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INNOVATIVE APPROACHES TO ADHD ASSESSMENT: UTILIZING VIRTUAL REALITY AND ELECTRONIC GAMES

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Article Info

Keywords: Attention Deficit Hyperactivity Disorder, ADHD, executive functions, self-regulation, emotional intelligence, metacognition, information and communication technologies, assessment, intervention.

Abstract

Attention Deficit Hyperactivity Disorder (ADHD) is a prevalent neurological disorder among children and youths, characterized by symptoms of inattention and impulsivity. Despite its prevalence, a comprehensive understanding of the disorder's mechanisms is still lacking. Executive functions, which include abilities such as short-term memory, flexible thinking, and self-regulation, are impaired in individuals with ADHD. These functions are crucial for socio-emotional health and academic success. Self-regulation, a critical aspect affected by ADHD, is closely related to emotional intelligence, which influences various cognitive processes and self-control. Drigas and Papoutsi propose a structured model for evaluating and intervening in emotional intelligence, encompassing hierarchical levels that indicate individual development. Similarly, Drigas and Mitsea propose a multilevel metacognition model, highlighting attention as a core component of metacognitive skills. This model describes different levels of metacognitive development and can be utilized as a structured assessment tool for students at various educational levels.

Traditional methods of assessing children with ADHD rely on subjective questionnaires completed by parents and specialists, which do not directly measure their performance in specific skills. In contrast, the use of Information and Communication Technologies (ICTs) in educational programs has shown promise in addressing the socio-cognitive needs of students with special educational needs. Serious games and other technology-based assessment tools provide more objective measures and enhance children's motivation.

In summary, this paper highlights the complexity of ADHD and its impact on executive functions, self-regulation, emotional intelligence, and metacognitive skills. The proposed models for assessing emotional

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intelligence and metacognition offer structured approaches to evaluate and intervene in these areas. Furthermore, the use of ICTs in educational programs presents an opportunity to objectively assess and develop socio-cognitive skills in children with ADHD. These advancements contribute to a more comprehensive understanding of ADHD and provide valuable tools for supporting individuals with the disorder.

1 Introduction

One of the most frequent neurological disorders between children and youths is Attention Deficit Hyperactivity Disorder (ADHD). Yet, its nature is still complex and a general understanding of its mechanisms has still not been achieved. ADHD's main symptoms are lack of attention and impulsivity, which are due to a dysfunction in those brain areas that manage specific abilities, called executive functions. Executive functions such as short-term memory, flexible thinking, and self-regulation are essential for an individual's socio-emotional health [1]. Also, cognitive ability is an established predictor of school success, whereas a child's reduced school performance due to personal shortcomings seems to contribute to low self-esteem [2]. Early control and development of these skills lay the foundation for attention, organizational skills, selective focus on tasks, emotion control, and self-assessment [1].

Self-regulation constituting a critical area in which children with ADHD have difficulty with is also related to emotional intelligence. Emotional intelligence is the steering wheel for sensing, thinking, learning, problem solving and decision making. It also emphasizes the features of self-control, like the individual's capacity to slow down instant gratification, tolerate irritations, and regulate impulses (power of the ego).

In their research, Drigas & Papoutsi [3] propose a structured model for the evaluation and intervention of emotional intelligence, consisting of hierarchical levels that indicate the progressive development of an individual. This model can have practical applications as an assessment tool for special education, interpersonal relationships, as also any other aspect of life. More specifically, these levels relate to receiving and recognizing emotional stimuli, to self-knowledge, self-management, empathy, social skills, and self-actualization. According to Maslow's theory, self-actualization is the highest realization of personal potential, self-fulfillment, and the pursuit of personal well-being [4–5].

Another studies by Drigas & Mitsea [6–8] that proposes a multilevel metacognition model argues that attention is at the "heart" of metacognitive skills and participates in processes such as selecting, filtering, suspension, processing, storage, retrieval, prediction, monitoring, adjustment, adaptation, recognizing, distinguishing, remembering, and knowledge transformation. According to this model, each level describes a higher-ranking control system that indicates the individual's metacognitive development. The progression from the lowest to the greatest levels of metacognition entails a shift to more complex kinds of self-awareness and self-observation, which leads to the formation of a more sophisticated control system. This multilevel metacognition approach might be utilized as a structured assessment model to fulfill the needs of students at various levels and types of schools. The student is considered as a collection of physical, emotional, cognitive, and spiritual requirements that grow throughout time, according to this viewpoint.

