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Computer-assisted learning for improving ADHD individuals' executive functions through gamified interventions: A review

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ABSTRACT

Computer-Assisted Learning (CAL), specifically gamified interventions, is a promising intervention for people suffering from Attention-Deficit/ Hyperactivity Disorder (ADHD) in terms of improving their life behavior, academic achievement, and self-control. Most of the studies showed improvement in ADHD individuals' engagement and motivation along with other skills the game targeted. They emphasized the importance of applying gamified interventions based on theoretical concepts. There is no survey that focuses on ADHD in relation to SG; this paper presents attempts to fill this gap. Using a literature review, this paper investigated the effects of Serious Games (SGs) on ADHD. Based on the analysis of several studies, this paper concludes that gamified intervention is a promising learning technique for improving the Executive Functions (EFs) for ADHD individuals; it can be used as a non-medical treatment alternative. This paper concludes with some recommendations for game creators.

1. Introduction

The use of computer-Assisted learning (CAL) has increased exponentially throughout the world in recent years. Because it is such an efficient method, several countries have adapted this type of teaching to further optimize their pedagogy [8]. CAL helps to keep students engaged by allowing them to access information with ease rather than requiring them to read several books on a singular topic to gain the same knowledge [8,25]. CAL is beneficial in motivating students to learn [6,42]; it has also proven useful in assessments [36,37,38]. In subjects such as Spanish and Math, it enables students to take tests and to improve their results upon re-testing. Most students have access to online courses, and CAL has proven to be an effective form of teaching pupils.

Serious games (SGs) are a part of CAL educational games; they have undergone extensive development in recent years with the help of experts' intervention in gamified activities [11,4,20]. Traditional teaching approaches do not catch on as well, as they can cause students to lose interest and increasing learning difficulty. Moreover, cognitively challenged students deal with pressure differently than other students—consequently, these students need pressure-free environments [17,7,5]. One way of overcoming this issue is to use SGs, which are becoming more and more accepted,by both educators and students, they keep this population of students from feeling the pressures of every day learning environments, helping them to feel more comfortable and to enjoy learning.

Attention-deficit/hyperactivity disorder (ADHD) is a medical condition involving a person's brain development and activity [21,35,16]. It affects a person's attention span and executive functions (EFs) and thus strongly impacts daily life behaviors and educational attainment. ADHD individuals may need special intervention, sometimes beyond medical treatment, to help them to control their personal and behavioral skills in order to interact with others. Many researchers have recognized these needs and addressed them in the literature. They have mainly attempted to reduce ADHD individuals' symptoms and improve their EFs with the help of CAL. They have employed gamified interventions, specifically SGs, to gain and hold ADHD individuals' attention and increase their motivation and engagement; to some extent, they have succeeded in this pursuit.

This paper investigated the effects of gamified interventions on ADHD individuals' performance by reviewing games described in the literature that were primarily developed to improve ADHD individuals' EFs. For each game, the paper focused on the game features, approach, and experimental results. The remainder of the paper is organized as follow: Section 1.1 introduces the basic concepts used in this paper and Section 1.2 explains the searching methodology, Section 2 reviews the

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Table 1
Basic Concepts.

Keyword	Definition
CAL	Computer-assisted learning is the development and implementation of technology within education for a variety of purposes.
ADHD	Attention-deficit/hyperactivity disorder is a medical condition involving deviation from normal brain development and activity.
EFs	Executive functions are a set of processes that help people to plan, organize, and successfully complete tasks. They are used to categorize neurologically based skills involving mental control and self-regulation.
SGs	Serious games are educational games designed for a primary purpose other than entertainment.
Gamified intervention	Gamified intervention incorporates game elements into non-game environments for learning purposes.
Attention	Attention is the concept of the behavioral and cognitive process of selectively concentrating on a specific aspect of information.

background, Section 3 describes existing ADHD SGs, Section 4 comprises a detailed discussion of these SGs, and Section 5 concludes.

1.1. Basic concepts

The basic concepts used in this paper are summarized in Table 1 to make the main concepts of the paper clear and understandable to the reader. The definition of each Keyword is specific and is limited to the context of this paper.

