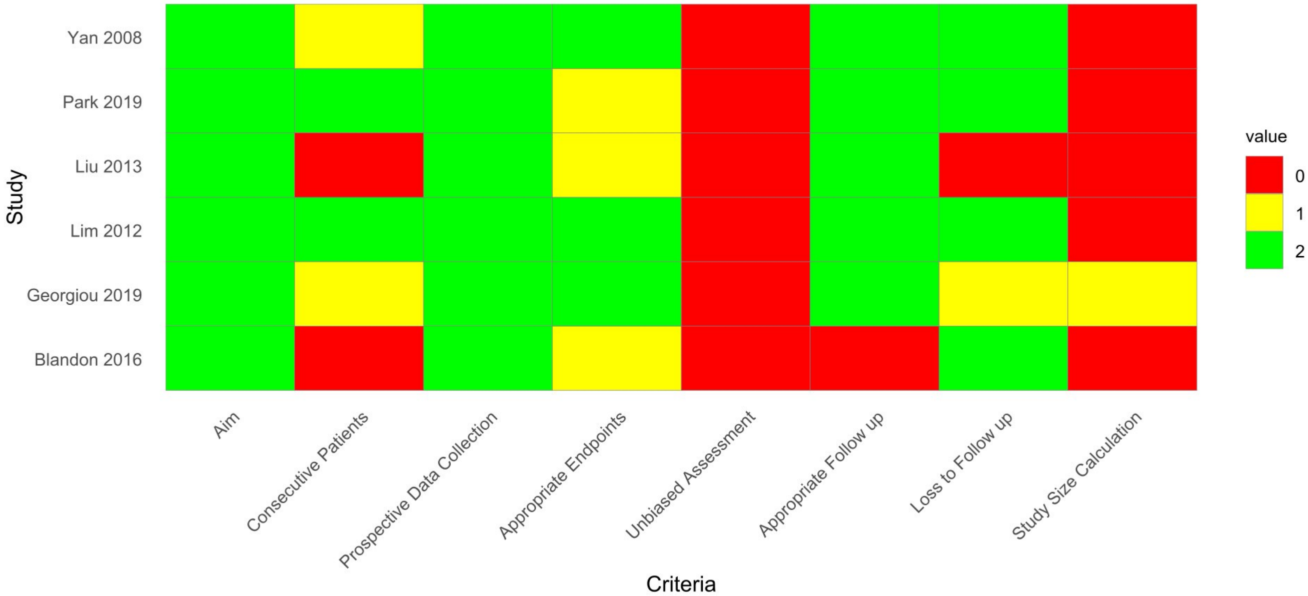
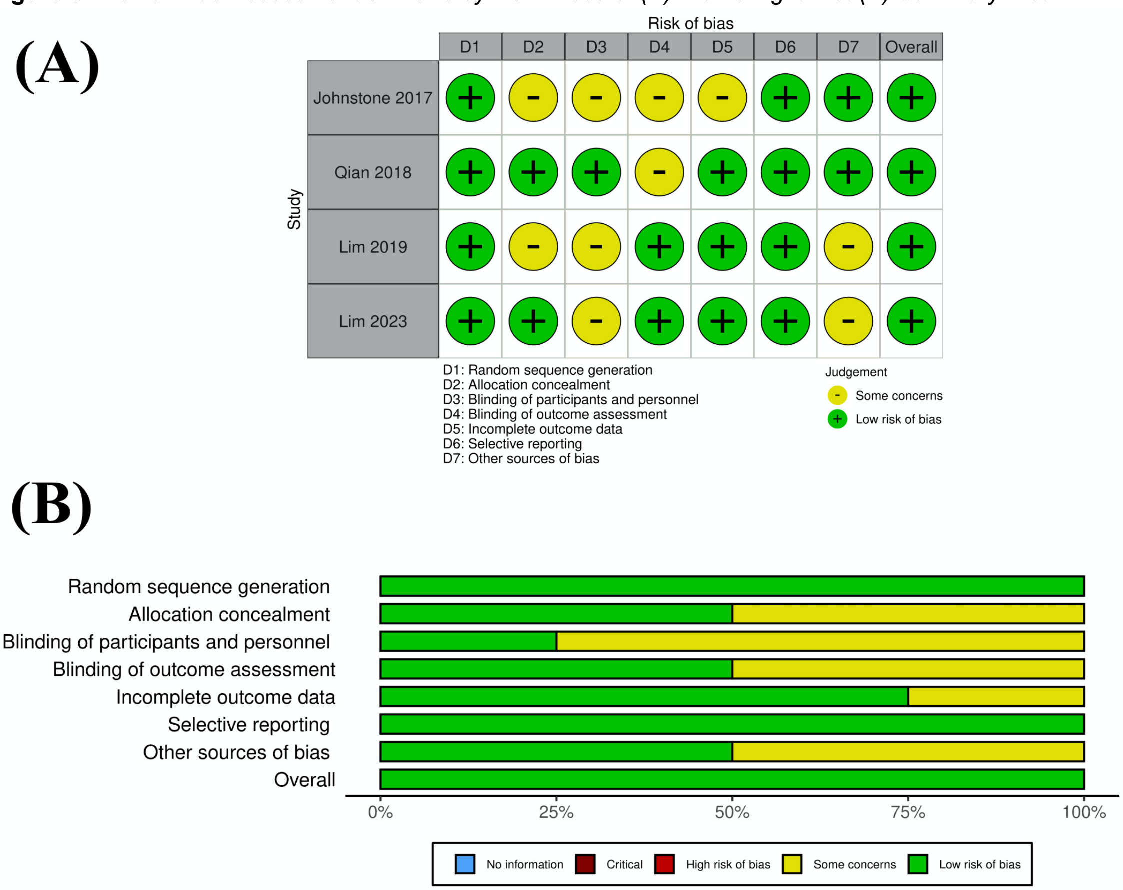



**Figure 8.** *Risk of Bias Assessment of RCTs by RoB 1 Scale. (A) Traffic Light Plot (B) Summary Plot.*



## Discussion

The idea behind developing games for attention training in children with ADHD is to enhance their engagement with the treatment program (Strahler Rivero et al., 2015). These games also provide real-time feedback, helping children adapt more effectively (Strahler Rivero et al., 2015). Although only a few games have been tested on children with ADHD, six major game designs for attention training have been highlighted in this review. The most well-studied game is *CogoLand*, developed by a research team in Singapore. This game operates on the active BCI principle, using an EEG device to record brain waves (4–36 Hz) and employing waves associated with attentive states (beta 1 and beta 2) to control gameplay (Lim et al., 2012, 2019). In *CogoLand*, an avatar's movement speed on an island is proportional to the user's attention level (high frequency beta waves). Other games, such as *Harvest Challenge*, *Focus Pocus*, and *FocusLocus*, developed by research teams in Colombia, Australia, and Greece, respectively, also use active BCI techniques to control gameplay and provide feedback to the user (Blandón et al., 2016; Georgiou et al., 2019; Johnstone et al., 2017; Teo et al., 2021). In contrast, an immersive fairy tale game developed by a research team in Korea employs the passive BCI technique (Park et al., 2019). This game modifies itself based on unintentional changes in the user's brainwave activity, such as decreased attention levels, and adjusts the game in a way that subconsciously increases these levels (Park et al., 2019). While current data is insufficient to establish a definitive comparison between active and passive BCI-based games, theoretical frameworks suggest that active BCI games require continuous interaction and engagement from the user, making them potentially better for actively training and improving attention control. On the other hand, passive BCI games require less problem solving and interaction from the user, so they might be more suitable for users with moderate attention deficits requiring less demanding tasks for attention training. Also, this technique might be more appropriate for younger children (e.g., ages 1 to 5), as they can engage without the frustration of complex tasks while still promoting cognitive development through a supportive and nonintrusive approach. Future studies using passive BCI games should consider this point.

