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Augmented, Virtual, and Mixed Reality Assessment and Training for Executive Functions in Children with ADHD: A Scoping Review

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Abstract

Background: Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by inattention, motor hyperactivity and verbal and cognitive impulsivity. Impairments in executive functions (EFs), in particular working memory, monitoring and organization of daily life-are frequently observed in children diagnosed with ADHD, and are reflected in behavioural, social-emotional and learning difficulties. The development and use of technologies such as virtual reality (VR), augmented reality (AR) and mixed reality (MR) for ADHD have increased in recent years, using a variety of tools to support including PC, video games, wearable devices and tangible interfaces. **Objectives:** To systematically map the current state of research on the use of AR, VR and MR technologies to assess and/or enhance EFs in children with ADHD. To evaluate the effects on their quality of life and on families' and caregivers' burden reduction. To explore the interventions' clinical validity. **Methods:** A scoping review according to PRISMA-ScR guidelines was conducted. A systematic search was carried out in the Scopus and Web of Science databases for studies published between 2015 and 2025.Empirical studies published in English that examined children with ADHD aged < 13 years were included. AR, VR, or MR-based interventions focused on EF were considered. For each study, the following features were recorded: year and country of publication, design, objectives, EFs considered, technology and hardware used, main results, and limitations. **Results:** Twenty studies were identified. The most frequently addressed functional domains were sustained and selective visual attention, working memory, and inhibition. Assessment interventions primarily involved the use of a head-mounted display (HMD) in conjunction with the Continuous Performance Test (CPT). Training interventions included immersive VR, serious video games, VR with motor or dual-task training, and MR. The results suggest that VR can enhance cognitive performance and sustained attention; however, longitudinal studies are required to evaluate its long-term effectiveness and integrate emotional skills. **Conclusions:** The use of these technologies is a promising strategy for assessment and training of EFs in children with ADHD. These tools provide positive, inclusive feedback and motivating tasks. Nevertheless, larger sample studies, longitudinal follow-ups to confirm the suitability and effectiveness of the technology-based programs are warranted.

Keywords: ADHD; executive function; VR; AR; assessment; training; quality of life

1. Introduction

Attention deficit hyperactivity disorder (ADHD) is one of the most prevalent neurodevelopmental disorders in children, with a prevalence ranging from 5.6% to 7.6%[1]. The disorder is frequently diagnosed during childhood, often persisting into adulthood[2], and it is characterized by persistent difficulties in attention, behavioural self-regulation, and response inhibition, resulting in impairments in daily life[3].

As demonstrated in the extant literature[4–7], children with ADHD exhibit immaturity in executive functions (EFs). EFs can be defined as a set of higher-order cognitive processes used to control and coordinate a wide range of mental processes and everyday behaviors[8,9]. There is a broad consensus that the underlying mechanisms of EFs can be categorized into three overarching domains: response inhibition, working memory (WM; updating), and cognitive shifting/flexibility [10,11]. These domains underpin more complex EFs, such as planning, problem solving, abstract reasoning, and behavioral and emotional self-regulation. A further classification differentiates between cool EF (cEF; cognitive) and hot EF (hEF; emotional) [12]. These dimensions overlap, although they are distinct, forming an integrated system that facilitates goal-oriented behaviors[13,14].

According to this distinction, cEFs function in emotionally neutral situations and require purely cognitive processes to solve abstract and decontextualized problems, such as Go/No Go tasks [15]or n-back tasks[16]. In contrast, hEFs are active in socially and emotionally significant situations, as well as in the choice between immediate gratification and greater long-term reward. These include the capacity to regulate emotions, make decisions, control impulses, and assess risk, as exemplified in tasks involving delayed gratification[17].

In children with ADHD, EFs deficits impair not only academic and social functioning, but also the management of daily activities and novel or complex task[17] For this reason, they represent a key element in neuropsychological assessments and targeted clinical [18–20]. The assessment of EFs in ADHD is predominantly reliant upon the utilization of paper-based neuropsychological tests, questionnaires and subjective observation. Standard treatment includes behavioural therapy, paper-based and/or computer-based cognitive training, video games, mindfulness, exercise and pharmacological treatment (e.g., methylphenidate)[21]. In recent years, immersive technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR) have gained increasing importance. VR can be defined as computer-simulated reality, and is a technology that simulates a three-dimensional (3D) environment in which an individual can fully immerse themselves through virtual agents[22]. AR is a technology that superimposes digital elements onto the real environment. This allows users to interact with virtual objects (e.g. text, images, 3D models) in the real world, thereby enriching it but not replacing it[23,24]. MR combines VR and AR to create a symbiotic environment in which real and virtual objects coexist and interact with each other in real time[25]. Current literature[14,26,27] has drawn attention to the fact that these technologies offer innovative approaches and significant advantages in terms of practicality, ecological validity, behavioural monitoring and experimental control. Traditional cognitive tests have limited ecological validity and poor generalizability because they assess cognitive functions in abstract and structured contexts, risking overestimating the real functional capacities of patients[28]. Immersive VR environments enable the assessment of EFs in realistic everyday settings[29], simulating complex and multitasking situations (e.g., supermarkets or kitchens).

