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Virtual reality interventions for attention deficit/hyperactivity disorder: a systematic review

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Virtual reality (VR) interventions have emerged as innovative approaches increasingly used to manage attention-deficit/hyperactivity disorder (ADHD) in children and adolescents. This systematic review included 22 randomized controlled trials, quasi-experimental, and open-label studies published between 2001 and 2025, comprehensively evaluating the feasibility of VR interventions, their effectiveness alone or combined with pharmacological treatment, the relative efficacy of different training modalities, and dosage-related factors. The results indicate that VR interventions, whether used independently or alongside medication, significantly improve core ADHD symptoms, executive functions, emotional regulation, and social skills, with long-term interventions (≥8 weeks) producing more pronounced and sustained benefits. Among the training modalities, interactive game training was the most frequently studied, followed by virtual scenario and exergaming, each demonstrating distinct effects on cognitive and behavioral outcomes. Overall, VR interventions generally demonstrated high adherence rates; however, adherence reporting was inconsistent across studies, and adverse effects were typically mild and transient. Future research should focus on large-scale randomized controlled trials employing standardized outcome measures and developing personalized VR protocols to further enhance treatment efficacy and clinical applicability for ADHD.

Attention-deficit/hyperactivity disorder (ADHD) is a neuro developmental condition involving persistent and developmentally atypical behaviors such as inattention, hyperactivity, and impulsivity that impair functioning across multiple settings[1]. Globally, this disorder affects approximately 7–8% of children and adolescents, with estimates varying by methodology and clinical criteria for diagnosis[2,3]. While some individuals experience symptom remission with age, many continue to exhibit impairing symptoms into adolescence and adulthood, contributing to lifelong functional challenges[4]. ADHD imposes a significant burden on families, schools, healthcare systems, and broader society, leading to increased risks of academic failure, social dysfunction, mental health comorbidities, substance misuse, and even justice system involvement[5,6]. Given its widespread prevalence and high social cost, early diagnosis and sustained intervention are critical[7].

Current clinical guidelines advocate for multimodal treatment approaches, combining pharmacological and non-pharmacological interventions tailored to individual needs[8]. Stimulant medications such as methylphenidate are often used as a first-line option, particularly in moderate-to-severe cases, but concerns regarding side effects, adherence, and long-term efficacy have led to increasing attention on non-pharmacological interventions[9,10]. Among non-pharmacological interventions, behavioral therapy is a well-established evidence-based treatment for ADHD, with robust support for improving attention and executive function[11]. In contrast, cognitive training and exercise interventions are considered experimental or of limited efficacy[12]. However, all non-pharmacological interventions generally face challenges, such as low engagement, lack of personalization, and difficulty maintaining long-term motivation, which can limit their overall effectiveness[13–15]. Specifically, neurofeedback may produce certain improvements in attention and executive function[16], whereas the efficacy of biofeedback is more variable and highly dependent on the specific context[17]. Cognitive training, such as working memory and attention training, shows limited or inconsistent effects, typically influenced by training intensity, task design, and participant engagement[18].

With rapid technological advances, VR technology has attracted increasing attention in ADHD interventions due to its high immersion, ecological validity, and ability to simulate real-life environments[19,20]. VR can provide multisensory dynamic interactions that enhance children's engagement and motivation while enabling personalized

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training tailored to individual needs, thereby improving intervention outcomes[21,22].

In recent years, various types of VR-based interventions have been introduced in the field of ADHD rehabilitation. Early VR programs were primarily built upon simple cognitive paradigms such as the Continuous Performance Test (CPT), often integrated with electroencephalogram (EEG)-based neurofeedback systems[23,24]. For instance, a study demonstrated that participants receiving VR neurofeedback training showed notable improvements in attention and behavioral control[24]. Since 2019, researchers have increasingly incorporated task-oriented interactive games into VR platforms to enhance motivation and engagement among children. Later, the study confirmed that VR-based cognitive training through interactive gaming improved attentional performance in children with ADHD[25]. Similarly, researchers combined visual attention training and breathing regulation within a VR system and found enhancements not only in attentional performance but also in physiological indicators such as maximal inspiratory pressure (MIP)[26]. These multisensory and biofeedback-integrated systems represent a shift toward more comprehensive and holistic VR-based intervention models.

Given the differences in active components and mechanisms among VR interventions, this review categorizes them into three types: VR Interactive Game Training, focusing on cognitive tasks to enhance attention, executive function, and problem-solving, with reward mechanisms improving attentional deficits in ADHD children[27]; VR exergaming/body-motion training, combining physical movement and cognitive training to target motor-cognitive integration, inhibitory control, and coordination[28]; and VR Virtual Scenario Training, simulating real-life scenarios to improve emotional regulation and social functioning, addressing limitations of other VR types[29]. This classification reflects both core intervention components and differing mechanisms, providing a theoretical basis for comparing efficacy across VR modalities.

Despite the growing application of VR in ADHD treatment, there remains a lack of systematic classification and evaluation of the different types of VR interventions. The previous review emphasized the potential of electronic, virtual, and augmented reality games in enhancing cognitive and metacognitive functions among children with ADHD[30]. However, it did not provide a detailed categorization of VR modalities and primarily focused on general digital interventions. In addition, several meta-analyses have evaluated the efficacy of immersive VR-based motor and cognitive training in children with ADHD, indicating improvements in executive function and motor skills[31–33]. Nonetheless, these reviews often lacked refined classification regarding types of VR interventions, dosage parameters (e.g., duration and frequency), and intervention outcomes. Moreover, the limited number of randomized controlled trials (RCTs) included in existing syntheses weakens the generalizability and robustness of conclusions.

Given these limitations, the present systematic review aims to comprehensively evaluate current evidence on VR-based interventions for children and adolescents with ADHD, focusing on four key aspects: (1) The feasibility and acceptability of VR interventions, assessed through adherence rates, satisfaction levels among participants and therapists, and intervention settings; (2) Whether VR is applied as a standalone intervention or in conjunction with pharmacological treatment, and the differential outcomes observed in each case; (3) The comparative effectiveness of three major types of VR training—VR Interactive Game Training, VR Exergaming (body-motion-based training), and VR Virtual Scenario Training—on cognitive and behavioral outcomes; (4) Dosage-related variables, including intervention duration, frequency, and total exposure time, with specific attention to the distinction between short-term and long-term interventions (with a minimum duration of 8 weeks).

Results

Search results

Figure 1 illustrates the process of study identification, including the initial search, title and abstract screening, and final study selection. The study selection process followed the PRISMA 2020 guidelines. A total of 1649 records were initially identified through database and register searches. After removing 881 duplicate records, 768 unique records remained for title and abstract screening. Based on the screening results, 33 full-text articles were retrieved and assessed for eligibility. Among these, 13 reports were excluded for not meeting the inclusion criteria. In addition, a manual search through citation tracking identified two additional records, both of which met all eligibility criteria and were also included in the review. Ultimately, 22 studies were included in the final systematic review.