The included studies have reported the effects of these gaming systems on various outcomes in children with ADHD. For this review, changes in ADHD-RS scores were used as the primary criteria to assess symptomatic reduction in ADHD patients (DuPaul et al., 1998). A change-from-baseline analysis of studies using *CogoLand* revealed significant reductions in ADHD-RS IA and HI scores after 8–24 weeks of BCI training. Specifically, significant differences were observed between the intervention and control groups in their respective changes from baseline for IA scores. The games primarily target inattention symptoms, as individuals need to increase their attention levels to play. This explains the reduction in IA scores. Since this training induces neuroplastic changes in the brain, the strengthened neuronal networks also reduce HI symptoms as observed in these studies. The included studies whose data was pooled in the meta-analysis were conducted in similar settings using similar equipment and population (which may lower the generalizability of the results), and there was little heterogeneity. That is why sensitivity analysis and assessment of publication bias were deemed unnecessary.

One study by Johnstone et al. (2017), which used the *Focus Pocus* game, also reported lower postintervention ADHD-RS scores in the intervention group compared to the waitlist control group. Significantly decreased scores at timepoint 2 (7–9 weeks postintervention) indicate the efficacy of this device as well. Blandón et al. (2016) also reported increased attention levels in subsequent training sessions, measured by a built-in algorithm. All this data is promising enough to justify including these gaming systems in large prospective trials to determine their efficacy in symptom reduction more effectively.

Several studies have employed continuous performance tests (CPTs) to evaluate a subject's ability to respond to target stimuli while ignoring distractor stimuli through the execution of routine, automated tasks (Homack & Riccio, 2006). A modified version of this test, known as the IVA-CPT, presents stimuli on a computer screen: subjects must click the mouse in response to the target stimulus, a "1," and refrain from clicking in response to the distractor stimulus, a "2" (Sherman et al., 2023, p. 289). The two studies included in this review that performed this test to assess the effectiveness of BCI-based therapy demonstrated significant improvements in both the overall scores and the audio and visual components of the RCQ and AQ, the two primary quotient scores derived from this test (Liu et al., 2013; Yan et al., 2008). These findings suggest that BCI-based therapy enhances self-regulation by improving control over impulsivity and increasing consistency and endurance, as indicated by the improved RCQ scores. Additionally, the enhancement in AQ scores reflects the subjects' increased ability to concentrate more effectively and sustain attention for longer periods after BCI-based therapy.

Other outcomes of efficacy included changes in the CGAS and CGI-S scores (Berk et al., 2008; Shaffer, 1983). The largest RCT utilizing BCI for ADHD, conducted by Lim et al. (2019), measured these scales and found significant differences from baseline at weeks 20 and 24, but not at the primary timepoint, week 8. This is likely because these scales are broader and assess improvements in general functioning, social interactions, and academic performance, which typically take more time to manifest. These improvements involve multiple areas of the child's life and require sustained changes in behavior and skills. However, the assessment of these scales is somewhat subjective as compared to the more objective ADHD-RS scale.

Learning disability (LD) is found in approximately 27 to 31 percent of students with ADHD (DuPaul & Volpe, 2009). The most common type of LD in children with ADHD is a reading disability, characterized by impaired phonological processing and comprehension problems (Purvis & Tannock, 2000). To assess the impact of BCI-based attention training on LD, Park et al. (2019) used an immersive fairy tale game. In this game, the dialogues of characters are written on the screen (with no audio), requiring the user to read them and make decisions. The results showed a significant improvement from baseline in reciting and reading comprehension of short passages, as determined by a standardized test on reading and comprehension (KINESE-BAAT). However, the study had a small sample size ($n$ = 5) and included only three BCI sessions, so the findings may not be generalizable.

Improving a child's behavior is a key objective in ADHD management. Common behavioral symptoms in ADHD include noncompliance, lack of independence in completing daily chores, disorganization, aggression, and defiance toward parents (Pfiffner & Haack, 2014). To assess these behavioral symptoms, the included studies used CBCL (Nøvik, 1999). Internalizing problems are particularly important in the context of ADHD, as these comorbidities can significantly impact behavioral improvements in these children (Al-Yagon et al., 2020). Studies have reported a lower CBCL score postintervention, indicating a significant impact of BCI-based attention systems on behavioral enhancement. Specifically, studies by Qian et al. (2018), Lim et al. (2019), and Lim et al. (2023), all reported reductions in internalizing problems following BCI-based attention training compared to baseline. Given that the CBCL is a broad-scale assessment, the reported improvements after BCI-based training warrant further exploration to better understand the scope and mechanisms of these behavioral changes.

Brain EEG patterns are known to be altered in ADHD patients. In the study by Georgiou et al. (2019), the theta-beta ratio (TBR) was calculated before and after intervention. The findings indicated a decrease in TBRs following attention training, suggesting that the brain patterns were shifting more towards an attention state. This reduction in the TBR implies an improvement in attention-related brain activity, aligning with the goal of the training to enhance attentional control (Georgiou et al., 2019). Further evidence of brain function modulation is provided by Qian et al. (2018), who used neuroimaging with fMRI to study the effects of BCI-based attention training in children. The aim of the training was to decrease intranetwork connectivity while increasing internetwork connectivity to enhance global brain efficiency and reduce local efficiency. By increasing connectivity within the salience/ventral attention network (SVN) and between the SVN and other critical networks, the training appears to enhance the coordination between attention systems, which is crucial for managing ADHD symptoms. The reduction in connectivity between the SVN and subcortical networks suggests a potential normalization of brain function, addressing known deficits in dopaminergic signaling associated with ADHD (Cubillo et al., 2012; Li et al., 2014).

Small worldness is the property of brain network that describes a state with high clustering of neurons and shorter path lengths between two nodes (Bassett & Bullmore, 2017). Small world networks are associated with high attention states (Qi et al., 2021; Xu et al., 2015). In the study, Qian et al. (2018), the small-worldness measure showed a significant change over time ($P$ = .045), indicating a difference in the brain network structure between the initial and final measurements. Furthermore, after the BCI-based training, the small-worldness of the intervention group remained relatively stable, while the small-worldness of the control group decreased significantly. This could imply that the BCI-based training helped maintain or preserve the brain's network structure in the intervention group.

