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REVIEW

Video games for the assessment and treatment of attention-deficit/hyperactivity disorder: a systematic review

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Abstract

Attention-deficit/hyperactivity disorder (ADHD) is a prevalent and serious disorder among children. Video games have shown potential for aiding in child healthcare. Video games could contribute to the assessment and management of ADHD, but there are no previous reviews on this topic. Here, we systematically review the evidence about video game-based assessment tools and interventions for children diagnosed with ADHD. This review followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines. The review protocol was registered in PROSPERO database. We searched four databases—PubMed, PsycInfo, Embase and clinicaltrials.gov—to identify original studies exploring either video game-based interventions or video game-based assessment tools in children with ADHD. After initial screening, full text revision and study selection, 22 articles were finally included in the review. Most studies used PC as platform, with a minority using a video console, pad, or 3D device. Video game-based assessment tools were generally effective in discriminating ADHD cases from controls, and in discriminating between ADHD subtypes. Video game-based therapeutic interventions were well accepted and generally effective in improving cognitive areas and decreasing ADHD symptoms. Gamification and cognitive training could be the main mechanisms underlying the usefulness and effectiveness of video game-based assessment tools and interventions. Software optimization and greater collaboration between developers and healthcare professionals are some of the priorities for future research in this area.

Keywords e-health · ADHD · Video games

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Key points

ADHD is a prevalent disorder that is often difficult to diagnose and treat. New technologies, including video games, could offer an alternative approach to the assessment and management of ADHD.

Video game-based assessment tools were generally effective in discriminating ADHD cases from controls, and in discriminating between ADHD subtypes.

Video game-based therapeutic interventions were generally effective in improving cognitive areas and decreasing ADHD symptoms.

Software optimization, and greater collaboration between developers and healthcare professionals are some of the priorities for future research in this area. Longer follow-up periods are needed to explore the long-term effects of video game-based interventions.

Introduction

Attention-deficit/hyperactivity disorder (ADHD) affects around 5% of children worldwide [1]. Children diagnosed with ADHD have a higher risk of substance misuse, comorbidity with other mental disorders, self-harm, and criminal behavior, as well as a reduced life expectancy [2–4].

Psychopharmacological treatment is not effective in 18–36% of patients, and it can have serious side effects [5, 6]. Low adherence to medication is also a common problem among children diagnosed with ADHD [7]. Additionally, access to specialized screening and treatment is limited in some areas [1, 8]. This calls for a search of alternatives for ADHD assessment and treatment.

To address these issues, authors are exploring alternative approaches, such as the application of new technologies in mental healthcare. Electronic Health (e-Health) could contribute to managing ADHD in children, as well as help closing the gap to mental healthcare provision [9]. Video games could be especially apt for this purpose. It would be expected that children with ADHD present with difficulties engaging in video games due to their short attention span. However, people with ADHD can focus for long periods of time on activities they enjoy, a phenomenon sometimes known as "hyperfocus" [10]. Video games are, therefore, a good opportunity to increase engagement with therapeutic interventions.

Concerns about the negative effects of video games have increased in the past years. Children diagnosed with ADHD may be at a higher risk of video game addiction [11]. However, in the right hands, video games may be a powerful ally. The so-called "serious games", designed for beneficial purposes, could complement traditional approaches [12–14].

Previous reviews have explored the potential of video games for child healthcare: alleviating neuromotor dysfunctions [15], fighting childhood obesity [16], educating about asthma self-care [17], reducing anxiety symptoms [18], or managing chronic conditions [19]. Gamification is a useful strategy to improve patients' engagement and motivation with certain therapeutic interventions, such as cognitive training [20]. There are also reviews about the benefits of cognitive training programs for children with ADHD, as well as cognitive interventions for children with neurodevelopmental disorders, showing promising results [21, 22]. However, there are no systematic reviews about video games for the assessment and treatment of ADHD.

Here, we review the literature evidence about video game-based assessment tools and interventions for children diagnosed with ADHD. We sought to answer the research questions: 'How useful are video games for the assessment of attention-deficit/hyperactivity disorder in children?' and 'How effective are video games for the treatment of attention-deficit/hyperactivity disorder in children?' We discuss the implications of our findings for clinical practice and future research.

Methods

This review followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines [23]. The review protocol was registered in the PROSPERO database (registration number CRD42020166313).

Inclusion/exclusion criteria

Inclusion criteria were:

i. Original studies published in peer-reviewed journals.
ii. Studies that include only people under the age of 18 in their sample, or that, having a mixed sample, provide separate results for child and adult populations.
iii. Studies that either:

Tested video game-based tools to establish a diagnosis of ADHD or assess some elements related to the disorder (cognition, functionality, symptom severity, etc.), providing outcomes about the usefulness of such interventions.

Usefulness was considered as concurrent validity, predictive validity, reliability, and practicality.