Traditional rehabilitation exercises can be monotonous and reduce treatment adherence. Virtual environments, thanks to gaming elements, a variety of scenarios, and immersive components such as head-mounted displays (HMDs), motion controllers, haptic feedback, and 3D sound environments, improve the sense of presence, motivation, and number of repetitions during rehabilitation[29]. This makes assessments more representative of real-world functioning and facilitates the identification of difficulties that cannot be detected with standardized tests[30]. Standard assessments and laboratory training may be limited by anxiety, poor attention span, and variability in results[31]. Immersive technologies overcome these limitations creating more engaging environments, offering immediate, multimodal feedback and positive reinforcement[32]. Furthermore, the complexity of each task can be the use of sensors and tracking systems[33] and adjusted in real time based on patient's performance[34,35].

Virtual environments can simultaneously elicit the cEF and hEF[36], offering realistic multisensory environments that increase attention, motivation, and engagement. The cEF is activated by complex navigation, multitasking, problem solving, and working memory management, while

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the hEF emerges from immediate rewards, social interactions, impulse control, and frustration tolerance[37,38]. Real-time feedback use allows for modulation of the load on both systems, preventing overload[39,40].

A recent meta-analysis has indicated a significant correlation between VR-based and traditional assessments in measuring distinct aspects of EFs, including cognitive flexibility, attention, and inhibition, despite the high heterogeneity among the studies reviewed[30].In rehabilitation, moderate-to-vigorous-intensity VR exercises produce positive effects on multiple subdomains of EFs, particularly inhibition, attention, working memory, switching, and planning[41,42]. Indeed, the immersive and motivating nature of user interaction in natural and social contexts induces a greater level of arousal that stimulates inhibitory control and cognitive flexibility skills[43].

In light of the above, this scoping review aims to explore and map the available studies on the use of VR, MR, and AR in the assessment and treatment of EFs in children diagnosed with ADHD. Specifically, it aims to identify the current empirical evidence, areas of application, strengths, limitations, and, finally, outline possible future directions for research and clinical practice.

A previous review has discussed some relevant sections on this topic[44]. This scoping review offers several key points that differ. First, the current work focuses exclusively on the specific domains of dysfunctional EFs and not on the management of other ADHD-related symptoms, such as academic performance. Second, the article focuses on children under the age of 13, highlighting a crucial stage in EFs development [45,46]

2. Methods

The scoping review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR)[47].

The review protocol was not prospectively registered.

The search was performed using the Web of Science and Scopus databases. Filters and limits were applied to include only full-text English-language publications from 2015 to 2025, in order to examine recent developments of technologies under consideration and their applicability.

The search was limited to empirical studies due to their higher methodological quality.

All sources were last searched on 22 May 2025.

The search strategy combined free-text terms in titles, abstracts, and keywords. Specifically, the search terms included "Attention Deficit Hyperactivity Disorder" (ADHD) and "executive functions" combined with "virtual reality (VR)/augmented reality (AR)/mixed reality (MR)" using Boolean operators (AND/OR).

The EFs under investigation were: namely, attention, working memory, planning, inhibition, cognitive flexibility, problem solving, and emotional regulation.

The term "Neurodevelopmental disorders" was also included among the keywords to avoid excluding relevant studies that, while not focusing exclusively on ADHD, included subgroups of participants with this diagnosis. In a subsequent phase of the review, specific data referring to participants with ADHD were extracted and analysed separately, if clearly identifiable within the study.

Initially, once duplicates were removed, the titles and abstracts of the studies were examined to ensure they met the eligibility criteria. Consequently, articles that were considered to be potentially relevant were subjected to a full-text review. Two reviewers screened titles/abstracts and full texts independently after a calibration exercise; disagreements were resolved by a third reviewer. The data extraction file was initially downloaded in Excel format from the reference databases and subsequently modified according to the specific needs of the review. No automation tools were used during screening. The data extracted included study characteristics (author, year, abstract), study design, type of technology and analysed EFs.

The eligibility criteria are outlined in the following section.

2.1. Inclusion Criteria

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Studies meeting the following criteria were included:
a. studies published between 2015 and 2025;
b. studies in English;
c. empirical studies;
d. participants aged <13 years;
e. participants with a confirmed diagnosis of ADHD according to DSM-5 (2013) or DSM-5-TR (2022) or ICD-11 (2019) criteria;
f. use of VR, AR, or MR to assess or improve EFs in individuals with ADHD.

2.2. Exclusion Criteria

Studies were excluded if they had the following characteristics:
a. participants ≥13 years of age;
b. participants with suspected ADHD or undergoing diagnostic evaluation;
c. review articles, commentaries, books, editorials, or letters;
d. studies published in languages other than English;
e. papers not relevant to the research objective;
f. studies involving AI, biofeedback techniques, and applied neurophysiology;
g. studies focused only on technological aspects and not on the effects of the assessment or intervention on participants.

2.3. Risk of Bias Assessment

Current guidelines indicate that methodological quality assessment in scoping reviews is optional and primarily descriptive[48]. We considered it appropriate to include an assessment of the methodological quality of the included studies, conducted using the Mixed Methods Appraisal Tool (MMAT)[49], a widely recognised and used tool for critically analysing quantitative, qualitative, and mixed-methods studies.

As the MMAT is applicable exclusively to empirical studies, a post-screening assessment was conducted for all included articles. This assessment focused on the articles adherence to the research question and the adequacy of data collection procedures. In the context of this scoping review, all studies met basic methodological requirements (see Table 1). The MMAT assigns a quality score of 0, 25, 50, 75, or 100 (with 100 indicating the highest quality). The assessment is based on specific criteria, including selection bias, study design, data collection methods, sample size, intervention integrity, and data analysis.