Although BCI-based therapy appears promising, it's important to recognize that responses to the training are highly individualized, with some children benefiting more than others. All studies reviewed provided a structured training environment, raising the possibility that positive responses might be due to the structured setting rather than the BCI system itself. For example, Lim et al. (2019) noted that even the untreated control group showed reduced inattentive symptoms, a phenomenon referred to as the "halo effect." The single arm meta-analysis done for this review could not account for this effect as only pre- and postinterventional scores were compared and there was no control for comparison. These limitations, along with the overall high risk of bias of included studies, cast doubt on the generalizability of current findings. Future research should aim to more accurately evaluate the effectiveness of BCI-based therapy and develop models that integrate both inattention and learning disabilities into a single interface. More controlled trials that either compare this therapy to placebo or other therapies used for ADHD are also needed. Additionally, employing both active and passive BCI techniques could enhance training and maintain effectiveness.

## Conclusion

Interventions involving BCI-based games help control the inattentive and hyperactive-impulsive symptoms of ADHD. They are also associated with behavior improvement, especially in regard to internalizing problems. Some evidence also suggests a beneficial role in managing learning disability, especially reading problems, in ADHD patients. Although these results are promising, future research should focus on simultaneously addressing inattention and learning disability in games in order to develop a more holistic BCI-based intervention for ADHD.

### Author Disclosure

This review did not receive any funding or other financial support. The authors declare that they have no financial interest in any company or its competitors that develops or markets the games discussed in this review. The authors declare that they have no financial or personal interests that could be perceived as a conflict of interest in connection with this research.

## References

Abarbanel, A. (1999). The neural underpinnings of neurofeedback training. In J. R. Evans & A. Abarbanel (Eds.), *Introduction to quantitative EEG and neurofeedback* (pp. 311–340). Academic Press. https://doi.org/10.1016/B978-012243790-8/50013-4

Adamou, M., Fullen, T., & Jones, S. L. (2020). EEG for diagnosis of adult ADHD: A systematic review with narrative analysis. *Frontiers in Psychiatry, 11*, Article 871. https://doi.org/10.3389/fpsyt.2020.00871

Al-Yagon, M., Forte, D., & Avrahami, L. (2020). Executive functions and attachment relationships in children with ADHD: Links to externalizing/internalizing problems, social skills, and negative mood regulation. *Journal of Attention Disorders, 24*(13), 1876–1890. https://doi.org/10.1177/1087054717730608

Arns, M., De Ridder, S., Strehl, U., Breteler, M., & Coenen, A. (2009). Efficacy of neurofeedback treatment in ADHD: The effects on inattention, impulsivity and hyperactivity: A meta-analysis. *Clinical EEG and Neuroscience, 40*(3), 180–189. https://doi.org/10.1177/155005940904000311

Ayano, G., Yohannes, K., & Abraha, M. (2020). Epidemiology of attention-deficit/hyperactivity disorder (ADHD) in children and adolescents in Africa: A systematic review and meta-analysis. *Annals of General Psychiatry, 19*(1), Article 21. https://doi.org/10.1186/s12991-020-00271-w

Bassett, D. S., & Bullmore, E. T. (2017). Small-world brain networks revisited. *The Neuroscientist, 23*(5), 499–516. https://doi.org/10.1177/1073858416667720

Berk, M., Ng, F., Dodd, S., Callaly, T., Campbell, S., Bernardo, M., & Trauer, T. (2008). The validity of the CGI severity and improvement scales as measures of clinical effectiveness suitable for routine clinical use. *Journal of Evaluation in Clinical Practice, 14*(6), 979–983. https://doi.org/10.1111/j.1365-2753.2007.00921.x

Blandón, D. Z., Muñoz, J. E., Lopez, D. S., & Gallo, O. H. (2016). Influence of a BCI neurofeedback videogame in children with ADHD. Quantifying the brain activity through an EEG signal processing dedicated toolbox. *2016 IEEE 11th Colombian Computing Conference (CCC)*, 1–8. https://doi.org/10.1109/ColumbianCC.2016.7750788

Bronte-Stewart, H. M., Petrucci, M. N., O'Day, J. J., Afzal, M. F., Parker, J. E., Kehnemouyi, Y. M., Wilkins, K. B., Orthlieb, G. C., & Hoffman, S. L. (2020). Perspective: Evolution of control variables and policies for closed-loop deep brain stimulation for Parkinson's disease using bidirectional deep-brain-computer interfaces. *Frontiers in Human Neuroscience, 14*, Article 353. https://doi.org/10.3389/fnhum.2020.00353

Carlson, C. L., Shin, M., & Booth, J. (1999). The case for DSM-IV subtypes in ADHD. *Mental Retardation and Developmental Disabilities Research Reviews, 5*(3), 199–206. https://doi.org/10.1002/(SICI)1098-2779(1999)5:3<199::AID-MRDD6>3.0.CO;2-#

Castellanos, F. X., & Proal, E. (2012). Large-scale brain systems in ADHD: Beyond the prefrontal-striatal model. *Trends in Cognitive Sciences, 16*(1), 17–26. https://doi.org/10.1016/j.tics.2011.11.007

Cervantes, J.-A., López, S., Cervantes, S., Hernández, A., & Duarte, H. (2023). Social robots and brain–computer interface video games for dealing with attention deficit hyperactivity disorder: A systematic review. *Brain Sciences, 13*(8), Article 8. https://doi.org/10.3390/brainsci13081172

Cubillo, A., Halari, R., Smith, A., Taylor, E., & Rubia, K. (2012). A review of fronto-striatal and fronto-cortical brain abnormalities in children and adults with attention deficit hyperactivity disorder (ADHD) and new evidence for dysfunction in adults with ADHD during motivation and attention. *Cortex, 48*(2), 194–215. https://doi.org/10.1016/j.cortex.2011.04.007

DuPaul, G. J., Power, T. J., Anastopoulos, A. D., & Reid, R. (1998). *ADHD Rating Scale—IV: Checklists, norms, and clinical interpretation* (pp. viii, 79). The Guilford Press.

DuPaul, G. J., & Volpe, R. J. (2009). ADHD and learning disabilities: Research findings and clinical implications.

*Current Attention Disorders Reports, 1*(4), 152–155. https://doi.org/10.1007/s12618-009-0021-4

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*(6), Article 46. https://doi.org/10.1007/s11920-019-1021-4

Georgiou, E., Thanos, K.-G., Kanellos, T., Doulgerakis, A., & Thomopoulos, S. (2019). Evaluating the relation between the EEG brainwaves and attention measures, and the children's performance in REEFOCUS game designed for ADHD symptoms improvement. In B. M. Cullum, D. Kiehl, & E. S. McLamore (Eds.), *Smart Biomedical and Physiological Sensor Technology XVI*, Proceedings Volume 11020. PIE Defense + Commercial Sensing. Baltimore, MD, USA. https://doi.org/10.1117/12.2518901

Gummadavelli, A., Zaveri, H. P., Spencer, D. D., & Gerrard, J. L. (2018). Expanding brain–computer interfaces for controlling epilepsy networks: Novel thalamic responsive neurostimulation in refractory epilepsy. *Frontiers in Neuroscience, 12*, Article 474. https://doi.org/10.3389/fnins.2018.00474

Higgins, J. P. T., Altman, D. G., Gøtzsche, P. C., Jüni, P., Moher, D., Oxman, A. D., Savović, J., Schulz, K. F., Weeks, L., & Sterne, J. A. C. (2011). The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ, 343*, Article d5928. https://doi.org/10.1136/bmj.d5928