Or:

Tested video game-based interventions in children with ADHD, providing outcomes about the effectiveness and/or feasibility of such interventions. Effectiveness in any significant area was considered, such as reduction of symptoms, academic performance, quality of life, prognosis, adherence to medication, etc. Feasibility was considered in terms of response rate, engagement, drop-out rate, and/or acceptability. Diagnoses of ADHD must be either confirmed by a clinician or established using a standardized diagnostic tool.

Exclusion criteria were:

i. protocols for Randomized Clinical Trials (RCTs), and other studies that do not provide measurable outcomes.
ii. Interventions that target parent/caregivers or healthcare providers only.

There were no restrictions regarding participants' gender or ethnicity.

Search strategy

We conducted a systematic literature search in four databases: PubMed, PsycInfo, Embase and clinicaltrials.gov. Last search date was 15th January 2020. There were no restrictions by date or language.

The following search terms were used: ("attention-deficit" OR "attention deficit" OR hyperactivity OR ADHD OR ADD OR hyperkinetic OR "attention-deficit/hyperactivity disorder" OR "attention deficit/hyperactivity disorder") AND ("video game" OR "video-game" OR videogame OR "video games" OR "video games" OR videogames OR "video-games" OR video gam* OR video-gam* OR videogam*).

The references of included studies were also screened.

Study selection process

The articles were selected if they were relevant to the research question, fulfilled the inclusion criteria, and had sufficient methodological quality. Eligible studies were critically appraised. Cochrane Collaboration's tool was used for assessing risk of bias in RCTs [24].

Studies were independently reviewed for inclusion by two authors (IPC and LKJ). Any inconsistencies were resolved with the involvement of a third author (APS). Agreement between reviewers was measured by intraclass correlation coefficient (ICC).

Data extraction

Data were identified, checked, and mined by two independent authors (IPC and LKJ). Using pre-made tables, the following variables were collected: author; design; country; year of study publication; sample size; age of the sample; gender distribution of the sample; measures; name of the videogame, platform and features; type of intervention, and main findings.

Main outcomes were effectiveness and feasibility of video game-based therapeutic interventions for the treatment of attention-deficit/hyperactivity disorder treatment, and usefulness of video game-based assessment tools for attention-deficit/hyperactivity disorder.

Results

Results of the bibliographical search

The initial search revealed 701 results. After initial screening, full-text revision and study selection, twenty-two articles were finally included in the review. Eleven articles explored video game-based therapeutic interventions; while, eleven articles explored video game-based assessment tools (see Fig. 1). ICC among reviewers was 0.93 (95% CI 0.84–0.98) for all articles (ICC = 0.95, 95% CI 0.82–0.99 for articles about treatment, and ICC = 0.91, 95% CI 0.72–0.99 for articles about assessment).

Characteristics of the reviewed studies: diagnosis

Table 1 summarizes the characteristics of the reviewed diagnosis-related studies [25–35].

In studies that reported video game-based assessment tools, the total number of participants was 1473. Sample size ranged between 20 [30, 33] and 798 [26]. Most common design was that of a validation study. There was a majority of male participants. Mean age across studies ranged from 8.6 to 14.7.

Characteristics of the reviewed studies: treatment.

Table 2 summarizes the characteristics of the reviewed treatment-related studies [36–46].

In the video game-based intervention studies, the total number of participants was 717. Sample size of the reviewed studies ranged between 17 [38] and 170 [39]. Most common design was Randomized Clinical Trial (RCT). Follow-up periods ranged between 3 weeks [45] and 24 weeks [44]. Most studies employed a sample composed solely of children with ADHD [36–40, 42–46]; while, one study used a control group entailing non-ADHD children [41]. As with diagnosis-related studies, there was a majority of male participants. Mean age across studies ranged from 7.8 to 15.6.

Video game-based assessment tools

Table 3 summarizes the main findings of the diagnosis-related studies [25–35].

Most of the video games were specifically designed for the assessment of ADHD and were not commercially available, that is, they belonged to the category of "serious games". In the study by Shaw et al. [35], however, commercially available video games were used in addition to a serious game. A computer was the most frequently used platform for the video games (eight out of eleven studies) [23, 25, 27–32]. Three studies created a virtual reality environment using motion sensors, headphones and 3D Glasses equipped in a head mounted display [24, 30, 33]. The remaining study used an Xbox Kinect, in which players control the video game through their body movements, which are captured by a camera [26].

In all of the reviewed studies, a video game-based Continuous Performance Test (CPT) or a similar Go/no Go task was administered to measure participants' executive functioning [25–35]. In the study by Shaw et al., in addition to a video game-based CPT, two commercially available video games were used to assess impulsivity and inhibitory performance, finding no differences between cases and controls [35].