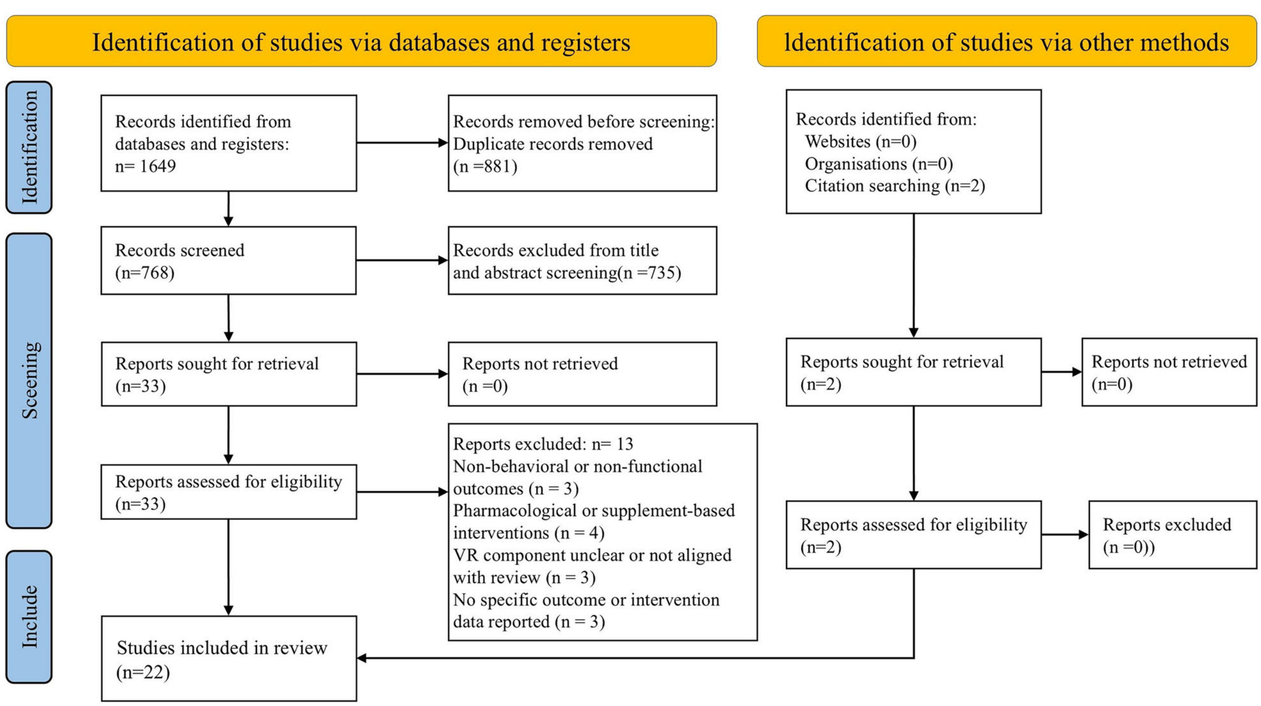

Fig. 1 | Flowchart of literature screening.

Study selection, characteristics, and participants

As presented in Table 1, this review included 22 studies, comprising 11 RCTs[23,29,34–42], 8 quasi-experimental studies (including one within-group pre-post design)[24–27,43–46], and 3 open-label experiments[47–49]. Most studies were conducted in South Korea ($n = 7$)[23–26,36,40,44], Italy ($n = 3$)[38,42,43], Germany ($n = 2$)[39,47], Switzerland ($n = 2$)[34,49], and China ($n = 3$)[27,29,45], with additional studies originating from Portugal[37], Spain[41], Iran[46], Israel[48] and France[35].

The publication years ranged from 2001 to 2025. Across these studies, a total of 896 participants were included. In child and adolescent studies, participants' ages ranged from 5 to 18 years, whereas in adult studies, participants' ages were reported in the range of 18–65 years. The majority were children and adolescents, with only four studies involving adult participants[37,39,47,49]. Participants were categorized into three groups: individuals formally diagnosed with ADHD ($n = 652$, 72.8%) according to DSM-IV, DSM-V, or ICD-10[25,26,29,34,35,38,40–49]; individuals exhibiting ADHD-related symptoms without a formal diagnosis ($n = 218$, 24.3%) identified via symptom checklists or behavioral observation[23,24,36,37,39]; and healthy controls ($n = 26$, 2.9%)[25,47]. All participants were cognitively and physically capable of engaging in VR-based training. Most interventions were conducted in clinical, laboratory, or educational settings, with some incorporating home-based or hybrid models.

Feasibility and acceptability

Participant dropout rates in VR-based interventions ranged from 0% to 23%. Thirteen studies reported adherence rates between 77% and 100%. Of the 13 studies reporting compliance, all but two demonstrated high adherence, with one study reporting 79%[41] and another 77% adherence[40], while all remaining studies exceeded 85%[34,39,47,48], with 7 achieving 100%[26,29,35,37,38,44,45]. Five studies reported strategies to enhance adherence[29,37–39,47]. One study promoted competition among participants by setting up a leaderboard[37]. Other measures to improve adherence included reminder systems (phone calls or WhatsApp/WeChat messages) and incentive mechanisms such as token economies, lottery rewards (€2 × 50), or monetary compensation (€100) for completing all training sessions. Five studies reported strategies to enhance adherence, with adherence rates exceeding 95% in all five studies, and two studies[29,38] achieving 100% adherence.

Ten studies assessed participant satisfaction. One study reported moderate satisfaction[47], while another reported that participants' satisfaction with the VR platform, assessed via a 9-item questionnaire, was generally high[37]. In another, the average interest score was 4.55 out of 5[44]. One study noted that 82% of participants enjoyed the experience and 79% would recommend it[41]. One study reported a satisfaction rate of 82.5%[48].

No serious adverse effects were reported. Mild side effects included: a sensation of "heaviness in the head" due to headset weight[44]; mild dizziness (mean score: 0.10/1), with 58% reporting increased dream activity[41]; mild simulator sickness[47]; and one withdrawal due to discomfort with the VR environment[39].

Intervention settings

Of the 22 studies, 18 were conducted in laboratory or clinical settings; 1 used hybrid environments (home and hospital); 1 was implemented entirely at home; and 1 was school-based; and 1 was conducted exclusively in a hospital setting. Among the laboratory/clinical studies, improvements in attention, symptom severity, working memory, and cognitive function were consistently observed[23–27,29,35–37,39,40,42,43,45–49]. The home-based study enhanced inhibition and cognitive flexibility but showed no significant changes in parent-rated Conners-3 scores, although a significant improvement was observed on the DSM-IV-TR global index[34]. The school-based intervention showed significant gains in academic performance, with the VR group outperforming the traditional training group[38]. In hybrid settings, participants demonstrated significant improvements in attention and inhibition[41]. In hospital-based settings, sense of presence improved in the experimental group, whereas no significant EEG changes[25].

Compliance was 90% in the only home-based study[34]. In the hybrid studies, one study reported a 79% compliance rate with a high dropout rate[41]. The school-based study achieved 100% compliance[38]. In clinical/laboratory settings, 8 studies did not report compliance[23–25,27,36,42,43,46], while one reported a 77% compliance rate[40], 9 studies achieved rates above 85%[26,29,35,37,39,44,45,47,48].

VR interventions for children vs. adults with ADHD

VR interventions for children with ADHD demonstrated clear efficacy in RCTs. For example, one study combined VR serious games with hospital- and home-based practice, resulting in significant improvements in parent-rated SNAP-IV symptoms (inattention and hyperactivity/impulsivity) and objective neurocognitive measures (e.g., working memory and executive function), outperforming medication-only or psychoeducation interventions[41]. Similarly, significant reductions in parent-rated ADHD-RS total scores and Conners-3 hyperactivity/impulsivity subscales were reported[35,42]. Quasi-experimental studies further supported the potential of VR to improve children's objective cognitive performance (e.g., error rates in attention tasks) as well as parent-reported symptoms[44,45].

VR interventions for adults with ADHD typically target specific functional deficits, such as higher-order executive functions, working memory, and cognitive control in complex environments. Limited RCT evidence indicates that VR may effectively improve these core cognitive domains. VR interactive games significantly enhanced processing speed and spatial working memory in young adults[37], while VR neurofeedback training reduced reaction time variability and increased prefrontal cortex activation[39].