1.2. Searching Methodology

The papers included in this research have been collected from the searching engines (Google, Google Scholar, Saudi Digital Library (SDL)). We were targeting the serious games developed for people with special needs in the society, specifically the ADHD individuals. We have used the following terms and Boolean operators: (Attention-Deficit/Hyperactivity Disorder or ADHD) and (serious games or games or gamified intervention or gamification) and (Executive Functions) and (Computer assisted learning (CAL)) as search keywords.

2. Background

2.1. Attention-Deficit/Hyperactivity disorder (ADHD)

ADHD is a medical condition involving brain development and activity that affects an individual's attention and self-control. It is one of the most common disorders among children, affecting approximately 5.5 million children between the ages of 4 and 17 [22,13,12]. Working memory (WM) is the ability to store information and then produce a response based on that internal representation [7]. Visual spatial WM is seen as the most critical neuropsychological deficit in children with ADHD [29,7]. Children with this disorder typically display behaviors that originate from inattentiveness, hyperactivity, or a combination of both. Even though ADHD is not considered to be a learning disability, it would be unfair to disregard the effects ADHD has on learning, as the whole process becomes more challenging for students with ADHD [29]. Thus, approximately 66% of children who are diagnosed with ADHD take daily medication to help control their symptoms [21,16]. Many of the medications available are stimulant-based. The theory behind these medications is that they regulate important neurotransmitters and norepinephrine, which are often in short supply in students with ADHD [30]. Children with ADHD do not always perform as well as others in tests, indicating challenges in their EFs. EFs are mental processes that control thinking, emotions, and behavior [21,30,29]. ADHD affects the way children learn in modules, which include EFs. As shown in Fig. 1, ADHD is divided into three subtypes [21,30]:

- Predominantly inattentive ADHD-I: the person is easily distracted, keeps switching between activities, and has difficulty maintaining focus on one task.
- Predominantly hyperactive impulsive ADHD-HI: the person has difficulty sitting still or waiting for things.
- Hybrid type ADHD-C: combines the symptoms of the previous two types.

People diagnosed with ADHD struggle to finish activities, as they quickly grow bored [30]. Therefore, it is common for students with ADHD to show academic underachievement and other educational problems [21]. Consequently, they require cognitive behavioral therapies to help them to perform better [35]. One such therapy is SGs, which are being developed at a greater volume than ever before. However, they are not necessarily targeted at people with ADHD [18,2]. This is important because the number of people diagnosed with ADHD is increasing, meaning that the demand for more SGs specifically designed for ADHD individuals is increasing as well. Fig. 2 shows the increase in numbers of children ages (4–17) diagnosed with ADHD in U.S. [9].

2.2. Serious games (SGs)

Educational games, known as SGs, have seen a huge boom in development in recent years. This is because of experts' intervention in gamified activities. Studies on SGs show huge improvements in their ability to motivate and develop positive attitudes. This is due to the way in which the learner is being entertained and involved in exciting learning activities, further developing the learner's patience and problem-solving skills. Nevertheless, developing SGs and integrating these with technology-enhanced learning (TEL) has proven challenging. Augmented reality (AR) is a form of TEL that focuses on integrating virtual information with reality. This technology has the ability to assist, motivate, and provide feedback, all of which can be tailored to the student and his or her specific needs [21,35,17]. This is more efficient and useful, as a single style of assistance cannot be useful to every individual student, especially those who have any type of disability. SGs have been used to develop impaired skills in people with disabilities, including ADHD individuals. Some ADHD individuals have even been diagnosed via SG assessment[28]; researchers have integrated SGs with advanced techniques for diagnosing, such as data mining, machine learning approaches[30,19,1], and fuzzy decision systems [32].

3. Existing SGs for ADHD

SGs represent a promising new area for ADHD learning, but this paper authors found few studies in the literature that tackle this type of intellectual disability. This section reviews the SGs that have been developed specifically to address single or multiple skills deficiency in ADHD. The main aspects of each game (i.e., name of the game, number of participants, age of participants, training period, skill targeted, methodology, platform/type, advantages, limitations, evaluation methods, findings) are summarized and presented for comparison in Table 2.