Children with ADHD are usually assessed through questionnaires completed by parents and specialists. However, this method seems to have several disadvantages, as it is characterized as subjective and does not directly assess the children's performance in the above skills. On the other hand, ICTs play a significant role in the use of educational programs, which aim at the control and development of the socio-cognitive skills of students with special educational needs [9]. Assessment tools such as serious games using new technologies have proved to be just as effective, since they stimulate children's motivation, and the results can be more objective.

2 2D games

Crepaldi et al. [10] designed a Serious Game called "Antonyms" as an alternative assessment tool for children with ADHD. In Antonyms, the user takes on the role of a super-hero (named Atansyon) tasked with saving a kingdom on the other side of the globe. Woodland (W), River Crossing (RC), Training School (TS), and Central Building (CB) are the four settings that Atansyon passes through. The actions required for completing the tasks and scenarios require self-control, planning skills, emotional self-regulation, control, attention to detail, and increased stand-by time. Antonyms are meant to be used with a therapist or activity supervisor present. Each mini-game includes several difficulty levels, so as the user continues, the activities grow more demanding and complex. The games also provide immediate feedback in the form of visual and audible notifications. Furthermore, the player's conduct during the game can be monitored, and their performance can be recorded based on the different types of faults (such as stand-by time mistakes and incorrect replies) and completion time.

Antonyms were evaluated in team of 16 boys between 8–11 years old. Eight children had been diagnosed with ADHD before to enrolling in the study, and eight children had never been diagnosed with ADHD or any other neuro-developmental impairment. Before the game, two standardized tests, commonly used for ADHD diagnosis, i.e. the Ranette and the Number Stroop assessments of the BIA test [11], were administered. The first one, Ranette, requires coloring a frog each time a particular sound ("GO") is heard and pausing when there is another sound ("STOP"). The test (lasting about 10 minutes) includes prolonged attention, selective attention (the kids had to select the target-sound), and suspension (the kids had to resist their impulsiveness to proceed). The other test, Number Stroop, presents stimuli that elicit 2 alternative and inconsistent replies, one of which (the one not to be chosen) is more impulsive than the other due to being a common automated response. This test measures the control and suspension of behaviors, by counting the errors during the process.

The data gathered from the youngsters without ADHD disclosed that their performance in Antonyms resembled the results in the administered standard tests for the diagnosis of ADHD, referring to the same areas (i.e. control and suspension of impulsivity). Specifically, the number of mistakes in the BIA Ranette sub-test matched the errors in TS and CB. In addition, children with ADHD performed lower in Antonyms than same-aged youngsters without ADHD usually do. These findings indirectly support the possibility of using Antonyms as a promising device in various evaluation strategies because it provides a pleasant and user-friendly environment and is based on a model of neuropsychological tasks that focus on attention and impulsivity [8].

In their research, Delgado-Gómez et al. [12], propose a video game aimed at assessing distraction in children with ADHD. In that type of game the players must steer a functional avatar (a raccoon in specific) to avoid various obstacles in its way. Specifically, the avatar will have to jump over 180 gaps in its path to avoid falling. These gaps are divided into eighteen (18) squares, and every square is defined by the avatar's velocity, the trunk's length, and the gap's length. A significant difference compared to other games that require virtual reality accessories is that the suggested videogame can be played on any computer or smartphone. This allows for assessments at zero cost. The game was designed utilizing the widely used Unity 3D game engine.

The study involved 28 children diagnosed with ADHD aged 8 to 16 years. While each child was taking the test, the respective caregiver or teacher completed the SWAN scale's inattention sub-scale developed for assessing ADHD [13]. The results showed that the amount of times the raccoon did not leap indicated a significant correlation with the severity of the children's inattention. Furthermore, when the interval between leaps grows, this link becomes greater (i.e. in jumps where the time between them is longer than two seconds). This could be explained by the fact that when the interval between jumps is short, children are fully engrossed in the game, and when the time between jumps is prolonged, they struggle to retain their attention [12].