Homack, S., & Riccio, C. A. (2006). Conners' Continuous Performance Test (2nd ed.; CCPT-II). *Journal of Attention Disorders, 9*(3), 556–558. https://doi.org/10.1177/1087054705283578

Jensen, C. M., Amdisen, B. L., Jørgensen, K. J., & Arnfred, S. M. H. (2016). Cognitive behavioural therapy for ADHD in adults: Systematic review and meta-analyses. *ADHD Attention Deficit and Hyperactivity Disorders, 8*(1), 3–11. https://doi.org/10.1007/s12402-016-0188-3

Johnstone, S. J., Roodenrys, S. J., Johnson, K., Bonfield, R., & Bennett, S. J. (2017). Game-based combined cognitive and neurofeedback training using focus pocus reduces symptom severity in children with diagnosed AD/HD and subclinical AD/HD. *International Journal of Psychophysiology, 116*, 32–44. https://doi.org/10.1016/j.ijpsycho.2017.02.015

Konrad, K., & Eickhoff, S. B. (2010). Is the ADHD brain wired differently? A review on structural and functional connectivity in attention deficit hyperactivity disorder. *Human Brain Mapping, 31*(6), 904–916. https://doi.org/10.1002/hbm.21058

Kovacevic, N., Ritter, P., Tays, W., Moreno, S., & McIntosh, A. R. (2015). 'My Virtual Dream': Collective neurofeedback in an immersive art environment. *PLoS ONE, 10*(7), Article e0130129. https://doi.org/10.1371/journal.pone.0130129

Li, F., He, N., Li, Y., Chen, L., Huang, X., Lui, S., Guo, L., Kemp, G. J., & Gong, Q. (2014). Intrinsic brain abnormalities in attention deficit hyperactivity disorder: A resting-state functional MR imaging study. *Radiology, 272*(2), 514–523. https://doi.org/10.1148/radiol.14131622

Lim, C. G., Lee, T. S., Guan, C., Fung, D. S. S., Zhao, Y., Teng, S. S. W., Zhang, H., & Krishnan, K. R. R. (2012). A brain-computer interface based attention training program for treating attention deficit hyperactivity disorder. *PLoS ONE, 7*(10), Article e46692. https://doi.org/10.1371/journal.pone.0046692

Lim, C. G., Lee, T.-S., Guan, C., Sheng Fung, D. S., Cheung, Y. B., Teng, S. S. W., Zhang, H., & Krishnan, K. R. (2010). Effectiveness of a brain-computer interface based programme for the treatment of ADHD: A pilot study. *Psychopharmacology Bulletin, 43*(1), 73–82.

Lim, C. G., Poh, X. W. W., Fung, S. S. D., Guan, C., Bautista, D., Cheung, Y. B., Zhang, H., Yeo, S. N., Krishnan, R., & Lee, T. S. (2019). A randomized controlled trial of a brain-computer interface based attention training program for ADHD. *PLoS ONE, 14*(5), Article e0216225. https://doi.org/10.1371/journal.pone.0216225

Lim, C. G., Soh, C. P., Lim, S. S. Y., Fung, D. S. S., Guan, C., & Lee, T.-S. (2023). Home-based brain–computer interface attention training program for attention deficit hyperactivity disorder: A feasibility trial. *Child and Adolescent Psychiatry and Mental Health, 17*(1), Article 15. https://doi.org/10.1186/s13034-022-00539-x

Liu, T., Wang, J., Chen, Y., Wang, R., & Song, M. (2013). Neurofeedback treatment experimental study for ADHD by using the brain-computer interface neurofeedback system. In M. Long (Ed.), *World congress on medical physics and biomedical engineering May 26–31, 2012, Beijing, China* (pp. 1537–1540). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-29305-4_404

Marzbani, H., Marateb, H. R., & Mansourian, M. (2016). Neurofeedback: A comprehensive review on system design, methodology and clinical applications. *Basic and Clinical Neuroscience, 7*(2), 143–158. https://doi.org/10.15412/J.BCN.03070208

Mridha, M. F., Das, S. C., Kabir, M. M., Lima, A. A., Islam, Md. R., & Watanobe, Y. (2021). Brain-computer interface: Advancement and challenges. *Sensors, 21*(17), Article 5746. https://doi.org/10.3390/s21175746

Nøvik, T. S. (1999). Validity of the child behaviour checklist in a Norwegian sample. *European Child & Adolescent Psychiatry, 8*(4), 247–254. https://doi.org/10.1007/s007870050098

Park, K., Kihl, T., Park, S., Kim, M.-J., & Chang, J. (2019). Fairy tale directed game-based training system for children with ADHD using BCI and motion sensing technologies. *Behaviour & Information Technology, 38*(6), 564–577. https://doi.org/10.1080/0144929X.2018.1544276

Peñuelas-Calvo, I., Jiang-Lin, L. K., Girela-Serrano, B., Delgado-Gomez, D., Navarro-Jimenez, R., Baca-Garcia, E., & Porras-Segovia, A. (2022). Video games for the assessment and treatment of attention-deficit/hyperactivity disorder: A systematic review. *European Child & Adolescent Psychiatry, 31*(1), 5–20. https://doi.org/10.1007/s00787-020-01557-w

Pfiffner, L. J., & Haack, L. M. (2014). Behavior management for school-aged children with ADHD. *Child and Adolescent Psychiatric Clinics of North America, 23*(4), 731–746. https://doi.org/10.1016/j.chc.2014.05.014

Piña, R., Rozas, C., Contreras, D., Hardy, P., Ugarte, G., Zeise, M. L., Rojas, P., & Morales, B. (2020). Atomoxetine reestablishes long term potentiation in a mouse model of attention deficit/hyperactivity disorder. *Neuroscience, 439*, 268–274. https://doi.org/10.1016/j.neuroscience.2019.10.040

Purvis, K. L., & Tannock, R. (2000). Phonological processing, not inhibitory control, differentiates ADHD and reading disability. *Journal of the American Academy of Child & Adolescent Psychiatry, 39*(4), 485–494. https://doi.org/10.1097/00004583-200004000-00018

Qi, J., Li, B.-Z., Zhang, Y., Pan, B., Gao, Y.-H., Zhan, H., Liu, Y., Shao, Y.-C., Weng, X.-C., & Zhang, X. (2021). Disrupted small-world networks are associated with decreased vigilant attention after total sleep deprivation. *Neuroscience, 471*, 51–60. https://doi.org/10.1016/j.neuroscience.2021.07.010

Qian, X., Loo, B. R. Y., Castellanos, F. X., Liu, S., Koh, H. L., Poh, X. W. W., Krishnan, R., Fung, D., Chee, M. W., Guan, C., Lee, T.-S., Lim, C. G., & Zhou, J. (2018). Brain-computer-interface-based intervention re-normalizes brain functional network topology in children with attention deficit/hyperactivity disorder. *Translational Psychiatry, 8*(1), Article 149. https://doi.org/10.1038/s41398-018-0213-8