Dovis et al. [15] studied the effectiveness of using game elements to improve EFs in ADHD. They determined the short- and long-term effects of gamified training for multiple EFs, including visual spatial WM, inhibition, and cognitive flexibility using different evaluation measures [39]. Here, various environments are used to train three EFs: full-active mode, where all three EFs are trained simultaneously; partially active

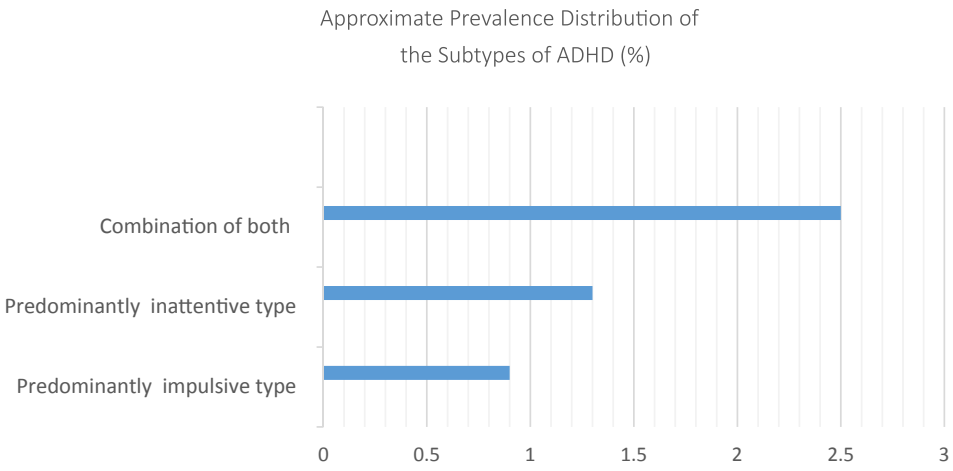

Fig. 1. The ADHD subtypes and their distribution in the population.

mode, where inhibition and cognitive flexibility are trained; and placebo mode, in which only WM is trained [15]. The SG is called "BrainGame Brian (BGB)" [26]; it features 25 sessions lasting 40–50 min each. Each session contains three ordered training tasks to train the three EFs. The researchers concluded that training multiple EFs simultaneously through the game was a successful strategy; further, they linked the improvements they detected to the type of medical treatment used [15].

In another study [10], researchers developed an SG titled "Plan-It Commander" to promote behavioral learning along with strategies needed for daily life functioning. It uses several psychological theories (e.g., the self-regulation model and the social cognitive and learning theory) to accomplish its intended objectives. It is an online game featuring three mini-games, each of which supports players' achievement of independent goals and focuses on specific skills. Moreover, each game is divided into 10 main missions—other optional and special features are included for motivational purposes. The creators gathered participants' and their parents' feedback about the SG using a survey questionnaire approach; they achieved positive acceptance.

Shaw et al. [31] analyzed the effect of inhibitory performance on ADHD individuals when they accomplished the same tasks in different contexts and compared their results with normal participants' results. They tested three different contexts: a commercial gaming context ("The Revenge of Frogger" and "Crash Bandicoot II"), a standard computerized context, and a game-like context. The results showed enhanced inhibitory performance, in which the ADHD individuals displayed equivalent performance to normal participants; they found this performance to be significantly better in the game-like context. Shaw et al. [31] emphasized using game or game-like contexts for ADHD learning to increase participants' motivation and reduce the errors that come with using traditional computer-based learning.

Retalis et al. [27] introduced and examined two games to assess their effects on ADHD. "Mathloons" is a mathematical game to practice basic math operations (i.e., addition, subtraction, multiplication, and division) over a limited range of numbers in an enjoyable way. "Space Motif" enhances players' organizational skills through ordering, sorting, and pattern-matching objects; it also aims to improve spatiotemporal skills. In both games, the improvement in players' EFs was statically significant, with a high rate of interest and motivation.