Overall, the included studies met the MMAT checklist criteria. Ten articles (50%) achieved scores ranging from 75% to 100%, indicating high methodological quality. Six studies (45%) satisfied between 50% and 75% of the criteria, indicating moderate quality. Four study (5%) was classified as low quality, with a score below 50%. The main methodological limitations were small sample sizes, incomplete control of confounding factors (lack of stratification by age or by ADHD subgroup, insufficient consideration of sex/gender differences and participants' socioeconomic and cultural background) and insufficient reporting. In several cases, certain criteria were rated as “can't tell,” suggesting incomplete reporting rather than the presence of clear systematic bias.

Table 1. Mixed Methods Appraisal Tool (MMAT).

First author, year	Screening	type of study	MMAT score	% Quality
Bioulac, 2020	✓	Randomized Controlled Trials	4/5	100%
Wong, 2024	✓	Randomized Controlled Trials	5/5	100%
Cho, 2022	✓	Non-Randomize Studies	4/5	100%

Coleman, 2019	✓	Non-Randomize Studies	2/5	50%
Fang, 2019	✓	Non-Randomize Studies	4/5	100%
Eom, 2019	✓	Non-Randomize Studies	3/5	75%
Hong, 2022	✓	Non-Randomize Studies	2/5	50%
Ju YM, 2024	✓	Non-Randomize Studies	3/5	75%
Kim, 2024	✓	Non-Randomize Studies	3/5	75%
Kim, 2020	✓	Non-Randomize Studies	5/5	100%
Merzon, 2022	✓	Non-Randomize Studies	5/5	100%
Muhlberger, 2020	✓	Non-Randomize Studies	5/5	100%
Negut, 2017	✓	Non-Randomize Studies	5/5	100%
Pasarín-Lavín, 2024	✓	Non-Randomize Studies	4/5	100%
Schena, 2023	✓	Non-Randomize Studies	3/5	75%
Seesjärv, 2022	✓	Non-Randomize Studies	4/5	100%
Shema-Shiratzk,2018	✓	Non-Randomize Studies	2/5	50%
Stokes, 2022	✓	Non-Randomize Studies	2/5	50%
Tabrizi, 2020	✓	Non-Randomize Studies	3/5	75%
Ou, 2020	✓	Quantitative descriptive studies	3/5	75%

Screening questions	S1. Are there clear research questions? S2. Do the collected data allow to address the research questions?
Randomized Controlled Trial	2.1. Is randomization appropriately performed? 2.2. Are the groups comparable at baseline? 2.3. Are there complete outcome data? 2.4. Are outcome assessors blinded to the intervention provided? 2.5 Did the participants adhere to the assigned intervention?
Non-Randomize Studies	3.1 Are the participants representative of the target population? 3.2. Are measurements appropriate regarding both the outcome and intervention (or exposure)? 3.3. Are there complete outcome data? 3.4. Are the confounders accounted for in the design and analysis? 3.5. During the study period, is the intervention administered (or exposure occurred) as intended
Quantitative descriptive	4.1. Is the sampling strategy relevant to address the research question? 4.2. Is the sample representative of the target population? 4.3. Are the measurements appropriate? 4.4. Is the risk of nonresponse bias low? 4.5. Is the statistical analysis appropriate to answer the research question

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3. Results

The study selection process is described in Figure 1.

A total of 499 studies were identified, including 142 duplicates. After reviewing titles and abstracts, 291 articles were excluded, along with the aforementioned reasons. Forty-one articles were reviewed. Of these, 21 articles were excluded (see Figure 1).

The scoping review ultimately included 20 relevant studies, which were selected based on predetermined inclusion and exclusion criteria.