Video game-based CPTs are based upon the traditional, computerized Conners' CPT-II [47], one of the most widely used tools for the assessment of people with ADHD. In Conners' CPT-II, participants must press the spacebar as quickly as possible when any letter but the X appears on the screen; while, they must inhibit themselves when the letter X appears. In the video game-based versions of the test,

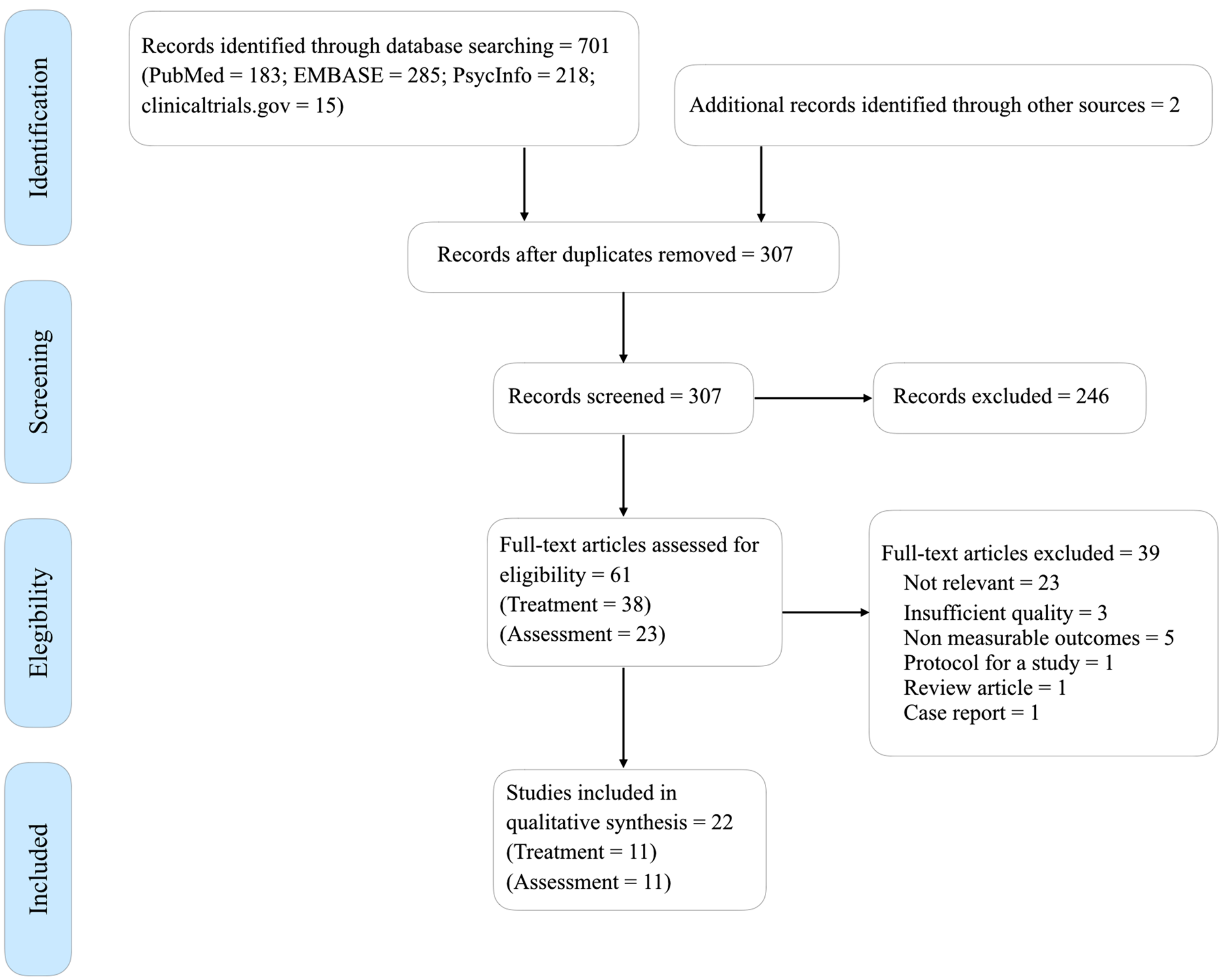

Fig. 1 Flow chart of the bibliographical search

Table 1 Characteristics of the reviewed studies: diagnosis

Study	Design	Country	Sample size	% Male	Population (*n*)	Mean age (SD) (years)
Areces et al. (2016) [25]	Diagnostic accuracy cross-sectional study	Spain	113	76.9	AD (27) I/H (28) Combined (31) Healthy controls (27)	10.96 (2.9) 9.64 (3.08) 11.45 (3.06) 12.67 (0.7)
Berger et al. (2016) [26]	Validation Study	Israel	798	61.02[a]	ADHD (339) Healthy controls (459)	9.27 (1.65) 9.71 (1.64)
Delgado-Gomez et al. (2017) [27]	Not specified	Spain	30	70	ADHD (30)	10.3 (1.4)
Díaz-Orueta et al. (2014) [28]	Validation Study	Spain	57	73.68	AD (23) I/H (2) Combined (32)	11.48 (2.23) 9.5 (0.7) 10.81 (2.73)
Faraone et al. (2016) [29]	Cohort study	USA	113	49.08	ADHD (66) Psychiatric controls (47)	12.3 (2.5) 13.6 (2.5)
Gutierrez-Maldonado et al. (2009) [30]	Not specified	Spain	20	65	ADHD (10) Control (10)	Not reported
Heller et al. (2013) [31]	Validation Study	USA	52	53[a]	ADHD (26) Control (26)	12.6[b] 14.7[b]
Mitchell et al. (1990) [32]	Validation Study	USA	201	73.13	Hyperactive (49) Control (152)	10.21 (1.76) 9.08 (2.14)
Parsons et al. (2014) [33]	Diagnostic accuracy cross-sectional study	USA	20	100	ADHD (10) Control (10)	10.6 (1.51) 10.2 (1.32)
Pollak et al. (2009) [34]	Validation Study	Israel	37	100	ADHD (20) Control (17)	12.6 (2.4)[c]
Shaw et al. (2005) [35]	Exploratory study	UK	32	90.62	ADHD (16) Control (16)	10.3[b] 8.6[b]

ADHD attention-deficit/hyperactivity disorder (without distinctions), *AD* attention-deficit, *Combined* ADHD combined type, *I/H* impulsivity/hyperactivity, *Psy.Control* Psychiatric control group, *SD* standard deviation, *UK* United Kingdom, *USA* United States of America

[a]Percentage calculated from data