Active treatment components of VR interventions

Among the 22 included studies, 11 used cognitive training as the primary intervention, 4 employed neurofeedback, 3 combined cognitive training with behavioral interventions, 1 used biofeedback, and 3 focused solely on behavioral interventions. Standalone VR cognitive training was shown to improve attention, working memory, and hyperactivity/impulsivity symptoms, as measured by objective neuropsychological tests (e.g., CPT reaction time tasks) and parent-rated scales such as the SNAP-IV[37,44]. When VR cognitive training was combined with medication or behavioral therapy, it provided additional improvements in core ADHD symptoms, objective cognitive performance, and social skills[29,41,42]. VR neurofeedback demonstrated greater effects on attention and EEG β-wave activity compared to standard screen-based neurofeedback, likely due to increased immersion[23,36]. fNIRS-based VR neurofeedback was superior to EMG biofeedback alone in activating the prefrontal cortex and enhancing inhibitory control[39]. One study reported negative findings: a single session of VR neurofeedback did not improve performance and actually increased distractibility, highlighting the importance of intervention dosage and adaptability, as well as the value of objective physiological measures in detecting potential adverse effects[47]. VR exergaming or behavioral strategy-based interventions were also effective in improving parent-rated ADHD symptoms, inhibitory control, and motor abilities[34].

VR as a standalone vs. combined intervention

Ten studies incorporated VR alongside traditional treatments, such as pharmacological, behavioral, or cognitive therapies. Among these, six studies directly compared VR + standard care with standard care alone. Across these studies, the combined approach consistently produced superior outcomes. Significant reductions in hyperactivity-impulsivity were reported using the parent-rated SNAP-IV[42]. Objective cognitive measures: Improvements were observed in CPT performance[26], working memory[41], and executive functions, including planning and problem-solving[42,43]. Greater improvements were reported in clinician-rated social skills and parent-rated executive functions[29].

Ten studies implemented VR as a standalone intervention. Based on the different control group settings, these studies can be categorized into three main types for comparative analysis. Compared with the no-treatment

Table 1 | Summary of included studies: study characteristics, participant details, VR intervention types, feasibility, and side effects

Author (year)	Study design	Age	Sample size; Setting	Sample Description (Diagnosis, Gender)	Types of VR training	Feasibility and acceptability	Outcomes and findings
Cunha et al.[37]	RCT	E: 21.69 ± 0.75, C: 20.17 ± 0.94;	E: $n = 13$ C: $n = 12$ Laboratory	Individuals with subclinical ADHD symptoms E: Females=13, C: Females=11	VR Interactive Game Training	Adherence: 100% (VR group) All 13 VR participants completed 10 sessions Satisfaction: Participants satisfaction with the VR platform, assessed via a 9-item questionnaire, was generally high, though some reported difficulties with the headset and controllers. Drop-out: 3.8% (1/26) of the participants (1 control participant was lost at follow-up)	The intervention group showed significant improvement in processing speed and spatial working memory, while the control group showed no significant changes.
Lee et al.[24]	quasi-experiment studies	Age: school-aged (not specified)	E: $n = 10$ C: $n = 10$ Laboratory	Individuals with subclinical ADHD symptoms Gender: all males	VR Interactive Game Training	NR	The experimental group demonstrated a significant reduction in errors of omission and commission on the CPT, unlike the control group.
Oh et al.[25]	quasi-experiment studies	Age: 8–9	E: $n = 8$ C: $n = 8$ Hospital	formal diagnosis E: Males = 1, C: Males = 5	VR Interactive Game Training	NR	The intervention improved the sense of presence but did not lead to significant changes in EEG measures.
Cho et al.[23]	RCT	Age: 14-18	E1: $n = 10$ E2: $n = 9$ C: $n = 9$ Laboratory	Individuals with subclinical ADHD symptoms Gender: all males	VR Interactive Game Training	NR	Both experimental groups showed improved CPT performance, with one group showing a more pronounced trend and a higher beta wave ratio.
Kim et al.[26]	quasi-experiment studies	Age: 8–13	E: $n = 12$ C: $n = 12$ Therapy center	formal diagnosis E: Males = 5, C: Males = 5	VR Interactive Game hybrid VR Exergaming	Adherence: 100%; Satisfaction: Nine of twelve participants enjoyed the training and wanted more sessions. Drop-out: 0	The intervention significantly reduced attention omission errors and improved pulmonary function compared to the control.
Kim et al.[44]	quasi-experiment studies	Age: 8–10	E: $n = 20$ C: $n = 20$ Clinic setting	formal diagnosis E: Males = 17, C: Males = 18	VR Interactive Game Training	Adherence: 100%; Satisfaction: High acceptability Avg interest score 4.55/5 Drop-out: 0	The experimental group showed significantly greater improvement in reducing attention errors and improving interactive metronome response time than the control.
Martin-Moratinos et al.[41]	RCT	E: 12.79 ± 2.86, C: 12.58 ± 2.67	E: $n = 33$ C: $n = 36$ Hospital and home	formal diagnosis E: Males = 31, C: Males = 30	VR Interactive Game Training	Adherence: 79% (26/33 completed 16+ sessions); Satisfaction:82% liked the experience; 79% would recommend it Drop-out: 9% (7/76) of the participants (5 in the E group and 2 in the C group)	The intervention led to significant improvements in working memory and several executive functions, with trends of improvement in core ADHD symptoms.
Schena et al.[42]	RCT	Age: 5–12	E: $n = 30$ C: $n = 30$ Rehabilitation center	formal diagnosis Gender: 33 males, 27 females	VR Interactive Game hybrid VR Exergaming	NR	The intervention significantly improved auditory attention, reduced hyperactivity/impulsivity, and enhanced planning and problem-solving skills.
Tabrizi et al.[46]	quasi-experiment studies	Age: 7–12 (mean=9.58)	E1: $n = 16$ E2: $n = 16$ C: $n = 16$ Rehabilitation center	formal diagnosis Gender: 32 males, 16 females	VR Interactive Game Training	NR	A significant improvement in memory was found for the primary experimental group compared to both the control and the second experimental group.
De Luca et al.[43]	quasi-experiment studies	Age: School-age (not specified)	E: $n = 30$; C: $n = 29$ Clinical	formal diagnosis E: Males = 23, C: Males = 23	VR Interactive Game hybrid VR Exergaming	Adherence: NR; Satisfaction: positive emotions reported during BRAVO gameplay; Drop-out: NR	Both groups showed enhanced auditory attention and reduced impulsive behaviors, but only the intervention group showed significant improvements in planning and problem-solving.

Table 1 (continued) | Summary of included studies: study characteristics, participant details, VR intervention types, feasibility, and side effects