Raza, M. Z., Omais, M., Arshad, H. M. E., Maqsood, Musab, & Nadeem, A. A. (2024). *Effectiveness of brain computer interface (BCI) based attention training game system for symptom reduction, behavioral enhancement, and brain function modulation in children with attention deficit* *hyperactivity disorder (ADHD): A systematic review*. OSF Registries. https://doi.org/10.17605/OSF.IO/85HPT

Rozas, C., Carvallo, C., Contreras, D., Carreño, M., Ugarte, G., Delgado, R., Zeise, M. L., & Morales, B. (2015). Methylphenidate amplifies long-term potentiation in rat hippocampus CA1 area involving the insertion of AMPA receptors by activation of β-adrenergic and D1/D5 receptors. *Neuropharmacology, 99*, 15–27. https://doi.org/10.1016/j.neuropharm.2015.07.003

Sebastián-Romagosa, M., Cho, W., Ortner, R., Sieghartsleitner, S., Von Oertzen, T. J., Kamada, K., Laureys, S., Allison, B. Z., & Guger, C. (2023). Brain–computer interface treatment for gait rehabilitation in stroke patients. *Frontiers in Neuroscience, 17*, Article 1256077. https://doi.org/10.3389/fnins.2023.1256077

Shaffer, D. (1983). A Children's Global Assessment Scale (CGAS). *Archives of General Psychiatry, 40*(11), Article 1228. https://doi.org/10.1001/archpsyc.1983.01790100074010

Sherman, E., Tan, J., & Hrabok, M. (2023). *A compendium of neuropsychological tests: Fundamentals of neuropsychological assessment and test reviews for clinical practice*. Oxford University Press.

Sidlauskaite, J., Sonuga-Barke, E., Roeyers, H., & Wiersema, J. R. (2016). Altered intrinsic organisation of brain networks implicated in attentional processes in adult attention-deficit/hyperactivity disorder: A resting-state study of attention, default mode and salience network connectivity. *European Archives of Psychiatry and Clinical Neuroscience, 266*(4), 349–357. https://doi.org/10.1007/s00406-015-0630-0

Slim, K., Nini, E., Forestier, D., Kwiatkowski, F., Panis, Y., & Chipponi, J. (2003). Methodological index for non-randomized studies (*MINORS*): Development and validation of a new instrument. *ANZ Journal of Surgery, 73*(9), 712–716. https://doi.org/10.1046/j.1445-2197.2003.02748.x

Sporns, O. (2011). The non-random brain: Efficiency, economy, and complex dynamics. *Frontiers in Computational Neuroscience, 5*, Article 5. https://doi.org/10.3389/fncom.2011.00005

Strahler Rivero, T., Herrera Nuñez, L. M., Uehara Pires, E., & Amodeo Bueno, O. F. (2015). ADHD rehabilitation through video gaming: A systematic review using PRISMA guidelines of the current findings and the associated risk of bias. *Frontiers in Psychiatry, 6*, Article 151. https://doi.org/10.3389/fpsyt.2015.00151

Sun, M. (2022). Study on antidepressant emotion regulation based on feedback analysis of music therapy with brain-computer interface. *Computational and Mathematical Methods in Medicine, 2022*(1), Article 7200678. https://doi.org/10.1155/2022/7200678

Teo, S.-H. J., Poh, X. W. W., Lee, T. S., Guan, C., Cheung, Y. B., Fung, D. S. S., Zhang, H. H., Chin, Z. Y., Wang, C. C., Sung, M., Goh, T. J., Weng, S. J., Tng, X. J. J., & Lim, C. G. (2021). Brain-computer interface based attention and social cognition training programme for children with ASD and co-occurring ADHD: A feasibility trial. *Research in Autism Spectrum Disorders, 89*, Article 101882. https://doi.org/10.1016/j.rasd.2021.101882

Tinius, T. P. (2003). The intermediate visual and auditory continuous performance test as a neuropsychological measure. *Archives of Clinical Neuropsychology, 12*(2), 199–214.

Trojan, S., & Pokorný, J. (1999). Theoretical aspects of neuroplasticity. *Physiological Research, 48*(2), 87–97.

Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of 'small-world' networks. *Nature, 393*(6684), 440–442. https://doi.org/10.1038/30918

Xu, J., Yin, X., Ge, H., Han, Y., Pang, Z., Tang, Y., Liu, B., & Liu, S. (2015). Attentional performance is correlated with the local regional efficiency of intrinsic brain networks. *Frontiers in Behavioral Neuroscience, 9*, Article 200. https://doi.org/10.3389/fnbeh.2015.00200

Yan, N., Wang, J., Liu, M., Zong, L., Jiao, Y., Yue, J., Lv, Y., Yang, Q., Lan, H., & Liu, Z. (2008). Designing a brain-computer interface device for neurofeedback using virtual environments. *Journal of Medical and Biological Engineering, 28*(3), 167–172.

Zander, T. O., Kothe, C., Jatzev, S., & Gaertner, M. (2010). Enhancing human-computer interaction with input from active and passive brain-computer interfaces. In D. S. Tan & A. Nijholt (Eds.), *Brain-computer interfaces: Applying our minds to human-computer interaction* (pp. 181–199). Springer. https://doi.org/10.1007/978-1-84996-272-8_11