The experiment results showed that children diagnosed with ADHD had more skipped jumps and more jumps very close to the gap. Thus, there was a strong link with the individuals' distraction as assessed) by the SWAN subscale (Attention-Deficit Hyperactivity Disorder Symptoms and Normal Behavior rating scale – SWAN). The researchers in this paper argue that this game has many primacies. To begin with, unlike other ways that take over 15 minutes, this particular evaluation takes about only seven minutes. This characteristic makes the game especially appealing in therapeutic settings when time is limited. Second, this evaluation method does not demand for any complex or costly devices, such as virtual reality equipment, since an ordinary PC or a device such as a tablet or smartphone is sufficient. Therefore, both the research results and the features of this particular videogame mark it a great tool for supporting specialists in the diagnosis of ADHD [12].

3 EEG-based serious games

Serrano et al. [14] designed a video-game named GokEvolution to measure attention in children with ADHD. Attention was tested by analyzing the EEG-BCI index provided by the NSMW device while the subjects were playing the game. The main disadvantage of these techniques is that the complex EEG-BCI systems require placing multiple electrodes on the scalp [15], which can cause difficulties if applied outside the laboratory. However, recent research has revealed that the NeuroSky MindWave (NSMW) device can evaluate participants, especially children, in a more accessible and effective way. NSMW requires placing an electrode on the forefront's left side that can transmit information via a Bluetooth connection [16]. Many researchers have comprised NSMW in their studies, demonstrating its appropriateness and trustworthiness in assessing emotional states [17–19] and in controlling attention [20].

In total, 52 children without ADHD (32 boys and 20 girls, of average age 8.98 years) and 23 children with ADHD (18 boys and 5 girls, of average age 9.5 years) were evaluated. During the study, none of the children with ADHD were taking any medication. The CARAS-R Difference Test was used to determine each child's attention skills and impulsive behavior [21]. GokEvolution had five levels of difficulty (0–4), and the goal was to completely grow and evolve the game's main character. The character showed his evolution at each level by changing its hair color and style. The required attention increased at each level of difficulty. Players had to win points and thus advance in the game by paying attention as much as possible, otherwise, they would lose points. Therefore, it was important that the players were able to monitor their performance (neurofeedback) through the game's main screen, which showed through horizontal bars their attention levels (NSMW counter) and the points earned at each level. The activity of the participant's left frontal lobe was recorded using the NSMW during the five-minute game, in order to assess the level of attention. The game indicated that the player was either attentive or inattentive when the NSMW counter ranged between 50 to 100, or 0 to 50, respectively. A player who would manage to remain focused during the entire game would complete the five levels in 5 s, 9 s, 14 s, 20 s, and 70 s, respectively. This means that in a perfect performance it would take about 2 minutes to complete the character development [14].

The changes in attention recorded by the NeuroSky MindWave, and combined with the results of the CARAS-R psychological test were utilized to determine the attention profiles of children with ADHD and without ADHD. The NSMW device proved effective in detecting changes in attention while the children were playing the GokEvolution video game. The ADHD group displayed a lesser, more volatile attention at all game levels than the control group. The researchers also concluded that the game could determine the level of attention based on the player's performance. For example, the control group participants who finished all levels could comprise a typical sample of normally developing children. According to the findings of this study, the videogame application, when used in conjunction with the NSMW, could be used as a proactive diagnostic tool for attention-related issues. Also, although only one electrode was used in the study (Fp1, more restricted than a multichannel electroencephalogram) and attention was measured in a non-clinical setting, the data were highly accurate [14].

Alaa et al. [22] researched the effects of a serious game called FOCUS, controlled by an electroencephalogram (EEG), to detect the level of attention in children with ADHD. Neurofeedback and brain-interface games are ideal in ADHD, as they recognize the disorder's symptoms due to the high motivation they create [23]. Different frequency bands comprise the EEG signal: band γ (> 30 Hz), band β (12–30 Hz), band α (8–12 Hz), band θ (4–7 Hz) and band δ (< 4 Hz). Each band relates to different functions: band γ (Gamma) is associated to problem-solving and memory, band β (Beta) is related to rapid activities, band α (Alpha) is essential for relaxation, band θ (Theta) is prevalent in states of sleepiness, and band δ (Delta) is prevalent during sleep [24–25]. The game was designed using the Unity Game Engine and can be played via a keyboard or the EMOTIV EPOC+. EMOTIV is a 14-channel wireless electroencephalogram device created for computer-brain interface related research. In addition, it can provide raw EEG data using open source software [22].