Author (year)	Study design	Age	Sample size; Setting	Sample Description (Diagnosis, Gender)	Types of VR training	Feasibility and acceptability	Outcomes and findings
Cho et al.[36]	RCT	Age: 13–15	E1: $n = 8$; E2: $n = 9$ C: $n = 9$ Laboratory	Individuals with subclinical ADHD symptoms; Gender: All Males	VR Interactive Game Training	NR	The VR-based intervention group showed significant improvements in all CPT measures, including correct responses and error reduction.
Fang et al.[27]	quasi-experiment studies	Age: 5–6	E: $n = 84$, C: $n = 15$; Clinical	ADHD tendency (SNAP-IV > 1.6) Gender: not specified	VR Interactive Game Training	NR	Both material and psychological rewards significantly improved inhibitory control and ADHD symptoms, with material rewards showing a broader effect.
Benzing et al.[34]	RCT	E: 10.46 ± 1.30, C: 10.39 ± 1.44	E: $n = 28$; C: $n = 23$ Home	formal diagnosis E: Males=86.4%, C: Males=81.8%	VR Exergaming (Body-Motion Game Training)	Adherence: Participants trained about 80 min per week (around 89% of the planned amount); Satisfaction: Participants reported high overall enjoyment on three 4-point Likert-scale items. ($M = 3.62$, SD = 0.64) Drop-out: 13.7% (6 in the E group and 1 in the C group)	The exergaming intervention improved motor abilities and cognitive inhibition and switching, with a significant effect on a global ADHD symptom score.
Ou et al.[45]	quasi-experiment studies	Age: 9–11	E: $n = 3$ Rehabilitation center	formal diagnosis; Gender: 2 females, 1 male	VR Exergaming (Body-Motion Game Training)	Adherence: 100%; Satisfaction: Initially appealing, needed more variety later Drop-out: 0	The intervention improved attention, reduced core ADHD symptoms of inattention and hyperactivity, and enhanced nonverbal intelligence.
Ji et al.[40]	RCT	E: 9.00 ± 1.46, C: 8.85 ± 1.63	E: $n = 16$; C: $n = 14$ Clinical	formal diagnosis E: Males = 14, C: Males = 12	VR Exergaming (Body-Motion Game Training)	Adherence: Participants completing <80% of sessions were excluded from analysis. Satisfaction: NR Drop-out: 28.6% (5 in the E group withdrew for scheduling reasons and 7 in the C group due to loss of interest)	Both groups improved in attention, but only the intervention group showed specific neural improvement (increased N2 amplitude) alongside enhanced self-regulation.
Shema et al.[48]	open-label pilot study	Age: 8–12	E: $n = 14$; Center for the Study of Movement	formal diagnosis Gender: 11 male, 3 female	VR Exergaming (Body-Motion Game Training)	Adherence: 15.8 out of 18 sessions (87.8%), Satisfaction: with a satisfaction rate of 82.5%. Drop-out: 0	The training improved memory, executive function, and reduced social problems, with a noted increase in gait regularity.
Wong et al.[29]	RCT	E: 8.63 ± 1.90 E2:8.30 ± 1.70 C: 8.67 ± 1.45	E1: $n = 30$ E2: $n = 30$ C: $n = 30$ Clinical	formal diagnosis E1: Males = 23, E2: Males = 26 C: Males = 24	VR Virtual Scenario Training	Adherence: 100% (VR group); Satisfaction: Assessed using a 7-point Likert scale, satisfaction was high ($M = 6.77$, SD = 0.43). Drop-out: 13.3% (1 in the TSST group and 11 in the WLC group)	Both intervention groups significantly improved social skills and executive functions, with one group showing superior gains compared to the other.
Frolli et al.[38]	RCT	E: 9.20 ± 0.32, C: 9.30 ± 0.50;	E: $n = 30$ C: $n = 30$ School	formal diagnosis E: Males = 42, C: Males = 40	VR Virtual Scenario Training	Adherence: 100%; Satisfaction: NR Drop-out: 0	The VR intervention group showed greater improvement in learning accuracy and higher levels of intrinsic motivation and engagement than the control group.
Selaskowski et al.[47]	open-label experimental study	E: 36.10 ± 10.70, C: 25.90 ± 3.10	E: $n = 18$ C: $n = 18$ Laboratory	formal diagnosis E: Males = 12, C: Males = 11	VR Virtual Scenario Training	Adherence: 95%; Satisfaction: Middle satisfaction in ADHD group (1.56/3) Drop-out: 5% (2 dropouts; reasons not reported)	The VR intervention was associated with increased omission errors, slower reaction times, and higher physiological and gaze distractibility.
Hudak et al.[39]	RCT	E: 22.90 ± 2.88, C: 23.90 ± 2.77;	E: $n = 10$ C: $n = 10$ Laboratory	Individuals with subclinical ADHD symptoms E: Males = 6, C: Males = 5	VR Virtual Scenario Training	Adherence: 10 participants in both the E and C groups completed all 8 sessions. Satisfaction: NR Drop-out: 4.7% (1 participant withdrawing due to discomfort)	The intervention reduced reaction time variability and errors on a Go/No-Go task, accompanied by a significant increase in prefrontal cortex activation.

Table 1 (continued) | Summary of included studies: study characteristics, participant details, VR intervention types, feasibility, and side effects

Author (year)	Study design	Age	Sample size; Setting	Sample Description (Diagnosis, Gender)	Types of VR training	Feasibility and acceptability	Outcomes and findings
Bioulac et al.[35]	RCT	E1: 9.50 ± 1.20, E2: 8.40 ± 0.99, C: 8.80 ± 1.07;	E1: *n* = 16 E2: *n* = 16 C: *n* = 19 Clinical	formal diagnosis E1: Males = 14, E2: Males = 16, C: Males = 11	VR Virtual Scenario Training	Adherence: 100%; Satisfaction: NR; Drop-out: NR	One intervention group showed significant improvements in CPT performance metrics, total ADHD-RS scores, inattention scores, and hyperactivity-impulsivity scores all decreased significantly,
Cuber et al.[49]	open-label exploratory pilot study	Age: 21.04 ± 1.60	E: *n* = 27 (university students with ADHD); Setting: University lab	DSM-5; ADHD (*n* = 27); Gender: F = 15, M = 5, non-binary = 5, Transgender = 1, Genderfluid = 1	VR Virtual Scenario Training	Adherence: Avg. 7.4/12 sessions Satisfaction: NR; Drop-out: NR	Significant improvement in attention ($p < 0.0001$, $d = 3.04$) Motivation ($p = 0.0001$, $d = 1.25$); Efficiency ($p < 0.0001$, $d = 1.76$) significantly improved

RCT randomized controlled trial, *E* experimental group, *C* control group, *VR* virtual reality, *NR* not reported.

control, three studies[24,37,44] found significant improvements in processing speed, working memory[37], and attention task performance, including reductions in omission and commission errors[44]. Compared to active control groups, two studies[23,36] compared immersive VR training with identical cognitive training delivered on a traditional fixed screen, showing that immersive VR led to greater improvements in CPT performance. Only one of these studies observed accompanying increases in EEG β-wave activity[23], suggesting enhanced neural modulation. One study[46] reported superior improvements on the Wechsler Memory Scale for VR cognitive training compared to stimulant medication. Additionally, one study[39] found that fNIRS-based VR neurofeedback outperformed EMG-based biofeedback in reducing Go/No-Go task errors and increasing prefrontal cortex oxygenation. Beyond comparisons with traditional interventions, two studies focused on optimizing the feedback mechanisms within VR systems. One study[27] showed that reward-based VR cognitive–motor training improved ADHD symptoms and executive function more than non-reward training, and another[47] found ADHD-specific VR neurofeedback revealed greater attentional instability and slower responses compared with healthy controls. A single-group study using VR-augmented treadmill training[48] did not observe immediate improvements in attention indices but reported enhancements in executive function, memory, gait stability, and psychosocial behaviors, with some cognitive benefits maintained at the 6-week follow-up. Two studies did not report whether VR was implemented as a standalone intervention or combined with other treatments[35,43].

Effectiveness across different types of VR-based training

(1) VR interactive game training (55%, 12 studies). As shown in Fig. 2, VR Interactive Game Training integrates immersive gameplay with cognitive tasks and real-time feedback mechanisms to enhance attention, working memory, and executive functions. Most programs required participants to perform goal-directed tasks such as target tracking, response inhibition, or memory-based matching while navigating virtual environments. Some interventions included adaptive difficulty levels or reward-based reinforcement to maintain engagement. Training was typically administered in laboratory or clinical settings, with session durations ranging from 10 to 45 min, training sessions were conducted 1–4 times per week over a period of 1 week to 6 months, with one study implementing 2 sessions per day[27]. Several studies also implemented remote, home-based formats to improve accessibility and ecological validity[41,44].

Figure 2 further illustrates that VR-based cognitive training can be conducted in diverse settings, including (a) clinical institutions, (b) rehabilitation centers, and (c) research laboratories, indicating its flexibility and potential for broader application in ADHD treatment.

Interactive VR game training was the most frequently used modality ($n = 12$). These interventions consistently led to improvements in attention, inattention/hyperactivity symptoms, executive functioning, and problem-solving abilities. One study additionally reported neurophysiological changes, including enhanced beta wave activity[23]. Among these 12 studies, three employed a combination of interactive and exergaming elements. These hybrid interventions were more likely to report improvements in impulsivity and hyperactivity symptoms[26,42,43].