Reading difficulty is one symptom of ADHD that [24] investigated via "Fairly-tale"—a narrative-driven interactive interface designed to help players to overcome this difficulty. They used a complex architecture featuring an adaptive behavior training game platform (ABTGP) with brain–computer interface (BCI) and motion sensing. This complex platform creates a stimulating context in which to play. Consequently, players' attention spans improved, and their hyperactive behavior decreased, which had a positive impact on their reading ability.

Videogames are a type of SG featuring animation and 3D models; they have been used to help people suffering from ADHD. One such game is "aTenDerAH" [22]; it integrates a 3D videogame into the ATutor e-learning platform to improve players' learning abilities by training cognitive skills. The case study used to assess this game was carried out in an e-learning course; the students who participated were motivated and gave positive feedback [13] designed an SG named

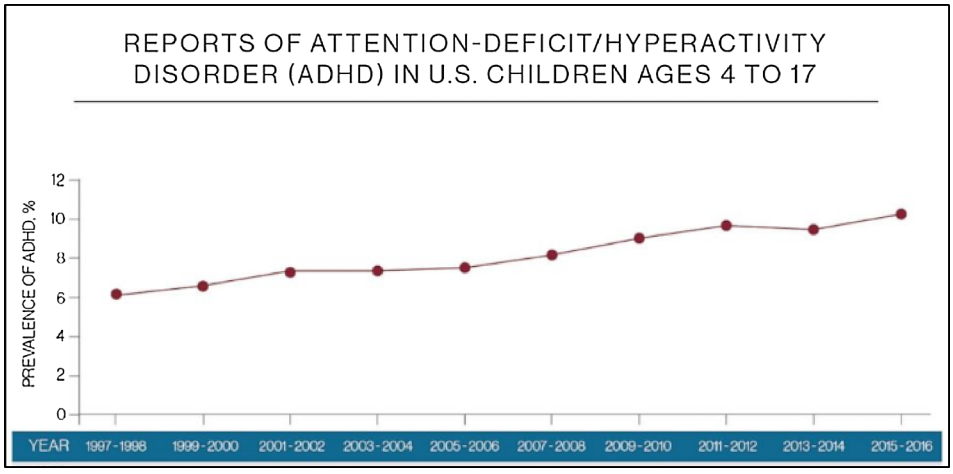

Fig. 2. The number of ADHD children ages (4–17) in U.S. [9].

Table 2
Existing Serious Games (SGs) for ADHD.

Name of Game	No. of Participants	Age of Participants	Training Period	Skill Targeted	Methodology	Platform/ Type	Advantages	Limitations	Evaluation Method	Findings
BrainGame Brian (BGB) [15]	89	8–12 years	25 sessions in 5 weeks	Multiple EFs & motivational behavior	Three environments:full-active, partially active, and placebo	Desk-based	- Cost-effective treatment - Easy to implement - Multiple EFs trained simultaneously	Supervision is needed	Observation& pre–post test	Improvements are greater when training multiple EFs rather than single EFs
Plan-It Commander [10]	42	8–12 years	20 h	Behavioral learning and daily life functioning	Based on psychological theories	Online game	- Guided by theories - Home context - Can be played by children independently - Support 3 different skills through 3 independent mini-games	Availability of Internet and sound facilities	Pre–post test	Positive acceptance
The Revenge of Frogger & Crash Bandicoot II [31]	16	6–14 years	14 min	Inhibition and on-task activity	Mixed methods	Laptop & PlayStation	- Improvements in inhibitory performance - Error reduction - On-task activity increase - Motivational	- Small sample size - No differentiation between the responses of different ADHD subtypes - No gender-based comparisons	Observation	ADHD individuals had equivalent performance to normal participants and were significantly better in game-like context
Mathloons [27]	11	4–8 years	8–11 sessions, each lasting 30 min	Math skills	Kinems approach	Desktop/ laptop	- Adjustable (e.g., difficulty, time, operation, etc.) - All collected data are stored - Motivational	Small sample size	Pre–post test	Improvement in EFs
Space Motif [27]	11	4–8 years	8–11 sessions, each lasting 30 min	Ordering, sorting, pattern-matching, andspatiotemporal skills	Kinems approach	Desktop/ laptop	- Adjustable settings - All collected data are stored - Motivational	Small sample size	Pre–post test	Improvement in EFs
Fairly-tale [24]	5	1st or 2nd grade	5 weeks	Reading skills	Interactive interface with feedback-driven controls	ABTGP	- Stimulated platform - All collected data are stored in cloud - Feedback-driven control - Instant feedback	Complex platform settings	Pre–post test, BCI values,interviews	Prominent improvement
aTenDerAH [22]	2	Young adults	1 month	Cognitive abilities & motivational behavior	Videogame integrated into e-learning architecture	ATutor e-learning platform	- Keep students' attention - No central coordination	Small sample size	Post test	Positive feedback
Antonyms [13]	10	8–12 years	Not specified	Impulsivity control	3 mini-games in a single frame	Personal computer	- Touch screen interaction - Can be used as assessment and rehabilitation tool - Immediate and multi-modal (i.e., visual and auditory) feedback	Pilot study done on non-ADHD children	Observation	Expect an increase in focused attention