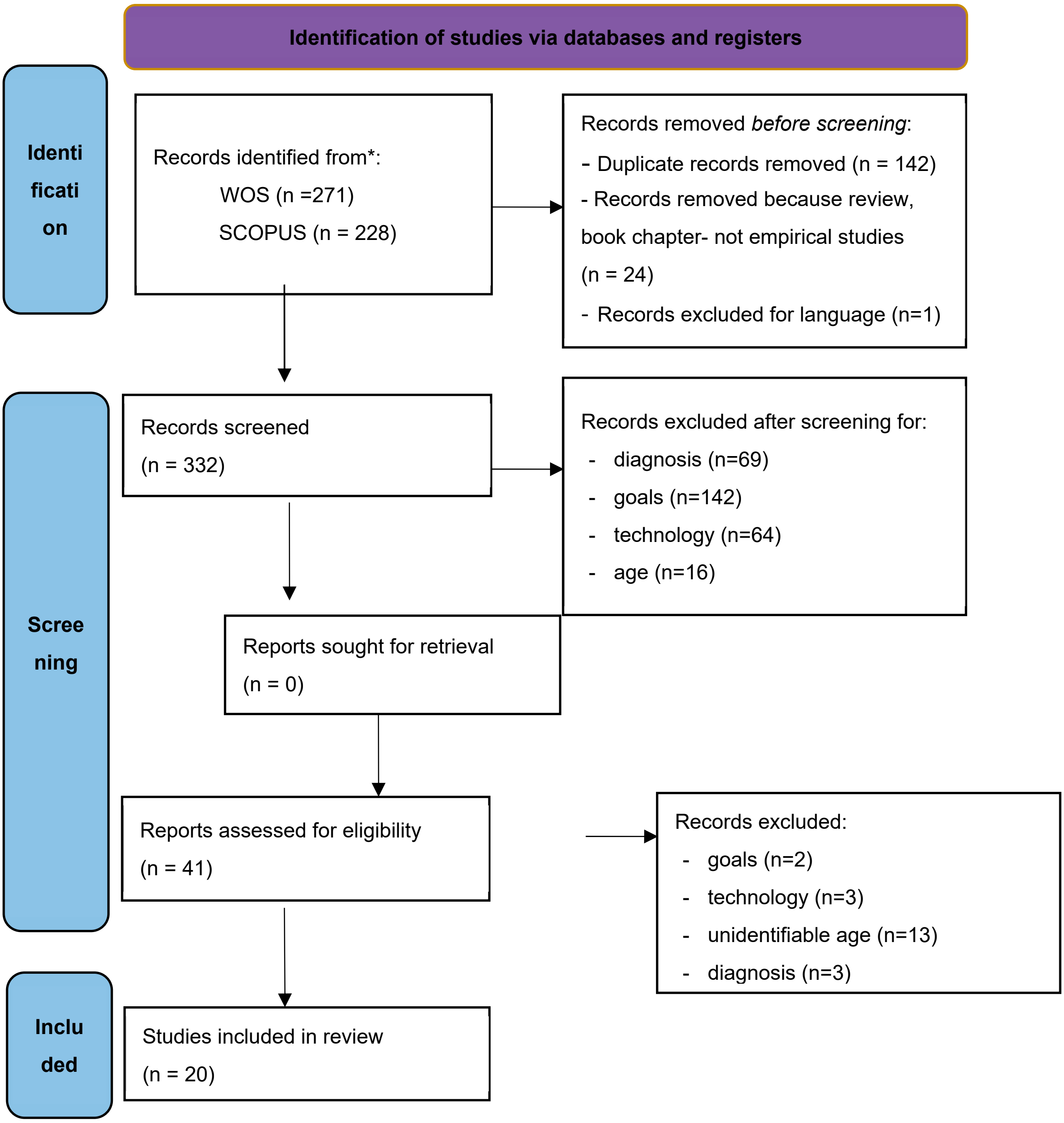

Figure 1. Flowchart of the studies analysed in this review, according to Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR).

The following information was extracted from the articles: research country, research design, participant characteristics, objectives, technology used, EFs investigated, and main results. A summary of this information is presented in Table 2.

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The included studies will be organized and discussed into two broad categories: 1) studies that used immersive technologies to assess EFs in children with ADHD; 2) studies that used these technologies as a rehabilitation intervention.

A total of 20 studies published between 2015 and 2025 from 10 countries were included in the analysis. Of these, 11 studies (55%) assessed EFs, while 9 studies (45%) conducted training interventions. VR was employed in 19 studies, while MR was utilized in a single study. Despite extensive research, no studies using AR that met the inclusion criteria were identified.

Table 2. Summary of the reviewed studies.

Authors	Country	Design	Sample	Aims	Technology	EFs domain	Findings	type of intervention
Bioulac S. et al. (2020)	France	Randomized Controlled Trial	51 children with ADHD (age = 7-11)	To develop and evaluate the effectiveness of a virtual classroom-based cognitive rehabilitation program to improve cognitive distractibility in children with ADHD.	The virtual classroom with HMD	Sustained visual attention; inhibition	The VR group showed significant improvements in attention and inhibition of correct responses in both the virtual classroom task and the CPT; effects comparable to those of methylphenidate	Training
Cho YJ et al. (2022)	South Korea	Controlled experimental study within-subjects	37 children: 20 ADHD (mean age = 11.85) + 17 control group	To investigate the correlation between head movements and signals of inattention and hyperactivity and whether influenced by different social stimuli	VR-CPT	Attention; inhibition	In subjects with ADHD, increased "out-of-context" head movement was associated with greater symptom severity. In both conditions, as the social cue increased, irrelevant head movements tended to decrease.	Assessment
Coleman, B. et al. (2019)	United States	Single-group pre and post design	15 children (ages = 6-13; mean age = 10.5)	Detect classroom improvements in sustained attention and behavioural control after working memory training using a VR based ecological performance measure.	VR with headset	Sustained attention; impulsivity; working memory	Post-training improvements in sustained and selective attention were observed in both standard neuropsychological tests and classroom VR tasks. Working memory training transfers to ecologically valid attention performance.	Training
Fang YT et al. (2019)	China	Between-groups design	140 children: 63 control group (mean age = 8.17) + 77	Explore the feasibility and availability of VR for evaluating symptoms of ADHD	VR with headset	Auditory and visual attention; impulsion/hyperactivity	The VR application significantly differentiated children with ADHD from the control group in terms of correct responses, incorrect responses, and total time (sustained	Assessment