[b]Standard deviation not reported

[c]Mean age and standard deviation data for all the sample

participants must interact with the test—by, for instance, pressing a button on the hand controller or executing a certain movement in the Kinect or VR systems—when certain items or characters appear; while, they must inhibit themselves when different items or characters appear. Video game-based CPTs are intended to have the same properties as traditional Conners's CPT II with the additional advantage of gamification.

Some of the studies tested the diagnostic ability of the video game-based assessment by comparing it with a clinical diagnosis [25, 26, 30–32]; while others employed a validated questionnaire as the gold standard [27–29, 33–35]. Areces et al. [25] tested the diagnostic accuracy of the video game AULA Nesplora against a clinical diagnosis of ADHD. This video game, which operates with 3D glasses in a head mounted display, creates a virtual reality environment to evaluate several cognitive areas (attention, impulsivity and processing speed) in children. The AULA Nesplora discriminated between children diagnosed with ADHD and controls [25]. In the study by Delgado-Gómez et al., authors aimed to discriminate between ADHD subtypes by comparing video game-based CPT with the Strengths and Weaknesses of ADHD Symptoms and Normal Behavior (SWAN) scale. They found a positive correlation between CPT-measured reaction time and inattentive subtype [27]. Faraone et al. [29] and Heller et al. [31] aimed to validate the PC game Groundskeeper against a clinical diagnosis of ADHD. In the study by Heller et al., diagnosis accuracy of the Groundskeepr was 78% for ADHD-inattentive type, and 75% for ADHD-combined type [31]. Faraone et al. obtained a similar Figure (0.79) in the ROC analysis [29].

Video game-based therapeutic interventions

Table 4 summarizes the main findings of the treatment-related studies [36–46].

Video games were specifically designed for the assessment of ADHD and were not commercially available, although one of the games was based on the popular, commercial game "Tetris" [38]. Most video games ran on a computer (eight out of eleven) [37–40, 42, 44–46], two ran on a