**Received:** August 24, 2024
**Accepted:** October 14, 2024
**Published:** March 24, 2025

## Appendix A

**Table 1A**
*Search Strategy of All Sources. (No Specific Search Strategy Was Used for ScienceDirect.)*

| Source | Search Strategy |
|---|---|
| PubMed | (“Attention Deficit Disorder with Hyperactivity”[Mesh] OR ADHD OR ADDH OR “Attention Deficit Disorders with Hyperactivity” OR “Attention Deficit Hyperactivity Disorders” OR “Attention Deficit Hyperactivity Disorder” OR “Attention Deficit-Hyperactivity Disorder” OR “Attention Deficit-Hyperactivity Disorders” OR “Deficit-Hyperactivity Disorder, Attention” OR “Deficit-Hyperactivity Disorders, Attention” OR “Disorder, Attention Deficit-Hyperactivity” OR “Disorders, Attention Deficit-Hyperactivity” OR “Hyperkinetic Syndrome” OR “Syndromes, Hyperkinetic” OR “Attention Deficit Disorder” OR “Attention Deficit Disorders” OR “Deficit Disorder, Attention” OR “Deficit Disorders, Attention” OR “Disorder, Attention Deficit” OR “Disorders, Attention Deficit” OR “Brain Dysfunction, Minimal” OR “Dysfunction, Minimal Brain” OR “Minimal Brain Dysfunction”) AND (“Brain-Computer Interfaces”[Mesh] OR “Brain Computer Interfaces” OR “Interface, Brain-Computer” OR “Interfaces, Brain-Computer” OR “Brain-Computer Interface” OR “Brain Computer Interface” OR “Brain-Machine Interfaces” OR “Brain-Machine Interface” OR “Interface, Brain-Machine” OR “Interfaces, Brain-Machine” OR “Brain Machine Interface” OR “Brain Machine Interfaces” OR “Interface, Brain Machine” OR “Interfaces, Brain Machine” OR “Machine Interface, Brain” OR “Machine Interfaces, Brain” OR “attention training system” OR “attention training facility”) |
| Cochrane CENTRAL | (“Attention Deficit Disorder with Hyperactivity” OR ADHD OR ADDH OR “Attention Deficit Disorders with Hyperactivity” OR “Attention Deficit Hyperactivity Disorders” OR “Attention Deficit Hyperactivity Disorder” OR “Attention Deficit-Hyperactivity Disorder” OR “Attention Deficit-Hyperactivity Disorders” OR “Deficit-Hyperactivity Disorder, Attention” OR “Deficit-Hyperactivity Disorders, Attention” OR “Disorder, Attention Deficit-Hyperactivity” OR “Disorders, Attention Deficit-Hyperactivity” OR “Hyperkinetic Syndrome” OR “Syndromes, Hyperkinetic” OR “Attention Deficit Disorder” OR “Attention Deficit Disorders” OR “Deficit Disorder, Attention” OR “Deficit Disorders, Attention” OR “Disorder, Attention Deficit” OR “Disorders, Attention Deficit” OR “Brain Dysfunction, Minimal” OR “Dysfunction, Minimal Brain” OR “Minimal Brain Dysfunction”) AND (“Brain-Computer Interfaces” OR “Brain Computer Interfaces” OR “Interface, Brain-Computer” OR “Interfaces, Brain-Computer” OR “Brain-Computer Interface” OR “Brain Computer Interface” OR “Brain-Machine Interfaces” OR “Brain-Machine Interface” OR “Interface, Brain-Machine” OR “Interfaces, Brain-Machine” OR “Brain Machine Interface” OR “Brain Machine Interfaces” OR “Interface, Brain Machine” OR “Interfaces, Brain Machine” OR “Machine Interface, Brain” OR “Machine Interfaces, Brain” OR “attention training system” OR “attention training facility”) |
| IEEE Xplore | (“Attention Deficit Disorder with Hyperactivity” OR ADHD OR ADDH OR “Attention Deficit Disorders with Hyperactivity” OR “Attention Deficit Hyperactivity Disorders” OR “Attention Deficit Hyperactivity Disorder” OR “Attention Deficit-Hyperactivity Disorder” OR “Attention Deficit-Hyperactivity Disorders” OR “Deficit-Hyperactivity Disorder, Attention” OR “Deficit-Hyperactivity Disorders, Attention” OR “Disorder, Attention Deficit-Hyperactivity” OR “Disorders, Attention Deficit-Hyperactivity” OR “Hyperkinetic Syndrome” OR “Syndromes, Hyperkinetic” OR “Attention Deficit Disorder” OR “Attention Deficit Disorders” OR “Deficit Disorder, Attention” OR “Deficit Disorders, Attention” OR “Disorder, Attention Deficit” OR “Disorders, Attention Deficit” OR “Brain Dysfunction, Minimal” OR “Dysfunction, Minimal Brain” OR “Minimal Brain Dysfunction”) AND (“Brain-Computer Interfaces” OR “Brain Computer Interfaces” OR “Interface, Brain-Computer” OR “Interfaces, Brain-Computer” OR “Brain-Computer Interface” OR “Brain Computer Interface” OR “Brain-Machine Interfaces” OR “Brain-Machine Interface” OR “Interface, Brain-Machine” OR “Interfaces, Brain-Machine” OR “Brain Machine Interface” OR “Brain Machine Interfaces” OR “Interface, Brain Machine” OR “Interfaces, Brain Machine” OR “Machine Interface, Brain” OR “Machine Interfaces, Brain” OR “attention training system” OR “attention training facility”) |

**Table 1A**

*Search Strategy of All Sources. (No Specific Search Strategy Was Used for ScienceDirect.)*

| Source | Search Strategy |
|---|---|
| ClinicalTrials.gov | Condition or Disease: “Attention Deficit Disorder with Hyperactivity” OR ADHD OR ADDH OR “Attention Deficit Disorders with Hyperactivity” OR “Attention Deficit Hyperactivity Disorders” OR “Attention Deficit Hyperactivity Disorder” OR “Attention Deficit-Hyperactivity Disorder” OR “Attention Deficit-Hyperactivity Disorders” OR “Deficit-Hyperactivity Disorder, Attention” OR “Deficit-Hyperactivity Disorders, Attention” OR “Disorder, Attention Deficit-Hyperactivity” OR “Disorders, Attention Deficit-Hyperactivity” OR “Hyperkinetic Syndrome” OR “Syndromes, Hyperkinetic” OR “Attention Deficit Disorder” OR “Attention Deficit Disorders” OR “Deficit Disorder, Attention” OR “Deficit Disorders, Attention” OR “Disorder, Attention Deficit” OR “Disorders, Attention Deficit” OR “Brain Dysfunction, Minimal” OR “Dysfunction, Minimal Brain” OR “Minimal Brain Dysfunction”<br>Intervention or Treatment: “Brain-Computer Interfaces” OR “Brain Computer Interfaces” OR “Interface, Brain-Computer” OR “Interfaces, Brain-Computer” OR “Brain-Computer Interface” OR “Brain Computer Interface” OR “Brain-Machine Interfaces” OR “Brain-Machine Interface” OR “Interface, Brain-Machine” OR “Interfaces, Brain-Machine” OR “Brain Machine Interface” OR “Brain Machine Interfaces” OR “Interface, Brain Machine” OR “Interfaces, Brain Machine” OR “Machine Interface, Brain” OR “Machine Interfaces, Brain” OR “attention training system” OR “attention training facility” |
| WHO ICTRP | Condition: “Attention Deficit Disorder with Hyperactivity” OR ADHD OR ADDH OR “Attention Deficit Disorders with Hyperactivity” OR “Attention Deficit Hyperactivity Disorders” OR “Attention Deficit Hyperactivity Disorder” OR “Attention Deficit-Hyperactivity Disorder” OR “Attention Deficit-Hyperactivity Disorders” OR “Deficit-Hyperactivity Disorder, Attention” OR “Deficit-Hyperactivity Disorders, Attention” OR “Disorder, Attention Deficit-Hyperactivity” OR “Disorders, Attention Deficit-Hyperactivity” OR “Hyperkinetic Syndrome” OR “Syndromes, Hyperkinetic” OR “Attention Deficit Disorder” OR “Attention Deficit Disorders” OR “Deficit Disorder, Attention” OR “Deficit Disorders, Attention” OR “Disorder, Attention Deficit” OR “Disorders, Attention Deficit” OR “Brain Dysfunction, Minimal” OR “Dysfunction, Minimal Brain” OR “Minimal Brain Dysfunction”<br><br>Intervention: “Brain-Computer Interfaces” OR “Brain Computer Interfaces” OR “Interface, Brain-Computer” OR “Interfaces, Brain-Computer” OR “Brain-Computer Interface” OR “Brain Computer Interface” OR “Brain-Machine Interfaces” OR “Brain-Machine Interface” OR “Interface, Brain-Machine” OR “Interfaces, Brain-Machine” OR “Brain Machine Interface” OR “Brain Machine Interfaces” OR “Interface, Brain Machine” OR “Interfaces, Brain Machine” OR “Machine Interface, Brain” OR “Machine Interfaces, Brain” OR “attention training system” OR “attention training facility” |