			ADHD group (Mean age = 8.34)				attention, inhibition, attentional control, and processing speed). The study's VR test is more sensitive to visual than auditory attention. Performance on the VR test was significantly correlated with scores on conventional clinical tests.	
Eom H. et al. (2019)	South Korea	Mixed design	38 children: 20 ADHD + 18 TDC (age: 6-17; mean age = 11.85) including N=13 ADHD (65%)≤ 12 years	Analyse differences in attentional performance using a VR neuropsychological	VR-CPT	Visual sustained attention; inhibition	VR-CPT performance correlated significantly with ADHD symptom severity, ADHD group exhibited comparable performance with TDC in the VR-CPT. Presence of a virtual teacher/social cues improved the attention performance of ADHD children.	Assessment
Hong N. et al. (2022)	Korea	Between-groups design	20 children: 11 control group + 9 ADHD group (mean age = 12)	Examine the impact of distractors on the sustained attention of children and adolescents with ADHD in VR.	VR-RVP with a HMD	Sustained attention; response inhibition	Children with ADHD performed comparable to controls in the distraction condition, but had poorer VR-RVP performance in the no-distraction condition. The presence of distractors in the VR-RVP task improved performance in participants with ADHD.	Assessment
Ju YM et al. (2024)	Republic of Korea	Cross-sectional between-subjects design	38 children: 23 typically developing + 18 developmental disabilities including 2 ADHD (ages = 7-12 years; mean age = 8,91)	Evaluate the clinical utility of a virtual reality-based kitchen error task to assess functional cognition in children.	VKET-C	Working memory; visual attention; inhibition; pianification	Children with ADHD committed more errors of omission (inattention) and commission (impulsivity). Although they showed fewer successful trials, they showed longer initial reflection times on some items. A positive relationship was found between task difficulty and the occurrence of commission errors.	Assessment

Kim J. et al. (2024)	Republic of Korea	A between subjects design	24 children ADHD: 12 experimental group + 12 control group (ages = 8 - 13; mean age = 10.7)	Verify of us in VR to treat visual attention in ADHD subjects	VR games based on breathing training	Visual attention	The visual attention of the Participants improved significantly in omission error, commission error better in the experimental group than in the control group	Training
Kim S. et al. (2020)	South Korea	Pre-post experimental design	40 children ADHD: 20 experimental group+ 20 control group (ag e= 8-10; mean age = 8,7)	Develop and evaluate a MR HMD based eye-contact training game as a treatment tool for children with ADHD	Serius game with MR HMD	Visual sustained attention; impulsivity;	Attention improved significantly, impulsivity partially decreased, and mean response times decreased in the ADHD group.	Training
Merzon L. et al. (2022)	Finland	Cross sectional	73 children (age = 9-13): 37 ADHD group (mean age = 10.5) + 36 control group (mean age = 10.9 years)	Develop a naturalistic VR task (EPELI) combined with eye tracking to detect attention deficits in children with ADHD.	VR with eye tracking	Visual attention	Group differences in all EPELI parameters. The ADHD group showed poorer performance with a greater number of eye movements, longer fixations, and shorter saccades with smaller amplitudes.	Assessment
Muhlberger A. et al. (2020)	Germany	Experimental study between-subjects design	128 children: 34 control group (mean age = 12.17) + 68 unmedicated ADHD (mean age = 11.43) +26 Medicated	To examine differences in CPT performance in a VRC scenario and correlations with standard questionnaires	CPT-VRC	Impulsivity; attention	Unmedicated children with ADHD showed greater inattention than both healthy controls and the methylphenidate-medicated group	Assessment

			ADHD = (mean age = 11.89)					
Negut A; et al., (2017)	Romania	Mixed design	75 children (age = 7-13; mean age=9.5): 33 ADHD (mean age=10.24) + 42 control group (mean age = 8.9)	Investigating the discriminant validity of a virtual reality-based measure for assessing attention compared to the CPT test	ClinicaVR Classroom-CPT	Sustained and selective visual attention	ClinicaVR Classroom CPT discriminated between participants with ADHD and healthy controls. Children with ADHD made more errors and had slower reaction times. Reaction times in VR were slower for both groups.	Assessment
Ou YK et al. (2020)	Taiwan	Case study	3 children with ADHD (ages = 8-12; mean age = 9,6)	Evaluate the use of immersive VR exercise games as a rehabilitation intervention in children with ADHD.	Immersive VR game	Attention; inhibition	Participants showed improvements in attention, especially focused, sustained, and alternating attention. Reduction of impulsive and oppositional symptoms.	Training
Pasarín-Lavín T. et al. (2024)	Spain	Experimental study	181 children: 159 neurotypical + 22 neurodivergent including 7 ADHD (mean age = 13.5)	To analyse differences in creativity and EFs components	VR: Nesplora Executive Functions – Ice Cream	Working memory; planning; cognitive Flexibility	Students with ADHD performed similarly to controls on working memory and planning, but scored higher on Flexibility	Assessment
Schena A. et al. (2023).	Italy	Quasi-experimental study	60 children ADHD (age=5-12; mean age = 8): 30 experimental group + 30	To evaluate the efficacy of IAmHero (VR) in improving symptoms and EFs in children with ADHD.	Serius games (IAmHero) with VR	Selective auditory attention; sustained visual attention; planning; inhibition; problem solving	Reduction of core ADHD symptoms assessed with standardized instruments	Training