Table 2 Characteristics of the reviewed studies: treatment

Study	Design	Duration	Country	Sample size	% Male	Population (*N*)	Mean Age (SD) (years)	Completion and compliance
Benzing et al. (2018) [36]	Randomized clinical trial	8 weeks	Switzerland	51	84.3[a]	Intervention (28) Control (23)	10.46 (1.3) 10.39 (1.44)	7 dropped out during the study 7 refused to participate in the post-test
Bikic et al. (2018) [37]	Randomized clinical trial	8 weeks	Denmark	70	84.24[a]	Intervention (35) Control (35)	9.77 (1.97) 10.14 (1.52)	4 dropped out of before completion. 66.5% of participants did ≥ 20 sessions
Bikic et al. (2017) [38]	Randomized clinical trial	7 weeks	Denmark	17	76.5	Intervention (9) Placebo (8)	15.6 (0.99)[b]	1 withdrew consent after randomization
Bul et al. (2016) [39]	Cross-over randomized clinical trial	3 months	The Netherlands	170	80.58[a]	Group 1: First Intervention then TAU (88) Group 2: First TAU then Intervention (82)	9.89 (1.28) 9.82 (1.24)	89.4% completed The study. 81.8% completed the 10-week follow-up
Chacko et al. (2014) [40]	Randomized clinical trial	5 weeks	USA	85	77.22[a]	Intervention (44) Placebo (41)	8.4 (1.4) 8.4 (1.3)	80% intervention group met compliance criteria (≥ 20 training days within 5 weeks)
Davis et al. (2018) [41]	Non-randomized clinical trial	4 weeks	USA	80	56.25[a]	ADHD (18) ADHD HSS (22) Non-ADHD (40)	10.35 (1.4) 10.2 (1.26) 10.54 (1.49)	Four participants from the non-ADHD group dropped out from the study
Dovis et al. (2015) [42]	Randomized clinical trial	3 months	The Netherlands	89	79.77[a]	Full intervention (31) Partial intervention (28) Placebo (30)	10.6 (1.4) 10.3 (1.3) 10.5 (1.3)	9% were lost to post-test 96.7% met compliance criteria (25 training days within 5 weeks)
García-Redondo et al. (2019) [43]	Quasi-experimental clinical trial	14 weeks	Spain	44	61.36[a]	Intervention (24) Control (20)	11.83 (2.71)[b]	Not reported
Lim et al. (2012) [44]	Non-randomized clinical trial	24 weeks	Singapore	20	80	Intervention (20)	7.8 (1.4)	85% completed the study
Prins et al. (2011) [45]	Randomized clinical trial	3 weeks	The Netherlands	51	82.35[a]	Intervention (27) Control (24)	9.59 (1.12) 9.33 (1.05)	100% study completion
Van der Oods et al. (2014) [46]	Pilot study of efficacy	14 weeks	The Netherlands	40	82.5[a]	Intervention (18) Wait list (22)	10 (0.97) 9.55 (1.43)	100% study completion

ADHD attention-deficit/hyperactivity disorder (without distinctions), *HSS* High severity subgroup, *SD* standard deviation, *TAU* treatment as usual, *USA* United States of America

[a]Percentage calculated from data

[b]Mean age and standard deviation data for all the sample

Table 3 Features and usefulness of the video game-based assessment tools

Study	Video game name	Platform	Video game-based assessment method	Gold standard/comparator	Main findings
Areces et al. (2016) [25]	AULA Nesplora	PC and HMD	Virtual Reality Environment to assess A, I, PS and MA through a Go/no go task	Clinical diagnosis	Distinguished between predominantly I/H and combined types from control, and between I/H type from AD type. (visual/auditory channel with and without distractors $p<0.001$)
Berger et al. (2016) [26]	MOXO-CPT	PC	Multilevel game with CPT tasks to assess A, I, H and RT	Clinical diagnosis	Except impulsivity index, fair to excellent ability to distinguish between ADHD from Control with Sp and S rates of 85% or higher
Delgado-Gomez et al. (2017) [27]	Kinect CPT	Xbox Kinect	Kinect-based CPT, assessing CE, CT and RT	SWAN scale	Correlation between RT and I ($p=0.04$)
Díaz-Orueta et al. (2014) [28]	AULA Nesplora	PC and HMD	Virtual Reality Environment to assess A, I, PS and MA	Conner's CPT II	AULA's convergent validity with CPT. Able to monitor the effects of pharmacological treatment of ADHD with regards to AD, I, PS and MA
Faraone et al. (2016) [29]	Goundskeeper	PC	Multilevel game with a Go/no Go task with distractors to assess A, I, H and EF	Conner's CPT II	Groundskeeper can significantly discriminate ADHD patients from other psychiatric patients, with a ROC analysis of 0.79, which is similar to Conner's parents scale (0.76), both better than CPT Groundskeeper maintains a FPr of zero for a S of 37%, a PPP of 100%, and a NPP of 53%
Gutierrez-Maldonado et al. (2009) [30]	Virtual Classroom	HMD	React to target stimulus to assess O, RT and RT variability	Clinical diagnosis	The mean value for omission errors found for the ADHD group was much higher than the non-ADHD group ($F=17.78$; $p<0.001$)

Table 3 (continued)

Study	Video game name	Platform	Video game-based assessment method	Gold standard/comparator	Main findings
Heller et al. (2013) [31]	Groundskeeper	PC	Multilevel game with Go/no Go tasks assessing A, I, H and EF	Clinical diagnosis	Groundskeeper was able to accurately detect Combined type 75% of the time and AD type, 78% through machine learning techniques. Able to accurately detect anxiety 71% of the time and depression 76% of the time. CPT and Conner's Brief rating scale were more predictive than the game
Mitchell et al. (1990) [32]	Not specified	Apple IIe microcomputer	React to one or two target stimuli, with increasing complexity	Clinical diagnosis	The H group was significantly slower, more variable and made more errors than Control group ($p<0.001$)
Parsons et al. (2014) [33]	Virtual Classroom	HMD	React to target stimulus to assess O and RT	Conner's CPT II SWAN scale	ADHD had more O, C and overall body movement than Control. ADHD were more impacted by distraction than Control. Virtual Classroom measures were correlated with traditional ADHD assessment tools at least with moderate effect sizes
Pollak et al. (2009) [34]	VR-CPT	PC	Multilevel game with different trials/tasks to assess O, C and RT	TOVA CPT	DHD showed slower RT and more O errors ($F(2,68)=3.8$ and 9.9, $p<0.05$ and $p<0.001$, respectively). S and Sp of the TOVA were 65% and 94%, respectively. S and Sp of the No VR-CPT were 84% and 88%, respectively. S and Sp of the VR-CPT were 79% and 94%, respectively