**Table 2A**
*Studies Excluded in Secondary Screening*

| Excluded Study | Reason for exclusion |
|---|---|
| Zhang 2021 | Healthy participants only |
| Gonzales 2022 | One healthy volunteer only |
| Ali 2015 | Healthy participants only |
| Rohani 2014 | Healthy participants only |
| Arpaia 2020 | No gaming system |
| Pires 2011 | Healthy participants only |
| Oliveira-Junior 2020 | No gaming system and healthy participants only |
| Usman 2021 | Healthy participants only |
| Khong 2014 | Healthy participants only |
| Bach-Morrow 2022 | No gaming system |
| Teo 2021 | Participants taking concomitant medication |
| Sagiadinou 2020 | BCI technology developed but not tested on subjects |
| Arvaneh 2019 | Healthy participants only |
| Khan 2021 | Healthy participants only |
| Reddy 2020 | BCI technology developed but not tested on subjects |

**Table 3A**

*Characteristics of the Eleven Included Studies*

| Study ID | Study design | Type of diagnosed ADHD | Eligibility Criteria | Duration of training | Efficacy measures reported |
|---|---|---|---|---|---|
| Blandón et al. (2016) | Single-arm trial | N/A | Children clinically diagnosed with ADHD | Two sessions only | Time spent to complete the task and game-oriented tasks |
| Georgiou et al. (2019) | Single-arm trial | | 1) ADHD diagnosis and no previous treatment: participants should preferably have a new diagnosis according to the DSM IV-TR or DSM-5 during the previous 3 months before joining the study; 2) Additionally, participants should preferably not have taken any type of drug approved for the treatment of ADHD before starting the study; 3) Participants' age range will be between 8 and 15 years old, and will also depend on the age limitations of the AR equipment that will be used for the MMR game; 4) IQ range: participants must have an average IQ range; 5) No other deficits and disorders: participants will show no presence of neurological deficit, neurodevelopmental disorder, and will not have a comorbid diagnosis (e.g., autism spectrum disorder, depression, bipolar disorder) | - | Attention levels, theta-to-beta ratio (TBF) |
| Johnstone et al. (2017) | RCT (intervention-control) | Subclinical, inattentive and hyperactive type | 1) Diagnosed based on DSM-IV criteria or scored in the borderline range on Conners 3-P scale; 2) No known history of epilepsy, periods of unconsciousness or serious head injuries; 3) No known psychological disorder; and 4) Have never displayed lower than expected academic abilities on WAIT-II scale | 6-8 weeks | ADHD-RS scores (modified), CBCL (multiple) |
| Lim et al. (2010) | Control-matched single-arm trial | Inattentive and combined type | 1) No previous pharmacological treatment; 2) No comorbid psychiatric condition/known sensorineural deficit; 3) No history of seizures; 4) No known mental retardation sign (IQ > 70) | 10 weeks | ADHD-RS scores (both IA and HI) |
| Lim et al. (2012) | Single-arm trial | Inattentive and combined type | 1) No previous pharmacological treatment; 2) Could satisfy DSM-IV-TR criteria; 3) No known sensorineural deficit or history of epilepsy; 4) IQ > 70 | 5 months (first 8 weeks one session per week, followed one session per month for 3 months) | ADHD-RS scores (both IA and HI) |

**Table 3A**
*Characteristics of the Eleven Included Studies*

| Study ID | Study design | Type of diagnosed ADHD | Eligibility Criteria | Duration of training | Efficacy measures reported |
|---|---|---|---|---|---|
| Lim et al. (2019) | RCT (intervention-control) | Inattentive and combined type | 1) Diagnosed based on DSM-IV TR criteria; 2) Children previously receiving pharmacotherapy had to undergo a washout period of at least 4 weeks; 3) No known intellectual disability, epilepsy and severe sensorineural deficits or coexisting psychiatric disorder | 5 months (first 8 weeks 1 session per week, followed 1 session per month for 3 months) | ADHD-RS scores (only IA), CGAS, CGI-S, and CBCL score (both internalizing and externalizing problems) |
| Lim et al. (2023) | RCT (Comparative) | Inattentive and combined type | 1) Diagnosed by DSM-IV or DSM-5, inattentive or combined subtype; 2) no learning disability; 3) No previous pharmacological treatment (washout period of 1 month for meds, 3 months for supplements); 4) No psychiatric illness and IQ > 70 | 8 weeks | ADHD-RS scores (both IA and HI), CGAS, CGI-S, and CBCL score (attention, internalizing and externalizing, total and ADH problems), |
| Liu et al. (2013) | Single-arm trial | N/A | 1) IQ > 80; 2) ADHD diagnosed by child psychiatrist; 3) Not taking concomitant stimulant medication; 4) No children with brain injury or comorbidity such as ASD and epilepsy | 10 weeks | Scores of IVA-CTP |
| Park et al. (2019) | Single-arm trial | N/A | 1) Diagnosed with ADHD, were receiving counselling at the time of the study | 5 weeks | KNISE-BAAT score, general reading and comprehension questionnaires |
| Qian et al. (2018) | RCT (intervention-control) | Inattentive and combined type | 1) Diagnosed based on DSM-IV criteria; 2) 1-month washout period for children previously on pharmacotherapy; 3) No known history of epilepsy and intellectual disability (IQ < 70) | 8 weeks | ADHD-RS scores (only IA), CBCL (internalizing problems) |
| Yan et al. (2008) | Single-arm trial | N/A | Clinically diagnosed with ADHD | 10 weeks | Scores of IVA-CTP |

**Table 4A**

*Inattention (IA), Hyperactive-Impulsivity (HI), and Modified Scores Reported in the Included Studies*

| Study ID | Assessor | ADHD-RS type | Time of assessment | Intervention group | | Control group | |
|---|---|---|---|---|---|---|---|
| | | | | Mean (SD) | Mean Difference (SD) | Mean (SD) | Mean Difference (SD) |
| Johnstone et al. (2017) | Parents | Modified total (score range of up to 72) | Baseline<br>At week 8 | 40.6 (5.9)<br>28.6 (5.8) | N/A | 40.6 (1.37)<br>38.1 (1.19) | N/A |
| | Teachers | Modified total (score range of up to 72) | Baseline<br>At week 8 | 26.27 (4.08)<br>18.03 (3.89) | N/A | 26.2 (0.54)<br>27.1 (0.54) | N/A |
| Lim et al. (2010) | Teachers | IA score | Baseline<br>At week 5 | 16.6 (9.7)<br>14.0 (8.3) | | 12.3 (3.6)<br>13.2 (4.3) | |
| | | | At week 10 | 10.6 (9.0) | Baseline/week 10 = −6.0 (5.9) | 11.5 (4.8) | Baseline/week 10 = −0.8 (5.6) |
| | | HI score | Baseline<br>At week 5 | 16.8 (9.3)<br>14.6 (7.7) | | 15.0 (6.1)<br>13.8 (6.4) | |
| | | | At week 10 | 11.2 (7.3) | Baseline/week 10 = −5.6 (2.2) | 10.5 (4.8) | Baseline/week 10 = −4.5 (7.6) |
| | Parent | IA score | Baseline<br>At week 5 | 18.0 (6.1)<br>17.8 (6.0) | | 17.9 (5.7)<br>18.4 (6.0) | |
| | | | At week 10 | 15.0 (5.9) | Baseline/week 10 = −3.0 (4.8) | 18.6 (5.7) | Baseline/week 10 = 0.8 (1.3) |
| | | HI score | Baseline<br>At week 5 | 14.9 (5.6)<br>14.1 (5.7) | | 17.6 (5.0)<br>16.5 (5.1) | |
| | | | At week 10 | 11.4 (4.6) | Baseline/week 10 = −3.5 (4.5) | 15.6 (5.7) | Baseline/week 10 = −1.0 (1.7) |
| Lim et al. (2012) | Parents | IA score | Baseline | 17.7 (5.0) | | | |
| | | | At week 8 | 13.1 (5.0) | Baseline/week 8 = −4.6 (5.9, *P* = .003) | | |
| | | | At week 20 | 13.6 (4.5) | | | |
| | | | At week 24 | 12.6 (3.4) | Baseline/week 24 = −5.0 (5.8, P < .01) | | |
| | | HI score | Baseline | 15.6 (3.9) | | | |
| | | | At week 8 | 10.9 (4.4) | Baseline/week 8 = −4.7 (5.6, *P* = .002) | | |
| | | | At week 20 | 10.2 (5.1) | | | |
| | | | At week 24 | 10.5 (4.3) | Baseline/week 24 = −5.7 (5.1, *P* < .01) | | |