			control group					
Seesjärvi E. et al. (2022)	Finland	Experimental design between subject	76 children (ages = 9-12): 38 ADHD (mean age = 10.4) + 38 control group (mean age = 10.9)	Validate the EPELI VR task to quantify goal-directed behaviour and executive symptoms of ADHD in realistic daily life contexts.	EPELI VR task with headset	Selective attention inhibition	Children with ADHD performed worse on the EPELI than controls. VR performance was correlated with ADHD symptomatology. The EPELI had good discriminant validity and performed better than conventional neuropsychological tests.	Assessment
Shema-Shiratzky S. et al. (2019)	Israel	Pilot study, single-group	14 children with ADHD (ages = 8 - 12; mean age = 9.3)	Examine the efficacy of a combined motor-cognitive training using VR in non-medicated children with ADHD	Dual-task training (treadmill with virtual obstacle course) using a motion capture camera	Inhibition working memory; flexibility; pianification; attention	There were significant improvements in EFs and memory, even at the six-week follow-up. There was an improvement in dual-task abilities. There was no significant change in sustained attention or vigilance index.	Training
Stokes JD et al. (2022)	USA	Cross-sectional, proof-of-principle observational study	20 children with ADHD (ages = 8-12; mean age = 10)	Evaluate the temporal dynamics of distraction via eye-tracking measures in a VR classroom setting	VR system connected to a headset with integrated eye tracking.	Sustained and selective attention	Distractors reduced the tendency to look at the board over time, even when the distractor itself was no longer actively present (up to 10 seconds later). Distractors interfered with performance regardless of the task being performed. The greater the distraction, the lower the response to the task.	Assessment
Tabrizi M; et al. (2020)	Iran	Quasi-experimental study	48 ADHD children (age = 7-12): 16 VR group + 16 medication group + 16; control group	Compare the effectiveness of VR with medication on the memory of ADHD students.	VR therapy software	Working memory	There was a significant difference in memory variables between the control and VR groups and the control and medication groups. Both interventions led to significant improvements in the memory, but VR therapy showed longer-lasting effects than medication	Training

Wong KP et al. (2024)	China	Randomized Controlled Trial	90 children (ages = 6-12; mean age = 8): 30 VR group + 30 Social VR group + 30 control group	Examine the fleasibility and effectiveness of VR-based social skills training	Social VR intervention	Social Skills; inhibition; emotion regulation	The VR group performed better in social skills, self-control, initiative, and emotional control than the traditional group	Training

Note. ADHD = Attention-deficit/hyperactivity disorder; EFs = Executive Function; VR = virtual reality; CPT = Continuous Performance Test; TDC = typically developing children; HMD = Head-Mounted Display; VR-RVP = VR Rapid Visual Information Processing task; VKET-C = Virtual Kitchen Executive Task for Children; MR HMD = Mixed Reality Head Mounted Display; EPELI = Executive Performance in Everyday Living; VRC = Virtual Reality Classroom.

3.1. Assessment

Studies assessing EFs in children with ADHD (N = 11) primarily evaluated executive cognitive performance using VR head-mounted display (HMD) technology combined with immersive neuropsychological tests in a virtual environment.

Participants' behaviour and executive performance were quantified through actions performed with game controllers and through automatic measures with HMDs or eye-tracking data. Integrating VR with eye tracking[50,51]increases the system's sensitivity in identifying oculomotor markers of attentional control, highlighting greater frequency and duration of gaze shifts toward irrelevant stimuli and enabling real-time detection of distraction.

Negut et al.[52] and, subsequently, Fang et al.[53] reported that the VR based on Continuous Performance Test (CPT) outperformed the traditional CPT in children with ADHD, showing stronger and more significant correlations with conventional neuropsychological measures, particularly in domains of inattention, inhibition, and processing speed. Mühlberger et al.[27] found that unmedicated ADHD children showed more omission errors and slower reaction times than treated, neurotypical ADHD children, highlighting the potential of VR in assessing selective and sustained visual attention.

Immersive virtual classroom environments enhance the ecological and discriminant validity of attentional assessments by closely replicating real classroom conditions. Specific characteristics of virtual environments that influence children's attentional performance include the presence of a virtual teacher (avatar)[54] and the addition of social cues through visual (pointing gestures) or verbal instructions[55]. These appear to facilitate engagement and improve usability. In particular, the presence of realistic distractors often improves, rather than impairs, the identification of attentional deficits, supporting the ecological validity of immersive VR[56].

Naturalistic and immersive VR tasks are particularly effective in highlighting everyday problematic behaviours related to planning, time tracking, and attention skills.

Serious games and VR-based daily life simulations, such as EPELI (Executive Performance in Everyday Living)[57], show high discriminant and predictive validity in differentiating children with ADHD from neurotypical controls. Task performance correlates with parent-rated executive attention difficulties and ADHD symptom severity, while increased commission and omission errors in everyday VR scenarios, including kitchen and multitasking environments[58], reflect deficits in inhibition and sustained attention.

While working memory and planning performance were sometimes comparable to controls, higher levels of perseveration and reduced cognitive flexibility were consistently observed[59].

3.2. Training

The rehabilitation treatment studies (N=9) simulated ecologically valid interactive situations for training EFs in children with ADHD. The applications analysed showed wide heterogeneity in terms of level of immersion, type of interaction, and therapeutic objectives. Overall, the main intervention categories were immersive VR systems with HMDs, VR serious games, VR combined with motor training or dual-task training, and mixed reality systems. The interventions lasted 3 weeks to 6 months, with a frequency of 1 to 3 sessions for week. Pre and post intervention outcomes were measured by us ing neuropsychological tests.