(2) VR Exergaming (18%, 4 studies). As shown in Fig. 3, VR Exergaming utilizes motion-sensing technology combined with movement-based games to promote both physical activity and cognitive enhancement. Participants are typically required to perform physical tasks such as jumping, arm swinging, or balancing, designed to simultaneously stimulate attention, executive function, and coordination. Training settings vary and include home, rehabilitation centers, and clinical institutions. Sessions last 30–60 min, conducted three times per week over a period of 4 weeks to 3 months.

Four studies focused exclusively on VR-based exergaming, emphasizing physical engagement. These interventions effectively improved inhibitory control, cognitive flexibility, and motor coordination. One study

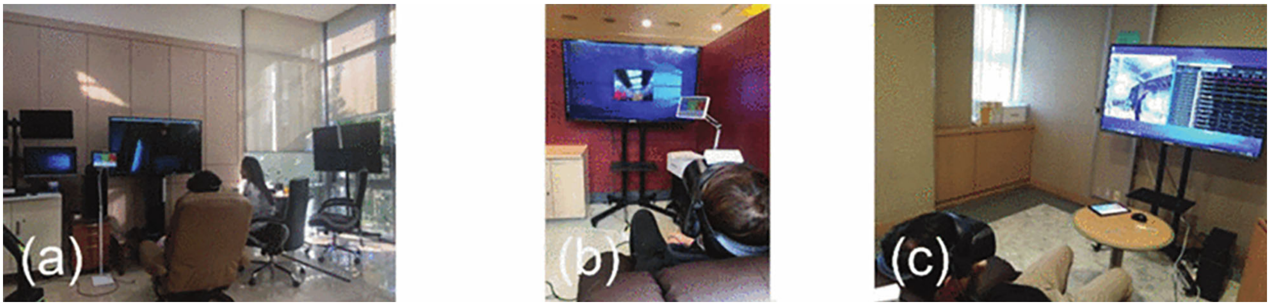

Fig. 2 | Diagram of VR Interactive Game Training. VR cogntive training for ADHD patients. **a** VR cognitive training center at Gil Hospital; (**b**) Samsung Medical Center; (**c**) Inha University Hospital[25]. Reprinted from Oh, S. H., Park, J. W., & Cho, S. J. (2022), Journal of Web Engineering, 21, 767–788. © 2022 The Authors. Licensed under CC BY 4.0.

Fig. 3 | Diagram of VR Exergaming Training[50]. Reprinted from Khundam and Nöel[50], *International Journal of Computer Games Technology*, 2021, Article ID 6668280.© 2021 The Authors. Licensed under CC BY 4.0.

also reported increased N2 amplitude and reduced reaction time in a go/no-go task following the intervention[40]. Another study reported cognitive improvements but no significant changes in parent-rated Conners-3 ADHD symptoms, although a significant effect was observed on the total global index score using DSM-IV-TR Symptom Scale T-scores[34].

(3) VR virtual scenario training (27%, 6 studies). As shown in Fig. 4, VR Virtual Scenario Training simulates real-world environments such as classrooms and social settings to target improvements in social skills, emotion regulation, and attentional control. Participants engage in tasks like following classroom instructions, managing distractions, or practicing social interactions with virtual avatars. Some studies also incorporate neurofeedback tools to provide real-time monitoring of neural activity and enhance self-regulation. Training is typically conducted in settings including schools, rehabilitation centers, and laboratories. Including one study with a single training session and other studies with training conducted 2–4 times per week over a period of 2 weeks to 4 months.

Six studies utilized VR-based virtual scenario training. These interventions demonstrated beneficial effects on emotional regulation, social behavior, and sustained attention. Notably, two studies reported significant improvements in social skills and intrinsic motivation[29,38].

The three main types of virtual reality (VR) training—interactive gaming, exergaming, and virtual scenario training—differ in content and duration, but all show good adherence and acceptance. Interactive gaming combines cognitive tasks with feedback, exergaming emphasizes physical movement, and virtual scenario training simulates real-life environments, often supplemented with neurofeedback. All three have minimal side effects and show great clinical potential. Figure 5 illustrates their characteristics and comparisons.

Dosage: duration, frequency, and total exposure

As presented in Table 2, the intervention duration ranged from 2 weeks to 6 months. Session length varied: five studies used 30-min sessions, seven used 10–25 min, and five used 30–60 min. Session frequency ranged from 1 to 4 times per week, with one study providing two sessions per day and another using a single-session intervention. Five studies did not report frequency.

Among the 22 included studies, six employed long-term interventions (defined as lasting at least 8 weeks)[34,38,41–43,45]. Of these, three studies reported improvements in core ADHD symptoms based on parent-rated scales such as SNAP-IV, ADHD-RS, and Conners-3[42,43,45]. One study reported that the intervention group showed only a trend toward improvement on the inattention and hyperactivity-impulsivity subscales of the SNAP-IV[41]. One study found no significant changes on the parent-rated Conners-3, but reported improvements in inhibitory control, cognitive flexibility, and the DSM-IV-TR total global index score[34]. Another study observed a significant increase in accuracy on academic achievement tasks after the intervention[38].

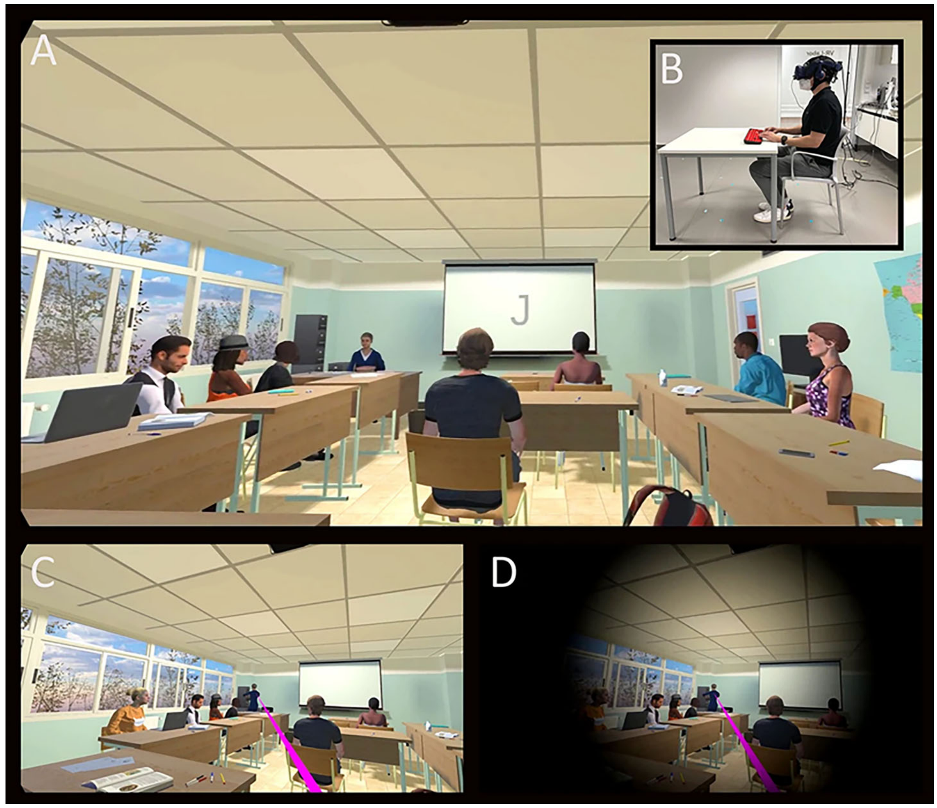

Fig. 4 | Diagram of VR-based virtual scenario training. A First-person view of the virtual seminar room showing the CPT on the front canvas; (**B**) Side view of a participant in the VR lab; (**C**) Distractor event; (**D**) Gaze-based feedback provision[47]. Reprinted from Selaskowski et al.[47], BMC Psychiatry, 23(1), 74. © The Author(s) 2023. Licensed under CC BY 4.0.