The player's aim in FOCUS is to collect, through an avatar, yellow-colored cubes as quickly as possible while receiving orders. The environment contains a square-shaped floor surrounded by a jungle. There are two states: the "push" state and the "neutral" state. In the neutral state, the player must stay still and relaxed. This is necessary in order to detect the player's movements (push state). The player must use the commands to make the avatar move forward. This can be done either via the keyboard or via the EMOTIV. In the latter, the EMOTIV wireless gyroscope monitors the head movements to turn the avatar left and right, maximizing this way the player's involvement while also creating a sense of realism in the game [22].

In the study participated 4 individuals with ADHD (2 men, 18 and 23 years old, and 2 women, 21 and 22 years old) and 5 individuals without ADHD (all men, 19 to 26 years old), where they were instructed to play the game with both control techniques, i.e. keyboard and EMOTIV, to collect the cubes. In both cases, their EEG signals were captured. The results showed that the players had a higher engagement and focus on the game when using the EMOTIV rather than the keyboard, probably because it was more difficult for them to move the character without pushing a button. Also, the EMOTIV-controlled game took longer to complete because steering an EEG game was a new experience for all participants. There was also an accuracy of up to 96% in the categorization of EEG data in identifying the attention status of participants without ADHD and an accuracy of up to 98% in the classification of EEG data for patients with ADHD. Since playing FOCUS with EMOTIV instead of a keyboard requires a strong commitment to one's focus and attention skills, this could allow for detecting and diagnosing individuals with attention deficits [22].

4 Virtual reality classrooms

The study by Yantong et al. [27] was conducted to investigate the feasibility of VR-based assessments in school-age children with ADHD who showed learning disabilities. Several findings show that the use of virtual-reality-based tools marks an essential breakthrough in diagnosing ADHD, in particular because it allows the comparison of control and ADHD groups in a realistic environment [28]. More specifically, in their study on the effects of virtual reality on children with disabilities, Drigas & Mitsea [29] concluded that these environments could recognize the symptoms of inattention, distraction, and hyperactivity.

The VR test's validity was rigorously explored by comparing its findings to those of youngsters in a control group. All participants were school children (6–18 years old). The DSM-V diagnostic criteria [30] were used to diagnose the children in the ADHD group. The Virtual Reality Medical Center system (VRMC) was used for the VR test. The overall runtime performance was established by using a high-tech computer with a resolution of 1,080 × 1,200 pixels, a refresh rate of 90 Hz, and a viewing angle of 110 degrees. This device includes a game-like brain-interface system, numerous sensors, position detectors, and a data-collection and statistical-analysis support system. Three scenes make up the VRMC approach for evaluating ADHD: 1) Position monitoring (30 items), 2) Stroop (41 items), and 3) Object identification (60 items). The whole test takes 20 minutes to complete. Four (4) indicators are used to illustrate the test results:

1. Correct data (correct answers)
2. Incorrect data (incorrect answers)
3. Accuracy (percentage of correct out of total answers)
4. Time (total test time)

The IVA-CPT was used to measure participants' capacity to sustain attention and control in the face of a variety of multisensory (auditory and visual) stimuli (in ages 6 and older). This instrument includes a number of scales, including those for auditory control, auditory attention, visual control, and visual attention. The Conners Parent Rating Scale (CPRS) and the Child Behavior Checklist (CBCL, ages 6–18) were also used to measure ADHD-related behaviors [27].

The findings of the comparison study revealed no significant differences between the ADHD and control groups in terms of age or gender. In children with ADHD, the factors associated to accuracy and right responses were considerably lower than in the control group. Additionally, children with ADHD took much longer to complete tasks than children without ADHD. The CPRS hyperactivity score was positively linked with incorrect answers on the VR exam. In a prior research, Gilboa et al. [31] found a link between VR (virtual classroom) evaluation factors and CPRS-R (Conners' Parent Rating Scales-Revised: Short) results in children with acquired brain injury. VR evaluations, according to these scientists, appear to be a valuable tool for diagnosing attention deficit disorders.