VR-based cognitive training interventions have been demonstrated to predominantly enhance inhibitory processes and attentional control, although the latter has exhibited less consistent outcomes. The benefits appear to be long-lasting, with effects observable even several weeks or months after the end of the intervention, and in some cases comparable to those obtained with pharmacological treatment[60–62].

Working memory appears to be particularly sensitive to VR interventions, especially when training includes cognitive or motor components[61,63]. However, the transfer of these improvements to sustained attentional performance appears to be more limited.

VR assessment provides empirical support for the effects of cognitive training. Coleman. et al.[64] used a VR-CPT to measure attention and response inhibition in children with ADHD before and after computerized cognitive training with Cogmed Working Memory training, finding that the improvement in WM also transferred to attentional aspects.

Emerging evidence suggests that VR and MR technologies can improve not only basic EFs, but also higher-order executive and socioemotional skills in children with ADHD. Serious games and social VR environments have been associated with improvements in planning, problem solving, and emotional regulation, particularly when scenarios are realistic and include real-time feedback[65,66]. Furthermore, technology-based interventions have shown improvements in selective and sustained visual attention as evidenced by breathing training games[67] and mixed reality eye contact games[68]. These findings underscore the efficacy of hybrid approaches in the rehabilitation of EFs.

The following Table 3 quickly shows which cognitive domains have stronger evidence than others, making it easier to interpret the collected data.

Table 3. interpretive summary table.

Type of intervention	EFs Domain	VR Approach	Overall Trend
Assessment	Attention	VR-CPT, classroom	Strong evidence
	Planning / Flexibility	EPELI, multitasking VR	Emerging
Training	Inhibition	Immersive VR, serious games	Moderate–strong
	Working memory	VR + cognitive training	Moderate
	Emotional regulation	Social VR scenarios	Emerging

4. Discussion

Children with ADHD exhibit impairments in several EFs components[69–71]. Children with ADHD tend to perform a greater number of irrelevant actions, suggesting deficits in inhibitory control and action monitoring mechanisms[28].

In recent years, research on immersive technologies for ADHD has significantly increased[44,72]proving to be a useful tool for assessing EFs performance in individuals with ADHD, distinguishing them from the neurotypical population. The present review aims to provide an update on the state of the art of interventions for the assessment and rehabilitation of EFs in children with ADHD aged 6 to 13 years, with particular reference to the use of VR, AR, and MR. In this age group, the majority of studies concentrate primarily on the assessment and/or enhancement of sustained attention in simulated and highly controlled contexts. There is a paucity of studies that address an integrated and comprehensive assessment of EFs, including both cognitive and socio-emotional components, through activities immersed in simulated contexts that more closely mimic everyday life.

The analysis of the included studies shows that the most frequently investigated EFs include sustained attention, response inhibition, working memory, and planning.

Among the various technological systems, the potential of VR is highlighted, and in the current review, it is the predominant technology.

The included studies agree with the literature indicating that VR allows for the recreation of ecologically valid contexts, precise monitoring of participants' behavioural responses, and replicable protocols, despite the varying lengths of real-world exposure to which children with ADHD may be subjected in their daily lives[73].

The potential effectiveness of VR in children with ADHD is highlighted by significant improvements observed in sustained and selective attention, as well as a reduction in impulsivity and average response times. These effects are comparable to those of pharmacological treatment, suggesting that VR may be an effective alternative or supplement to traditional therapies[28,60]. The role of distractors is interesting. Although children with ADHD are generally more distractible, studies show that distractors can temporarily improve attention under controlled conditions[74].

These findings suggest that moderate external stimulation can enhance cognitive performance, thus challenging the traditional approach of eliminating all distractions.

The improvements in EFs observed with immersive technologies can be explained by several interconnected mechanisms: 1) immersion creates a sense of presence, reducing external distractions and promoting sustained attention[75]; 2)the multisensory nature of virtual environments activates multiple perceptual channels simultaneously, compensating for deficits in cortical arousal in line with the Moderate Brain Arousal theory[76]; 3) interactivity provides immediate feedback, thereby enhancing procedural learning, emotional regulation and self-control through interaction with avatars. Practising social skills in a safe environment reduces performance anxiety and allows complex scenarios to be repeated without negative consequences[66]; 4) gamification increases motivation through reward and progression mechanisms, which are crucial for engaging children with ADHD[77]. This allows for longer training sessions with greater ecological validity than traditional paper-and-pencil tests.

This review did not identify any studies investigating the use of AR in relation to ADHD. This was likely due to the filters applied for the search, particularly the age range we focused on. Although some studies on AR were identified, they were excluded because they were not relevant (N=8), reviews and meta-analyses (N=5), or studies that combined neurophysiological techniques (N=2). Further explanations could be traced back to technological limitations, as AR devices (smartphones, tablets, AR glasses) with environmental tracking and digital overlay capabilities have only recently become available for developmental research. Furthermore, the reasons for this gap could be related to safety: while in VR the child is completely isolated from the physical environment (and therefore under control), in AR the child interacts simultaneously with real and virtual elements, which increases the risk of accidents, particularly among children with ADHD and greater motor impulsivity[78].