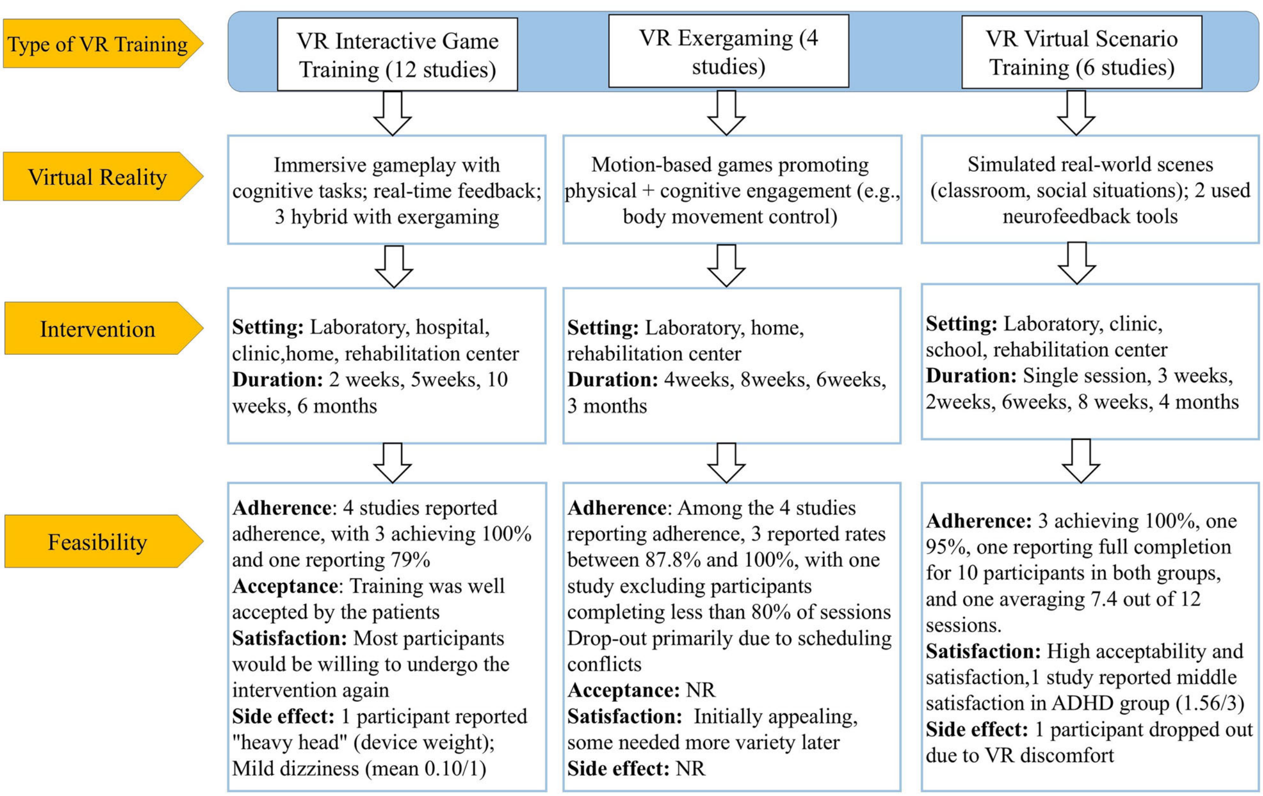

Fig. 5 | Categorization of VR intervention types and feasibility. The figure categorizes three types of VR interventions, detailing their associated virtual modality, intervention characteristics, and feasibility for practice.

Table 2 | Summary of VR intervention characteristics and training dosage

Author (year)	Intervention	Virtual training dosage (duration, frequency, total time)	Side effect
Cunha et al.[37]	E: VR games C: no intervention	30 min/session, 2 times/week, 5 weeks, 10 sessions	NR
Lee et al.[24]	E: VR Neurofeedback training C: no intervention	10 min/session,10 sessions	NR
Oh et al.[25]	E: Psychomotor program+VR games C: no intervention	8 sessions (Duration per session not specified)	No side effect observed in study
Cho et al.[23]	E1: VR Neurofeedback training E2: fixed monitor Neurofeedback training C: no intervention	20 min/session, 8 sessions over 2 weeks,2 weeks	NR
Kim et al.[26]	E: Psychomotor program+VR breathing training C: Psychomotor program only	15 min/session, 2 times/week, 4 weeks, 8 sessions	NR
Kim et al.[44]	E: VR eye-contact game C: No intervention	30 min/session, 2 times/week, 5 weeks, 10 sessions	Minimal: 1 participant reported "heavy head" (device weight)
Martin-Moratinos et al.[41]	E: Standard pharmacological treatment + serious video game (VR/computer) C: Standard pharmacological treatment only	20 min/session,2 times/week,10 weeks; 20 sessions	Mild dizziness (mean 0.10/1); Increased dream activity (58% of VR users)
Schena et al.[42]	E: IAmHero VR serious game +conventional therapy C: Conventional therapy only	30 min/session, 1 session/week, 6 months, total 24 sessions	NR
Tabrizi et al.[46]	E1: Virtual reality therapy E2: Ritalin, atomoxetine, dexamphetamine C: No intervention	10 sessions, with no specific frequency mentioned	NR
De Luca et al.[43]	E: VR-based serious games C: Traditional therapy	Six-month experimental period; Weekly frequency not specified	NR
Cho et al.[36]	E1: VR Neurofeedback training E2: fixed monitor Neurofeedback training C: no intervention	20 min/session, 8 sessions over 2 weeks, 2 weeks	NR
Fang et al.[27]	E: VR-based cognitive-motor training with different reward feedback (coins/tokens + verbal encouragement/badges) C: VR training without reward feedback	25 min/session; 2 sessions/day; 28 sessions over 2 weeks	NR
Benzing et al.[34]	E: VR exergaming training C: no intervention	3 sessions/week, 30 min/session; 8 weeks intervention; 24 sessions	NR
Ou et al.[45]	E: VR exergaming training No control group	40 min/session (with breaks), 3 times/week, 3 months	NR
Ji et al.[40]	E: VR exergaming training C: Stationary bicycle exercise	50 min/session, 3 times/week, 4 weeks	NR
Shema et al.[48]	E: VR-augmented treadmill training (avoiding virtual obstacles while walking)	18 sessions,3 times/week, 6 weeks, each session lasting 30–60 min	No side effect observed in study
Wong et al.[29]	E1: VR-based social skills training (HMD) E2: Role-playing and didactic instruction C: No intervention	20 min/session, 4 sessions/week, 3 weeks, 12 sessions total	Sweating in 16 participants, no other discomfort
Frolli et al.[38]	E: History learning via 3D immersive VR videos (HMD) C: Educator-guided reading with feedback	4 months, Frequency not specified	NR
Selaskowski et al.[47]	E: ADHD VR Neurofeedback training C: HC VR Neurofeedback training	Single 18-min CPT session	No adverse events; Mild simulator sickness
Hudak et al.[39]	E: fNIRS neurofeedback + immersive VR (virtual classroom) C: EMG biofeedback (muscle activity control)	60 min/session, 4 sessions/week, 2 weeks, 8 sessions total	1 participant dropped out due to VR discomfort;
Bioulac et al.[35]	E1: Virtual Classroom Cognitive Remediation E2: Long-acting Methylphenidate C: Supportive Psychotherapy	30 min/session, 2 sessions/week, 6 weeks	None side effects reported
Cuber et al.[49]	E: VR environment (cabin + noise-canceling headphones) vs. Baseline (usual study environment)	50 min/session, up to 12 sessions (typically twice/week)	Mild discomfort: eye strain, headset weight, headache

C control group, *E* experimental group, *HMD* head-mounted display, *ADHD* attention-deficit/hyperactivity disorder, *HC* healthy controls, *fNIRS* functional near-infrared spectroscopy, *EMG* electromyography.