**Table 4A**

*Inattention (IA), Hyperactive-Impulsivity (HI), and Modified Scores Reported in the Included Studies*

| Study ID | Assessor | ADHD-RS type | Time of assessment | Intervention group | | Control group | |
|---|---|---|---|---|---|---|---|
| | | | | Mean (SD) | Mean Difference (SD) | Mean (SD) | Mean Difference (SD) |
| Lim et al. (2019) | Clinician | IA score | Baseline | 18.9 (4.25) | | 18.6 (4.38) | |
| | | | At week 8 | 15.5 (4.48) | Baseline/ week 8 = −3.5 (3.87) | 16.7 (5.14) | Baseline/ week 8 = 1.9 (4.42) |
| | | | At week 20 | 15.6 (5.26) | Baseline/ week 20 = −3.3 (5.55) | | |
| | | | At week 24 | 15.6 (5.26) | Baseline/ week 24 = −4.7 (5.94) | | |
| | Parents | IA score | Baseline | 18.9 (4.84) | | 18.6 (4.24) | |
| | | | At week 8 | N/A | Baseline/ week 8 = −4.0 (4.80) | | Baseline/ week 8 = −1.8 (4.21) |
| | | | At week 20 | N/A | Baseline/ week 20 = -4.1 (5.59) | | |
| | | | At week 24 | N/A | Baseline/ week 24 = -5.3 (6.17) | | |
| Lim et al. (2023) [The intervention is clinic and the control is home] | Clinician | IA score | Baseline | 16.1 (5.69) | | 17.9 (5.61) | |
| | | | At week 8 | 14.0 (6.30) | Baseline/week 8 = 3.9 (5.09) | 14.7 (4.97) | Baseline/ week 8 = 3.2 (6.20) |
| | | HI score | Baseline | 10.9 (8.16) | | 12.5 (5.72) | |
| | | | At week 8 | 10.3 (5.02) | Baseline/week 8 = 2.5 (4.34) | 11.2 (6.23) | Baseline/ week 8 = 1.3(4.17) |
| | Parents | IA score | Baseline | 15.9 (6.97) | | 17.7 (4.32) | |
| | | | At week 8 | 14.1 (6.31) | Baseline/week 8 = 1.8 (4.39) | 14.7 (4.97) | Baseline/ week 8 = 3.0 (4.24) |
| | | HI score | Baseline | 11.8 (8.44) | | 12.2 (5.37) | |
| | | | At week 8 | 9.7 (5.29) | Baseline/week 8 = 2.1 (4.15) | 11.4 (6.26) | Baseline/ week 8 = 0.8 (3.74) |
| Qian et al. (2018) | Parents | IA score | Baseline | 16.27 (4.25) | | 18.9 (5.18) | |
| | | | At week 8 | 13.16 (4.07) | | 17.2 (5.76) | |

**Table 5A**

*Pre- and Postinterventional RCQ and AQ Scores Reported by Two Studies*

| Study ID | Time point | RCQ | | | | | | AQ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Overall | | Auditory | | Visual | | Overall | | Auditory | | Visual | |
| | | M | SD | M | SD | M | SD | M | SD | M | SD | M | SD |
| Yan et al. (2008) | Pretreatment | 84.29 | 14.291 | 85.143 | 15.082 | 87.143 | 19.777 | 71.143 | 15.279 | 79.286 | 16.799 | 68.857 | 19.786 |
| | Posttreatment | 95.857 | 9.685 | 97.286 | 10.095 | 94.571 | 13.636 | 93.429 | 12.012 | 96.572 | 16.257 | 90.857 | 11.098 |
| Liu et al. (2013) | Pretreatment | 83.216 | 16.172 | 86.357 | 17.372 | 83.929 | 17.394 | 70.572 | 16.928 | 74.571 | 18.364 | 72.143 | 21.746 |
| | Posttreatment | 97.286 | 6.900 | 98.571 | 7.208 | 96.714 | 10.179 | 94.071 | 8.325 | 91.857 | 9.114 | 95.143 | 11.408 |

**Table 6A**

*Assessment of Risk of Bias of Nonrandomized Studies Using MINORS. Each Criterion Can Receive a Score of 0, 1, or 2. N/A Shows That the Criterion Was Not Applicable to That Study Because It Was Noncomparative.*

| Study | General Criteria | | | | | | | | Specific Criteria for Comparative Studies | | | | Overall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aim | Consecutive Patients | Prospective Data Collection | Appropriate Endpoints | Unbiased Assessment | Appropriate Follow-up | Loss to Follow-up | Study Size Calculation | Adequate Control Group | Contemporary Groups | Baseline Equivalence | Adequate Statistics | |
| Lim et al. (2010) | 2 | 2 | 2 | 2 | 1 | 2 | 0 | 2 | 1 | 2 | 1 | 2 | 19 |
| Lim et al. (2012) | 2 | 2 | 2 | 2 | 0 | 2 | 2 | 0 | N/A | N/A | N/A | N/A | 12 |
| Blandón et al. (2016) | 2 | 0 | 2 | 1 | 0 | 0 | 2 | 0 | N/A | N/A | N/A | N/A | 7 |
| Park et al. (2019) | 2 | 2 | 2 | 1 | 0 | 2 | 2 | 0 | N/A | N/A | N/A | N/A | 11 |
| Georgiou et al. (2019) | 2 | 1 | 2 | 2 | 0 | 2 | 1 | 1 | N/A | N/A | N/A | N/A | 11 |
| Yan et al. (2008) | 2 | 1 | 2 | 2 | 0 | 2 | 2 | 0 | N/A | N/A | N/A | N/A | 11 |
| Liu et al. (2013) | 2 | 0 | 2 | 1 | 0 | 2 | 0 | 0 | N/A | N/A | N/A | N/A | 7 |