Table 3 (continued)

Study	Video game name	Platform	Video game-based assessment method	Gold standard/comparator	Main findings
Shaw et al. (2005) [35]	The Pokémon Task, The Revenge of Frogger and Crash Bandicoot II	PC and PlayStation 2	The Pokémon Task is a video game-based CPT, The Revenge of Frogger and Crash Bandicoot II are commercially available video games through impulsivity and inhibitory performance were assessed	Conner's CPT II	No difference between the inhibitory performance of ADHD compared Control on two commercially available computer games. On two computerized tasks, Control showed no significant difference on performance across the two tasks; however, ADHD showed a significant reduction in impulsive responding and an increase in on-task activity on The Pokémon Task compared to the Conner's CPT II

3D 3 dimension; *A* Attention; *AD* attention-deficit, *ADHD* attention-deficit/hyperactivity disorder (without distinctions), *CE* commission Errors, *Combined* ADHD combined type, *CPT* Continuous performance test; *EF* Executive functions; *FPr* False positive rate, *H* Hyperactivity, *HMD* Head mounted display, *I* Impulsivity, *MA* motor activity, *NPP* negative predictive power, *O* Omissions, *PC* personal computer, *PPP* positive predictive power, *PS* Process speed, *RT* reaction time, *ROC* receiver operating characteristic, *S* sensitivity, *SOA* simulation of occupational activities, *Sp* specifity, *SWAN* strengths and weaknesses of ADHD symptoms and normal behavior, *TOVA* test of variables of attention, *VR* virtual reality

pad [41, 43], and one ran on the video game console Xbox Kinect [36].

The most common type of intervention (nine out of eleven studies) was cognitive training. Cognitive training consists of a series of tasks (such as solving puzzles or performing memory exercises) aimed at improving one or more facets of executive functioning, such as attention [36–38, 41, 43, 44] working memory [40, 42, 45, 46], reaction time [36, 37], cognitive flexibility [42, 46], or motor ability [36, 41]. The theory behind the effectiveness of cognitive training is based on neuroplasticity and the possibility of reorganization of neurological functions [38].

Video game-delivered cognitive training was generally effective, with significant differences between intervention and control groups in seven studies [36, 39–42, 45, 46]. In all of these studies, the improvement was measured in terms of better cognitive functioning; while in one of the studies, it was expressed as both an improvement in cognitive functioning and as a reduction in ADHD symptoms [46]. For instance, in the study by Benzing et al. [36], intervention group showed faster reaction time, switching and motor ability than the control group after playing the Shape Up game for Xbox 3 times a week for 8 weeks. For its part, Bul et al. [39] obtained an improvement in daily life skills (22.7% improvement in Time management and 7.8% improvement in planning/organization) after playing the behavioral training PC video game Plan-It Commander 3 times a week for 10 weeks.

The remaining study, by Lim et al. [44], used attention training and neurofeedback through the video game CogoLand, which was not controlled with a usual manual controller. Instead, it was operated by a Brain–Computer Interface, with EEG electrodes detecting the brainwave activity of children, so that the avatar only moved if children were focused. There was a significant reduction in ADHD symptoms after playing the game 3 times a week for 8 weeks.

Acceptability

Engagement rates with the video game-based interventions were generally high, with low rates of dropouts. For instance, in the study by Bikic et al. [37] participants in the intervention group completed 34.4/35 of the sessions; while, controls completed 31.2/35, with no significant difference among groups. In the study by Chacko et al. [40], exploring the videogame Cogmed WMT, 80% of participants in the intervention group met compliance criteria (≥ 20 training days within 5 weeks).

Satisfaction questionnaires yielded mixed results. For instance, Bikic et al. [37] employed the Activity Perception Questionnaire (APQ) to explore feasibility. Both cases and controls scored low on the dimensions of Interest ('did you like the training, was it interesting?'); and Value ('was it