In addition, the VR test mistakes were linked to CBCL ratings for attention issues, social skills issues, cognitive issues, and aggressive behavior. Finally, in terms of the VR test and the IVA-CPT, it was discovered that the total time spent completing the VR test was directly related to the amount of visual and auditory attention measured in the IVA-CPT. As a result, the researchers in this study concluded that a VR test can detect ADHD symptoms, potentially validating it as a supplemental diagnostic tool [27].

To test youngsters with ADHD, Neguţ et al. [32] compared the analog CPT (Computerized Continuous Performance Test) with a virtual classroom setting. The Continuous Performance Test (CPT) is a sort of evaluation in which participants are asked to choose a response to a particular auditory/visual stimulus which is presented at regular intervals. Diverse versions of CPTs, such as the OPATUS CPTA assessment (https://opatus.se/), have been created for objective assessment of children with ADHD. The integrated visual and auditory continuous performance test (IVA-CPT) has been proven in previous investigations to accurately distinguish children with ADHD from control children [33]. Thirty-three (33) youngsters with ADHD and forty-two (42) without ADHD, ranging in age from 7 to 13, took part in the study. Specifically, half of these children (from both groups) received the evaluation using ClinicaVR: Classroom-CPT, while the rest were evaluated using the traditional CPT.

In the experiment, the Raven Standard Progressive Matrices Plus Romanian version was used to assess the participants' intelligence, and the Cognitive Assessment System [34–35] was utilized to assess their overall cognitive condition. In addition, a 15-sentence bespoke scale for children was created to summarize their experience with ClinicaVR: Classroom CPT or regular CPT, which was graded on a scale of 1 to 5. (E.g. time seemed to pass rapidly when I was playing on the computer).

The participant in the ClinicaVR Classroom is subjected to stimuli for an extended period of time and must reply as rapidly as possible while also suspending undesired behaviors. A rectangle classroom with desks, a chalkboard, doors and windows on either side, pupils, and a teacher comprise the virtual classroom setting. Using 3D headset glasses and headphones, the students were completely immersed in the classroom. Each participant sits at his desk and must respond to target objects that appear on the blackboard in the form of a game. For example, target objects were letters of the alphabet that flashed rapidly over the board, and the student had to click the left mouse button only when a certain letter appeared. Three forms of distractions were utilized in this process: acoustic (such as a bus sound, door knock, step sounds, and school bell), optical (such as a paper falling, an airplane flying, or a teacher looking at her watch), and mixed (such as a person walking into the classroom while the sound of a door opening) [32].

The children completed first the neuropsychological tests and then were evaluated either through the ClinicaVR: Classroom-CPT or the traditional CPT. This process took about two hours, and then the recorded dependent variables were measured, i.e. responses, execution errors, omission errors, and the average stimulus-response time. Higher scores indicated absorption, focused attention, increased enjoyment, curiosity, personal innovation, and higher ease of use [32].

ClinicaVR: Classroom-CPT scores indicated a distinction between participants with ADHD and those without ADHD. As expected, children with ADHD achieved lower scores, since they had fewer correct answers, more omissions, and a slower response to target stimuli. The fact that the participants with ADHD gave more incorrect answers in the ClinicaVR: Classroom-CPT than children without ADHD is in consistency with the results of the traditional CPT (Computerized Continuous Performance Test). Also, there were differences in the results when the evaluation was done with distractions and without distractions. The disruptive factors increased the symptoms of inattention in participants with ADHD, and this finding was more evident in the ClinicaVR: Classroom-CPT scenario compared to the analog CPT [32].