(*continued on next page*)

Table 2 (*continued*)

Name of Game	No. of Participants	Age of Participants	Training Period	Skill Targeted	Methodology	Platform/ Type	Advantages	Limitations	Evaluation Method	Findings
							- Participants' behaviors easily monitored			
The Journey to Wild Divine [3]	24	5–15 years	12–24 sessions, each lasting 45 min	Breathing and relaxation skills	On-screen mentors and sensors	Laptop	- Reduced disruptive behaviors - Participants were interested and motivated	- Small sample size - Minor side effects like dizziness, mood swings, and loss of appetite	Observation & pre–post test	Positive effects on reducing disruptive behaviors
ChillFish [32]	16	Adults (25–41 years)	22 min	Relaxation skills	Uses respirationas a game mechanism	Personal computer	- Easy and playful design - Uses special non-wearable equipment - Not affected by room temperature	Need to balance between engagement and relaxation	Stress indicator value	Positive effects
Dance Dance Revolution (DDR) [23]	74	6th grade	2 sessions weekly, each lasting 25 min	Reading skills	Participants match on-screen movement cues to form a dance	Sony PlayStation consoles	- Very motivated architecture	- Small sample size - Participants must attend - Intervention period	PAL–RW	Positive effects
Self-City [14]	2	13–15 years	6 sessions, each lasting 30–45 min	Social skills	3D virtual world in which series of events form a mission	Personal computer	- Simple tasks - Game activities are from real-life situations - Easy to master the game - Interesting environment	Low graphic resolution	Observation	Increased level of attention for long periods
Nintendo DS Brain Game (NDSBA) [40]	10	Adolescents (5th–11th grade)	20 min for 5 weeks	Academic engagement	Daily brain games	Nintendo DS	- Supports two types of ADHD - Sufficient tools for parameter measurements	- Small sample size - Improvement not seen in all participants - Large number of instruments used for evaluation	Lab-assist results, observation,pre–post test	Increased focus and improved EFs
Algebra Champ [34]	3	High school	10 min for each class, 8 classes total	Math skills	Practicing mathematical exercises	Web-based application	- Simple interface - Level of difficulty selection	- IT restriction for security issues - Word problem - The results are school-specific	Pre–post test & interviews	Improvement in math performance
ATHYNOS [4]	11	7–10 years	8 sessions, each lasting 20 min	Attention skills	Combined architecture of game elements and AR	Desktop	- Reduced response time - High level of interest and motivation - High level of satisfaction	None	Observation	Improvement in concentration level

"Antonyms" for educational and rehabilitation processes. It consists of three mini-games integrated into single framework—each game contains a series of activities to promote learning, the autonomous management of impulsive behaviors, and the inhibition of irrelevant thoughts. Its implementation has not been completed, but the deliverables from the initial pilot study predict positive effects in improving attention in ADHD individuals.