Table 4 Features and effectiveness of the video game-based interventions

Study	Video game name	Platform	Features	Type of intervention	Procedure	Main findings
Benzing et al. (2018) [36]	Shape Up	Xbox Kinect	Exergame aimed to improve A, I, H, MA and RT	CT	8 weeks 3 times/week, at least 30 min	Intervention group showed faster overall RT ($F(2.48)=4.08$; $d=0.58$; $p=0.049$), switching ($F(2.48)=5.09$; $d=0.65$; $p=0.029$) and MA ($F(2.48)=7.69$; $d=0.80$; $p<0.001$)
Bikic et al. (2018) [37]	ACTIVATE	PC	Videogame with different trials/tasks to improve A, I, H and RT	CT	6 times/week for 8 weeks	Primary hypothesis "intervention would have an effect on sustained attention" could not be confirmed ($p=0.643$). Intervention group showed greater accuracy in planning ($b=1.22$; $p=0.006$)
Bikic et al. (2017) [38]	Scientific brain training and tetris	PC	Six different programs, each of them aimed to improved different areas of cognition	CT	30 min, 5 days a week, for 7 weeks	Both interventions are feasible, but not very interesting for adolescents with ADHD No significant differences between groups on cognition and symptoms
Bul et al. (2016) [39]	Plan-It commander	PC	Serious Game where Management and planning/organizing are the main tasks	BT	A max of 65 min, 3 days a week for 20 weeks	Evidence of improvement in the performance of daily life skills: 22.7% improvement in Time management skills ($p<0.001$) and 7.8% improvement in Plan/Organization skills ($p=0.001$)
Chacko et al. (2014) [40]	Cogmed WMT	PC	Training program to improve storage and processing components of verbal and no verbal WM	CT	30–45 min, 5 days a week, 25 days	Intervention group did not result in significantly greater improvements except in greater improvements on measures of verbal ($b=9.17$; $p=0.005$) and nonverbal ($b=17.07$; $p<0.001$) simple working memory storage

Table 4 (continued)

Study	Video game name	Platform	Features	Type of intervention	Procedure	Main findings
Davis et al. (2018) [41]	Project EVO	Ipad	Employment of a perceptual discrimination A/Memory task and a continuous visuomotor "driving" task	CT	30–45 min, 5 days/week, 4 weeks	ADHD group ($p = 0.033$) and ADHD HSS group ($p = 0.003$) showed significant improvement in A (Effect Size (d) = 0.35) Both the ADHD group ($p = 0.016$; Effect Size (r) = 0.38) and the non-ADHD group ($p = 0.040$; Effect Size (r) = 0.32,) showed a decline in Omission. ADHD HSS improved significantly on WM ($p = 0.014$; Effect Size (r) = 0.51) and I ($p = 0.027$; Effect Size (r) = 0.47)
Dovis et al. (2015) [42]	Braingame brian	PC	Adventure/crafting video game aimed to improve WM, CF and I	CT	35–50 min 25 sessions	Improvement in Inhibition (− 18.66 score; $p < .001$), CF training (− 19.14 score; $p < .001$, and for all the levels of the WM training ($p < .001$)
García-Redondo et al. (2019) [43]	Boogies academy and cuibrain	Tablet	Serious games based on Gardner's Theory of Multiple Intelligences	CT	10 min, 2 days a week, 14 weeks	In the intervention group there was a 25.6% improvement in Total quality of attention, a 28.0% improvement in Concentration, and a 26.9% improvement in Correct responses. Improvement was significantly greater than in the control group for Total quality of attention ($p = 0.013$), Concentration ($p = 0.009$) and Correct responses ($0 = 0.002$)
Lim et al. (2012) [44]	CogoLand	PC	BCI system. The avatar moves if the patient is focused, detected by EEG	AT, NFB	8 weeks, 3 sessions/week, 30 min. Then, once each month for 3 months	Significant improvement in ADHD symptoms: − 4.6 and − 4.7 for inattentive symptoms and hyperactive-impulsive symptom, respectively (both $p < 0.01$). Monthly booster did not significantly improve symptoms further

Table 4 (continued)

Study	Video game name	Platform	Features	Type of intervention	Procedure	Main findings
Prins et al. (2011) [45]	Not reported	PC	Classic WMT with gamification elements (storyline, animation, reward system)	CT	3 weeks, 1 session/week, 35 min	Memory span in the intervention group significantly increased (t 1⁄4 3.075, *df* 1⁄4 26, $p < 0.01$), no significant increase was found in the control group
Van der Oods et al. (2014) [46]	Braingame brian	PC	Adventure/crafting video game aimed to improve WM, CF and I	CT	5 weeks, 25 sessions, for a max of 50 min	Intervention group showed significant improvement in inattention (26.0% reduction; $p < 0.01$) and hyperactivity/impulsivity (26.7% reduction; $p < 0.01$) Intervention group showed more improvement in EF (total score) ($p < 0.05$) and metacognition ($p < 0.05$)

A(T) Attention (training), *AD* attention-deficit, *ADHD* attention-deficit/hyperactivity disorder (without distinctions), *BCI* brain–computer interface, *BT* Behavior training, *C* commissions, combined ADHD combined type, *CF* cognition flexibility, *CPT* continuous performance test, *CT* cognitive training, *EEG* ElectroEncephaloGram, *EF(T)* Executive function (training), *H* hyperactivity, *HSS* high severity subgroup, *I* impulsivity, *MA* motor ability, *max* maximum, *min* minutes, *NFB* NeuroFeedBack, *O* Omissions, *PC* personal computer, *PS* process speed, *RT* reaction time, *SBT* scientific brain training, *STM* short-term memory, *TAU* treatment as usual, *TOVA* test of variables of attention, *VR* virtual reality, *w* weeks, *WM(T)* working memory (training) useful to do the training?'); and modestly in the dimension of Choice ('was it your choice to play?').