This scoping review identifies key challenges regarding the transfer of gains observed in virtual environments to real-world settings. Only a limited number of studies have systematically examined the retention of these improvements over time or their generalization to non-virtual contexts.

Despite their promising potential, the integration of immersive technologies into routine clinical practice faces significant ethical and practical challenges. The high cost of equipment, particularly for mixed reality systems, limits access to care[79]. Furthermore, the complexity of the devices and the need to manage potential adverse effects (e.g., cybersickness) require clinical supervision and adequately trained personnel, resulting in further increased implementation costs[80].

Although the available evidence suggests that interactive technologies, particularly AR, could improve communication, emotional comfort and the therapeutic alliance in paediatric settings[81,82], significant ethical concerns remain.

These related to the collection and protection of children's behavioural and biometric data, as well as potential long-term effects of prolonged screen exposure on visual, postural, and social development[83].

Future research should focus on longitudinal studies that evaluate the post-intervention effectiveness at 12 and 24 months. Real-world ecological outcome measures should be included, such as academic performance and classroom behaviour, assessed by teachers using validated scales, and social functioning, assessed by parents through structured observations or standardized questionnaires. Future studies should implement randomized clinical trials and standardized protocols that specify the duration, frequency, and progression of sessions. It is also necessary to control for confounding biases, such as participant medication status, by stratifying samples or reporting treatment, dosage, and timing of psychostimulants in order to isolate the effects of immersive technologies.

Multicentre studies are also needed to test generalizability across populations, settings, and cultures, and to inform the development of personalized interventions.

An important finding of this review is that most studies have used VR primarily to replicate traditional CPT paradigms in immersive environments, rather than developing new assessment tools

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that fully exploit the potential of VR. While this approach facilitates comparability with existing literature, it also represents a missed opportunity.

VR facilitates the development of ecologically valid scenarios. The concept of ecological validity[84,85] refers to the extent to which cognitive demands reflect those encountered in everyday life[86], not just visually familiar contexts. Recent studies have begun to explore multi-errand paradigms, such as SmartAction-VR[28], research in this area remains limited.

5. Limitations and Future Research Perspectives

This scoping review has several limitations that could impact the breadth and completeness of its findings.

First, the review was limited to articles published in English, potentially excluding valuable articles; second, studies using artificial intelligence and techniques such as biofeedback, EEG, and neurofeedback were excluded. This has not only reduced the number of studies on VR and, in particular, AR, but also limited the inclusion of objective measures of cognitive and behavioural change, thus limiting the interpretation of the data to behavioural and observational assessments.

Because we were unable to precisely quantify the proportion or number of ADHD participants aged 6–13 years in mixed-sample studies, potentially relevant studies were excluded for mapping EFs interventions.

Despite the strengths of the works mentioned, there are two limitations to consider.

First, the generalizability of the results remains limited due to the small sample size of the studies reviewed and the lack of comparison with a control group in some studies. Only two studies[61,62] conducted a follow-up, making it difficult to assess the actual stability of the results obtained. Furthermore, significant variability in symptom severity was found, likely due to the presence of comorbidity with other disorders and/or medication use.

It is noteworthy that ADHD studies have repeatedly used VR - CPT, thereby constraining the research focus. Finally, given the young age of the participants, the studies could be affected by the novelty and arousal effects of first-time VR use.

In view of the methodological limitations previously referenced, the following recommendations are proposed:

- greater uniformity among protocols regarding measures (frequency, duration, contexts, pre- and post-intervention tests), types of VRtechnology, presence or absence of distractors, and the use of control groups;
- longitudinal studies with large samples to generalize and consolidate the results over time;
- greater individualized treatment of emotional skills, as virtual environments may not faithfully replicate the wide range of real-world contexts and situations to which children are exposed[87].

Experimental methodologies and randomized controlled trials (RCTs) with samplesof 6-13 children could prove particularly useful for increasing the robustness and replicability of the findings.

Were commended that future studies incorporate real-world outcome measures to enhance interpretability and impact. It is further recommended that studies be implemented using VR to investigate alterations in temporal perception[88–90]. Temporal perception is understood as a possible diagnostic criterion, and the implementation of VR in this capacity could facilitate the rehabilitation of the aforementioned deficit and associated EFs.

6. Conclusions

In conclusion, the results indicate that VR supports the assessment and rehabilitation of EFs in ADHD. Immersive environment can:(1) target attentional and inhibitory behaviours in more realistic contexts, although the results are inconclusive; (2) offer flexibility and immediate feedback; (3) improve children's motivation to assess and improve executive difficulties; (4) integrate ecological data with standardized data.

In the absence of the eligible data, it is not possible to draw conclusions about the use of AR for the purposes of this review. Increasing the use of AR is recommended, as it could offer greater advantages in terms of accessibility and transferability of skills to real-world contexts.AR applications can run on common devices such as tablets and smartphones, reducing costs and increasing inclusiveness [91].

Recent literature highlights how AR is a tool capable of inducing cognitive changes. Specifically, following a four-week training period, there was a significant increase in scores on working memory, cognitive flexibility, inhibition, reaction time, and attention when compared to pre-intervention values[92]. Moreover, the enhancements were sustained at a six-month follow-up, indicating the enduring capacity of these methodologies to facilitate cognitive development[93].

Potentially also be used in non-laboratory settings such as schools, suitable for training EFs, support the teaching and learning process, and facilitate social interactions by promoting emotional skills[94].

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