Another type of SG is biofeedback games, which aim to teach players how to modify their bodies' functionality in order to improve their health, such as training them in breathing and relaxation techniques [3] examined ADHD individuals' ability to learn from the biofeedback game "The Journey to the Wild Divine." In their study, participants divided into two groups. The first group played the game for 12 sessions and the second group played for 24 sessions to test the effects of short- and long-period usage. In both cases, the game had a positive impact on reducing disorderly behavior in ADHD. "ChillFish" [32] is another biofeedback game that uses respiration techniques to calm ADHD individuals and help them to reach a state of relaxation by reducing their stress levels. The game uses a non-wearable controller created from LEGO pieces in the shape of a fish; it contains a sensor to detect changes in body temperature while breathing. The players' movement character in the game is controlled by the sensor's value. The adult participants attained positive effects from playing the game, but the need to balance engagement and relaxation is one of the game's challenges requiring improvement. [33] continued the study of ChillFish, evaluating it on children. The experiment was not successful like it was in adults, as very few of the children successfully completed the test (only 3 out of 12 children completed the experiment successfully). However, for the children who completed the test, their results were similar to those of the adults.

McGraw et al. [23] developed an effective interactive game using multimedia intervention to reveal the presence of reading impairment in ADHD individuals. "Dance Dance Revolution" (DDR) is a game in which participants match onscreen movement cues to form a dance. The creators used the process assessment of the learner: test battery for reading and writing (PAL–RW) to evaluate the participants' performance. There were some limitations in the study, but the results were encouraging. Another virtual interactive game called "Self-City" [14]is a 3D virtual world intended to help ADHD individuals to interact with real simulated social situations. People play individually, responding to a series of events to complete one mission. The initial results showed increased concentration levels for long spans of time, helping players to control their behavior and deal with situations in positive ways.

One type of brain game, "Nintendo DS Brain Age (NDSBA)" [40], was used to investigate the ability of such games to increase ADHD individuals' academic engagement if played on a daily basis. The researchers used a large number of instruments to measure their parameters of the mental state participants reached; they also used a combination of evaluation methods. Most of the participants noticed positive improvement in their focus, calmness, engagement, behavior, etc. with daily playing. The researchers recommended these games be played on a daily basis to achieve long-term effects.

For an active and creative classroom, one study [34] emphasized the importance of game-based learning as a complement to traditional leaning in school curricula for ADHD individuals' development. They argued that this would help them to engage and interact positively in the classroom. They evaluated the results of using "Algebra Champ" to improve ADHD individuals' skills, particularly in math; the results were encouraging.

Emerging assistive technologies have also contributed to this field, such as augmented reality serious games (ARSG) [41], which help to engage children with ADHD by creating motivating environments via innovative treatment methods. For example, "ATHYNOS" [4] combines AR with SG to create a novel architecture for improving ADHD individuals' cognitive–behavioral patterns. The structure showed significant improvement in managing time, social skills, and concentration.

4. Discussion and recommendations

This study explored a novel CAL strategy based on an assistive intervention that helps treat people with ADHD. CAL can be used to support learning processes that help students to achieve better results than traditional learning. A gamified intervention approach (i.e., SGs) is used as a special training intervention to reduce ADHD individuals' symptoms.

Overall, this study found a positive impact of using SGs as an assistive tool in training interventions for ADHD individuals' EFs and overall attitudes. The effectiveness of SGs has been proven with evidence, although most of the studies in the literature conducted their experiments with a small sample size. However, their initial findings are encouraging, suggesting future work on the topic with larger datasets is in order. In addition, Table 2 illustrates that while the time duration for training (i.e., playing time) was short for some SGs, the results had positive and long-term effects, and significant improvement was notable in most of the cases. This short interaction proves the effectiveness of SGs and their ability to be employed as a short-term treatment, which is especially recommended for less severe cases of ADHD.

The SGs had a positive effect on skills impairment, which is the main facet of ADHD. SGs are an attention-grabbing approach that keeps players concentrated for long time-spans. This mood can be sustained as long as the player remains motivated. Thus, this paper recommends that game developers aim to keep players' motivation high for an adequate time-span, especially for ADHD-I individuals. It is very important to keep motivation high—otherwise, it players' attention can be diverted, and the objectives of the game can be lost. This can be achieved using attractive contexts and adequate interactive instruments such as AR, tangible devices, touch screens, multimedia interventions, etc. These technologies can increase players' motivation and engagement, enhancing their behavior, self-control, and academic performance.