Discussion

Video game-based assessment tools and therapeutic interventions were generally useful and effective in the diagnosis and treatment of ADHD. This is consistent with previous reviews that have shown how children with mental disorders can benefit from video game-based strategies [18].

Of note, there was a majority of males across the studies, which can be argued is another element that limits the extraction of conclusions. However, ADHD affects male population predominantly [48], so this might be considered a natural reflection of the epidemiology of the disease rather than a bias of the reviewed studies. In regard to age, most studies employed a pre-adolescent sample, which is reflected in the content and relative simplicity of the video games. Of note, in the study by Bikic et al. (2017), which employed an adolescent sample (mean age = 15.6), participants showed a low interest in the intervention.

The benefits of video games

The benefits of "serious games" can be explained by several mechanisms. One of these mechanisms is "gamification", a trending technique in e-Health interventions that promotes behavioral change and users' engagement [49]. In children, the rewarding effects of video games may be of special importance to increase adherence. Video games may not be perceived as a treatment or as an imposition by caretakers, which can be less burdensome for children. Video games can also increase participation, motivation and feelings of agency [13]. However, novelty seeking is a strong feature of ADHD [50]. Thus, long-term engagement may be more problematic, possibly resulting in a progressive reduce in engagement over time.

Several studies show that video games can improve cognition and have a positive impact on neurobiology [13, 51]. Video game-based cognitive training may help in the formation and restructuring of neurobiological pathways, especially in children, who have increased neuroplasticity compared to adults [52].

Some of the reviewed games, particularly the CogoLand game explored in the study by Lim et al. [44], employed neurofeedback training, which can improve concentration and other neurocognitive skills. The effects of neurofeedback have been showed in neuroimaging studies, which showed a normalization in brain functioning in ADHD patients [53].

Video games are also being used successfully in Autism Spectrum Disorders (ASD), which often are comorbid with ADHD [54, 55]. For instance, a pilot study showed promising results of an interactive video game for improving cognition in children with ASD and ADHD symptoms [55].

Implications for clinical practice

Video game-based assessment tools and therapeutic interventions could supplement traditional approaches. Due to the limitations of public health systems, gaps in the provision of follow-up for ADHD patients are frequent. Since they can operate without face-to-face visits with professionals, home-based interventions could reduce this gap by, for instance, compensating for the delay between medical appointments.

Gold standard for ADHD diagnosis is a specialized clinical evaluation, which cannot be replaced. However, access to this evaluation is still limited in some populations. Video games could facilitate screening. Using machine learning classification techniques, executive functioning deficits could be inferred from gameplay data, providing an objective measurement tool.

There are several barriers to overcome before video game-based assessment tools and therapeutic interventions can be fully implemented in the clinical practice. Healthcare providers need to be trained in the basics of e-Health to be able to offer guidance to their patients and coordinate with them the use of new technologies [56]. Caretakers may have some reservations about video game-based interventions due to the lack of integration of e-Health into public health systems. In this regard, it is worth noting the efforts made in some countries, such as the UK, to integrate e-Health within the service portfolio [57].

Future lines of research

Software optimization is a priority for serious games development. An attractive interface is a valued feature, as is an appropriate adaptation of the software to the requirements of health settings. Healthcare professionals and computer engineers must collaborate closely, so that serious games can reach the quality of their commercial counterparts [58, 59].

Another possibility is using the potential of commercial video games instead of designing serious games. Commercial video games present with some obvious advantages: the budget of commercial video game developers is several times superior to that of healthcare researchers, which allows them to create more attractive interfaces and more sophisticated functioning. This can make them better accepted among children. Some authors are calling for selecting or adapting video games that can be useful for our health goal among those available in the market [60].

Most of the reviewed video games ran on a computer; while a minority ran on a tablet or video console. In contrast, none of the reviewed video games operated on a smartphone. This is in contrast with the rise of smartphone-based technology in both commercial and healthcare settings [61]. Smartphones represent a good opportunity for implementing e-Health, and some reviews and meta-analysis have shown the effectiveness of mobile health applications for mental disorders [62, 63].

Strengths and limitations

To our knowledge, this is the first systematic review about the usefulness and effectiveness of video game-based assessment tools and therapeutic interventions in children with ADHD. Our findings must be considered in light of some limitations: the number of results were low, and the heterogeneity of the reviewed studies precluded performing a meta-analysis.

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Compliance with ethical standards

Conflict of interest The authors declare they have no conflict of interest.

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