In contrast, among studies with interventions shorter than 8 weeks, three reported improvements in ADHD symptoms as assessed by parents or clinicians[27,35,48]. Although the remaining studies did not specifically report changes in core symptoms, significant improvements were observed in cognitive and attentional domains (e.g., CPT, working memory tasks) in the VR intervention groups.

Regarding session duration, five studies administered sessions longer than 30 min[39,40,45,48,49]. Improvements in parent-rated inattention and hyperactivity symptoms were reported in one study, and adherence rates exceeded 85% in three studies, while one study reported that five participants in the experimental group withdrew due to scheduling conflicts[40]; and another study did not report adherence[49]. Five studies employed 30-min sessions, of which two reported improvements in core ADHD symptoms based on parent or clinician ratings (ADHD-RS, SNAP-IV) and one observed no significant changes on the Conners-3 scale[34,35,42]. Additionally, seven studies used sessions of 10–25 min, with one reporting improvements in parent-rated SNAP-IV scores[27].

Discussion

This systematic review evaluated the effectiveness and characteristics of VR-based interventions as non-pharmacological treatments for children and adolescents with ADHD. The included studies varied in design, setting, treatment goals, and VR formats. Despite generally small sample sizes and inconsistent methodological quality, the overall findings suggest that VR interventions are a feasible and promising adjunct or alternative treatment. Given the heterogeneity in study parameters and outcome measures, meta-analysis was not conducted, and the results should be interpreted with caution.

Overall, VR interventions demonstrated significant improvements in core ADHD symptoms, particularly attention deficits and hyperactivity/impulsivity, and outperformed no-intervention control groups. Notably, one study reported superior memory improvement in the VR group compared to the pharmacological treatment group[46]. Although few studies directly compared VR with pharmacological or psychological treatments, some evidence suggests that combining VR with traditional interventions may yield superior outcomes. For example, Kim et al. found that combined VR and standard treatment resulted in greater improvements in attention than traditional treatment alone[26]. Another study reported significant improvements were observed in working memory and executive functions with combined intervention[41]. These findings highlight that while VR interventions are independently effective, their integration with standard therapies may offer additional benefits. Future studies should explore the synergistic effects of VR when used alongside conventional treatments such as medication or cognitive behavioral therapy. Moreover, identifying subgroups—based on age, symptom presentation, or functional needs—that may benefit most from VR or combined interventions is essential for individualized treatment. As VR technology becomes more accessible, developing multimodal, scalable, and cost-effective VR protocols may play an increasingly vital role in comprehensive ADHD management strategies.

Among the three major types of VR interventions, interactive game-based training was the most commonly employed and yielded the most consistent results, improving attention, executive function, and problem-solving skills. Some studies also reported neurophysiological improvements (*e.g.*, enhanced beta wave activity), suggesting potential brain-level changes[23]. In contrast, while exergaming benefited cognitive flexibility and motor control, its effects on attentional deficits were less stable[34]. Virtual scenario-based interventions showed promising outcomes in emotional regulation and social functioning, complementing the limitations of other VR training types[29]. Notably, hybrid training approaches demonstrated superior efficacy in reducing hyperactivity and impulsivity symptoms[42,43]. These findings suggest that interactive game-based VR is best suited for improving attention and executive functions, exergaming may enhance motor-cognitive integration and inhibitory control, while virtual scenario training is more appropriate for emotional and social skill enhancement. Tailoring the intervention type based on specific treatment goals may optimize outcomes.

Participants in the VR intervention groups generally reported high satisfaction. The overall feasibility and acceptability of VR interventions were favorable. Among the 13 studies reporting compliance, adherence was generally high, with most exceeding 85% and seven studies achieving 100%. Low dropout rates and high engagement indicate that VR interventions are well-received among children and adolescents with ADHD. This is likely attributable to the immersive, interactive, and gamified nature of VR, which enhances user motivation and engagement[41]. Qualitative data further support this, with participants describing the experience as enjoyable, challenging, and helpful in improving focus and emotional regulation[37,43,44]. Visual feedback and instant rewards embedded in VR may also play a key role in promoting behavior change and sustaining participation. These findings highlight VR's dual strengths in therapeutic efficacy and user experience, making it a practical and engaging intervention modality.

The reporting of adherence plays a critical role in interpreting intervention outcomes. Studies that reported adherence demonstrated significant improvements across multiple domains, including cognitive, behavioral, and even neurophysiological measures, accompanied by high completion rates and participant satisfaction. Such comprehensive reporting enhances the credibility and feasibility of the interventions. In contrast, studies that did not report adherence mainly documented effects at the cognitive and behavioral level, such as CPT performance, memory, and auditory attention and impulsivity. Although positive outcomes were reported, the lack of information on participants' actual engagement introduces uncertainty in interpreting the results. The lack of adherence data makes it unclear whether non-significant findings, such as the absence of EEG changes, reflect true intervention inefficacy or insufficient participant engagement[25]. Overall, consistent and detailed reporting of adherence is essential for accurately interpreting and comparing the effects of VR-based interventions for ADHD.

Regarding adverse effects, the included VR intervention studies generally reported no serious adverse reactions. A few studies mentioned mild side effects, mainly including a sensation of "heaviness in the head" caused by the weight of the head-mounted device[44], mild dizziness (mean score 0.10/1) and increased dream activity reported by 58% of participants[41], mild simulator sickness[47], and one withdrawal due to discomfort with the VR environment[39]. These mild discomforts were generally transient and acceptable, not affecting overall adherence. Overall positive participant feedback suggests that VR interventions are safe and acceptable. Future studies should focus on technological improvements to reduce these mild adverse effects, further enhancing the comfort and user experience of VR interventions.

VR interventions show potential for both children and adults with ADHD, but their effects vary by age. In children, VR interventions combined with adult-supported behavioral strategies can improve parent-rated ADHD symptoms and objective cognitive measures[35,41,42,45]. In adults, VR primarily targets individual cognitive deficits, enhancing processing speed, working memory, and prefrontal cortex activation, with effects arising from direct interaction with VR tasks[37,39]. These findings highlight the importance of designing VR interventions tailored to different age groups and suggest that future research should explore combined intervention approaches and the transfer of VR training effects to real-world settings.

In terms of setting, most studies were conducted in clinical environments, which provide standardized implementation and higher adherence. However, the feasibility of delivering VR interventions in home settings has gained increasing attention, especially for individuals with limited access to clinical facilities. For instance, in a home-only intervention, participants completed approximately 80 min of training per week, corresponding to around 89% of the planned training time[34]. Future research should explore the scalability of home-based VR interventions, including the development of user-friendly platforms, remote monitoring tools, and technical support systems. Comparative studies assessing the effectiveness and adherence of VR interventions in clinical versus home environments are also warranted. With ongoing advances in VR technology, optimizing its application across diverse settings will be key to improving accessibility and sustained engagement in ADHD care.

Regarding dosage, long-term interventions (≥8 weeks) were associated with more significant and lasting improvements in attention and executive functions[42,43]. One 6-month program led to improvements in hyperactivity/impulsivity, learning difficulties, family relationships, and both visual and auditory attention[42]. In contrast, single-session interventions were generally ineffective[47]. These findings underscore the importance of sufficient intervention duration and frequency in achieving therapeutic benefits.