Nonetheless, SGs can have a negative impact if they are overused; thus, they must be used with caution. For example, game addiction can lead to other serious problems, requiring long-term treatment. SG use should be monitored and controlled by a therapist or parent, as some games can be played at home, or use some SGs feature settings to automatically turn off after a certain amount of time (i.e., session time). Supervising ADHD individuals is crucial and plays a vital role in their improvement whilst lessening negative side effects of game play.

One point worth mentioning about this gaming solution is the availability of the devices required to play these games. Nowadays, personal computers, Liquid Crystal Display (LCD) monitors, autofocus webcams, and PlayStation are common devices in many homes; they are available everywhere and are relatively affordable. In addition, game creators are beginning to write games for mobile applications, which will help in disseminating SG technology. This might bolster the computer game market, giving it a promising future and creating opportunity for more SG development.

There is a need to find non-pharmaceutical treatments for children with ADHD, and using gamified intervention may fill this gap due the impressive effects these games have within a short period of time. This solution needs more investigation and research in the future to confirm its effects, especially because parents prefer non-pharmaceutical solutions [40].

These studies do have several limitations, which are summarized in the subsequent points:

- Most of the studies did not differentiate between ADHD subtypes in the experiments, so there was no clear specification about the suitability of the game for different types based on their targeted skills. The most common type is the combined type, as shown in Fig. 1.
- One study proved that training multiple EFs simultaneously through the game was successful. This finding needs more evidence to help

researchers determine whether targeting a specific skill is better than targeting multiple skills. The answer will influence SG creation and help developers to achieve their objectives.
- Gender comparisons were missing, which opens a new topic for researchers to investigate (i.e., how the effects of SGs may differ in males versus females). This will help creators to balance the needs of each gender in various aspects when creating SGs.
- The effects of multiple players were not discussed; however, this aspect may be involved in enhancing social and communication skills. The wide use of online games and improvements in internet technology may help to spread such game options.

Since gamification intervention can be used as a replacement for traditional interventions for treating ADHD, it is necessary that SG specifications be based on pedagogical theoretical concepts and therapists' advice to creators; this will ensure that creators have a well-rounded understanding of patients' needs, allowing them to build SGs that highly match their needs.

In sum, this paper found that gamified interventions are a promising technology—more contributions need to be made in this field. Consequently, an interdisciplinary team consisting of concerned parties such as educators, designers, programmers, therapists, and parents must be invited to integrate their efforts, collaborating to develop SGs that target the impaired skills in ADHD individuals. They should consider the following elements: different types of ADHD, limiting gaming time, using advanced interactive media, encouraging multi-player games, and creating gamified interventions based on theoretical principles. This can augment ADHD medical treatment, and in some cases, could even replace it.

5. Conclusion

With technological innovations, CAL's contributions have grown immensely, especially in regard to helping people with special needs. One promising CAL strategy is gamified intervention (i.e., SGs), which can be used as a special training intervention for people diagnosed with ADHD. This paper analyzed existing ADHD SG studies and explored SGs' effects on ADHD individuals' performance. Most of the studies reported improvement in ADHD individuals' engagement and motivation, along with other skills the games targeted. Gamified intervention is a promising learning technique that improves ADHD individuals' EFs; it can be used as a non-medical treatment supplement or alternative.

The paper also clarified some of SGs' limitations and suggested possible solutions to these that game inventors could consider moving forward. Moreover, it found that integrating SGs with TEL could assist people suffering from ADHD by keeping their motivation and engagement up within the game via advanced interactive devices. However, this needs to be balanced, as using SGs for long periods of time can lead to gaming addiction, amongst other problems. Therefore, educators, designers, programmers, therapists, and other stakeholders should be involved in the creation of SGs to maximize its benefits and control its drawbacks. In the future, the present researchers intend to develop an SG that addresses some of the recommendations included here.

Declaration of Competing Interest

None.

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