VR interventions have demonstrated reliable near-transfer effects in children and adolescents with ADHD, with most studies reporting significant improvements on laboratory-based cognitive tasks (*e.g.*, CPT, ATA, working memory, and executive function tests) and neurophysiological measures (EEG, fNIRS)[23,24,36,37,39,44]. Evidence for far-transfer effects is limited, although some studies have shown improvements in core symptoms based on parent-rated scales[27,35] and preliminary enhancements in social skills and motor functions[29,48]. In addition, one study reported that VR interventions could achieve classroom learning transfer, with the experimental group showing significantly higher accuracy on a history knowledge test and greater intrinsic motivation and engagement compared to the control group[38]. In addition, one study reported that VR interventions could enhance learning motivation and efficiency[49].Overall, while VR interventions clearly improve cognitive performance in laboratory settings, evidence for far-transfer effects in daily life, school, and social functioning remains limited, highlighting the need for more objective assessments and long-term studies.

Although most studies report positive effects of VR interventions in children and adolescents with ADHD, some null findings reveal limitations. One study found no improvement in core symptoms on the parent-rated Conners-3 scale[34], and another reported only a trend toward improvement on the SNAP-IV inattention and hyperactivity-impulsivity subscales[41]. Cognitive improvements were inconsistent across studies, with some studies found no significant changes in attention or executive function measures[41,43,48]. Neurophysiological results also conflicted, with one study showing no EEG changes[25] and another reporting increased β-wave activity[23]. One study highlighted potential negative effects, including more omission errors, slower reaction times, and increased distraction after VR training[47]. These findings suggest that VR effects may depend on participant characteristics, task type, intervention dosage, and individual sensitivity.

Despite the promising findings, several limitations should be acknowledged. First, although 22 studies were included, many had small sample sizes and varying study designs—including RCTs, quasi-experimental studies, and pilot experiments—limiting the generalizability and consistency of results. Second, the diversity in VR intervention formats, dosage, settings, and outcome assessments hindered quantitative synthesis, reducing the ability to draw definitive conclusions about intervention efficacy. Third, reporting of critical feasibility outcomes such as adherence, satisfaction, and adverse effects lacked standardization in many studies, impeding a comprehensive evaluation of intervention safety and usability. Fourth, only English-language publications were included, introducing potential language and publication bias and possibly omitting relevant studies from non-English databases. Additionally, some studies excluded participants with comorbid psychiatric conditions, limiting the applicability of findings to the broader, more heterogeneous clinical population. The cost of VR equipment and related technologies is relatively high, especially in developing countries, which may limit the accessibility of interventions and exacerbate treatment inequalities. Therefore, when implementing VR interventions, cost-effectiveness should be considered, and low-cost or shared solutions should be explored to improve accessibility. Future research should prioritize large-scale, high-quality RCTs with standardized protocols to clarify the comparative advantages of different VR modalities and identify optimal target populations.

Further investigations should aim to establish standardized VR intervention protocols and core outcome sets, incorporate both observer- and self-rated measures aligned with DSM criteria, and assess broader functional domains such as emotional well-being and quality of life. Large, rigorously designed trials are needed to compare VR directly with pharmacological treatments and elucidate underlying mechanisms of action, including neurocognitive, behavioral, and motivational pathways. The selection of VR intervention types should be tailored to treatment goals: interactive games for cognitive enhancement, exergaming for motor-executive integration, and scenario-based VR for emotional and social difficulties. Personalized VR intervention strategies based on ADHD subtypes or symptom profiles represent a promising direction for future development.

In summary, this systematic review indicates that VR interventions represent a promising non-pharmacological approach for treating children and adolescents with ADHD. These interventions are effective in improving core symptoms such as attention deficits, hyperactivity/impulsivity, executive function, emotional regulation, and social skills. The reviewed VR formats—interactive gaming, exergaming, and scenario-based training—are applicable across clinical and home settings, with high adherence and user acceptance and minimal adverse effects. Some evidence also points to neurophysiological benefits (*e.g.*, improved EEG patterns), though further research is needed to clarify the underlying mechanisms. Future studies should employ larger sample sizes, standardized outcome measures, and rigorous RCT designs to validate both the independent and adjunctive effects of VR interventions. Moreover, expanding VR accessibility through optimized hardware (*e.g.*, head-mounted displays) and tailoring interventions to age, symptom type, and functional needs may enhance their effectiveness and practical utility.

Methods

Search Strategy and Study Identification

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A comprehensive literature search was conducted in October 2025 across six electronic databases: PubMed, Web of Science, Scopus, Embase, MEDLINE, and PsycINFO. The final search was performed on October 10, 2025. The search included peer-reviewed studies published in English from the earliest available date of each database. Keywords and their related terms for ADHD, VR, and intervention were combined using Boolean operators (see Supplementary Table 1). Titles and abstracts were independently screened by two reviewers to exclude studies that clearly did not meet inclusion criteria. Full texts of potentially eligible studies were further reviewed independently. Disagreements were resolved through discussion. To ensure comprehensive coverage, reference lists of included studies and relevant systematic reviews were also manually screened. The results of the initial screening and full-text review are shown in Fig. 1. A total of 1649 records were identified. After screening and eligibility assessment, 22 studies were finally included in the review, including two identified through manual searching.

Eligibility criteria

Eligible studies included participants diagnosed with ADHD or hyperkinetic disorder according to established diagnostic criteria (e.g., DSM-IV, DSM-5, or ICD-10), or individuals exhibiting clinically relevant ADHD symptoms. Participants of all ages were included, encompassing children, adolescents, and adults, with clear reporting of participant ages. Studies utilized VR-based non-pharmacological interventions aimed at improving behavioral, cognitive, executive, or motor outcomes.

All studies were required to employ RCTs, quasi-experimental designs, or open-label trials. Control conditions included waiting list, treatment as usual (TAU), pharmacological intervention, placebo, or alternative non-pharmacological interventions. To comprehensively evaluate the intervention effects, single-group studies or case studies without a control group were also included, provided that pre- and post-intervention assessment data were reported.

Studies were excluded if the primary intervention involved pharmacological treatment, dietary supplementation, or homeopathy. Studies combining VR with pharmacological or psychological treatments were included only if the VR component was clearly described and aligned with the objectives of this review. Studies not published in English or those reporting only neurophysiological or neurobiological outcomes without behavioral or functional assessments were also excluded.

Data extraction and synthesis

Data were extracted using Microsoft Excel as the platform to systematically organize and record relevant information from all included studies. Data were extracted using a standardized form covering key study details such as authorship, year, country, sample size, participant age, sex, diagnosis, study design, VR intervention type, duration, frequency, setting, control conditions, and primary outcomes (attention, core ADHD symptoms, working memory, and other neuropsychological measures). Two independent reviewers extracted all data. Discrepancies were resolved through discussion, and if necessary, a third reviewer adjudicated. All extracted data were cross-checked to ensure accuracy and minimize inter-rater bias. Due to variability in interventions and outcomes, a narrative synthesis was conducted. Risk of bias for all included studies was assessed using the Joanna Briggs Institute (JBI) critical appraisal checklists appropriate for each study design. Key domains evaluated included study design, sampling methods, measurement of outcomes, statistical analysis, and reporting. Two independent reviewers (Yujie Cao and Leilei Ma) performed the assessment, and any discrepancies were resolved through discussion; if consensus could not be reached, a third reviewer adjudicated. The results of the assessment are presented in Supplementary Tables 2 and 3. This process ensured a systematic evaluation of methodological quality and enhanced the transparency and rigor of the review.

Data availability

All data analyzed in this study are included in this article and its supplementary information files.

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Author contributions
Yanpei Wang conceived and designed the study; Yujie Cao carried out the literature analysis and the writing of manuscripts under the supervision of Yanpei Wang. Yujie Cao and Leilei Ma accessed and verified the study data, developed the analysis plan, and performed the statistical analyses under the supervision of Yanpei Wang. Yujie Cao, Leilei Ma, Ningyu Liu, Jiali Wang, Charlotte Walton, and Yanpei Wang amended and proofread the draft of the paper. All authors reviewed and commented on the study and manuscript.

Competing interests
The authors declare no competing interests.

Additional information
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