Areces et al. [36] conducted a research to compare the effects of the AULA Nesplora among three groups of ADHD students (inattention type, impulsive type, and mixed type), as well as a control group. AULA Nesplora is a diagnostic tool for ADHD in a virtual classroom context. Previous studies have discovered that AULA Nesplora delivers more valid and complete information than the commonly utilized CPTs [37]. A clinical sample of 90 boys and 27 girls aged 5 to 16 years old was used in this investigation. The Diagnostic and Statistical Manual of Mental Disorders [30] was used to assign participants to the ADHD groups. They were separated into four groups: a control group, an inattentive ADHD group, an impulsive ADHD group, and a combined ADHD group. The total IQ (TIQ) was measured using Wechsler's WISC-IV scale [38], and the ADHD Assessment Scale [39] was utilized by the families.

The major focus of research is AULA Nesplora [40]. In this test, participants between the ages of 6 and 16 are assessed on their attention, impulsivity, stimulus processing speed, and motor activity. The test is conducted in a virtual reality environment using 3D headset glasses with motion sensors and headphones (Head Mounted Display, HMD). The participant assumes the role of a student sitting at a desk in the classroom, staring at the chalkboard. Sensors on the glasses detect every movement of the head. As a result, the program changes the viewing angle, providing the impression to the participant that he is in a virtual classroom. The test is divided into three sections, each of which is gradually explained by a virtual teacher. The first phase, for example, is designed to fully immerse the user in the virtual reality world so that he may visually find and pop balloons [36].

In terms of attention deficit and hyperactivity/impulsivity, the variables assessed by the aforesaid test are comparable to those of other traditional CPTs. More specifically, the following variables are assessed:

1. Omissions: These mistakes happen when a person is supposed to respond to a target stimulus but doesn't. It's a statistic that measures how selective and concentrated your attention is.
2. Commissions: These happen when the user presses the button even when the target stimulus hasn't occurred yet. This measure is linked to a loss of control and a sense of suspension.

3. Average response time: Is a measurement of processing speed (reaction time) that is expressed in milliseconds.
4. Motor activity: The frequency and relevance of head movements are recorded (i.e. required vs. obsolete moves).

As predicted, there were differences between the control group and the ADHD groups. Regarding the omission variable, there were differences between the groups that shared the element of inattention (i.e. inattentive and combined ADHD type groups) and the control group, where the first two groups exhibited a greater deficit. Regarding the commission variable, there were differences between the groups that shared the element of impulsivity/hyperactivity (i.e. hyperactive and combined ADHD type groups) and the control group, where again the first two groups exhibited a greater deficit.

The variations in motor activity were quite comparable to those recorded for the commission variable (with differences between the groups of inattentive ADHD type and hyperactive ADHD type). In particular, there was higher activity in those groups with impulsivity/hyperactivity being the main element. Finally, disparities in response time were found between the inattentive ADHD group and the control group, with the first group performing slower [36].

The AULA Nesplora test was found to be successful in distinguishing between different forms of ADHD and separating them from a control group after examining the factors in each of the test circumstances. Therefore, the findings of this study may be useful in directing professionals toward a better estimation, intepretation and assessment based on the data supplied by this test [36].

5 Discussion and conclusions

This study aimed to review the literature on the use of electronic games in virtual or non-virtual environments to identify the symptoms of ADHD. Children with ADHD exhibit a set of symptoms. The main symptoms of the disorder are inattention, hyperactivity, and impulsivity. According to Angelopoulou & Drigas [41], memory and attention are linked when performing a task. Therefore, their role is crucial to assessing the cognitive functions of individuals with ADHD, since the higher the working memory level is, the longer is also the attention span. Additionally, children with ADHD are more prone to have working memory deficits. Typically, medical professionals arrive at a diagnosis of ADHD in children by examining the answers of a questionnaire filled out by teachers and parents. However, this method is complicated for children with ADHD, and is also prone to inconsistent results, making it unfavorable for precise and truthful diagnosis.

On the contrary, the methods of diagnosing through electronic games and virtual reality classrooms may be more valid, as the result of the diagnosis depends entirely how well the children with ADHD perform in the games. This can motivate children to participate in the diagnosis, and may also lead to more objective diagnostic outcomes. Furthermore, since attention deficit is the dominant symptom of ADHD, it is feasible to discover if children exhibit this trait by using tests that address only the levels of attention [42]. The EEG signals can detect attention levels through brain-computer interface devices. This diagnostic method uses a combination of brain-computer interaction technology with serious games in order to record the player's EEG signal during play.

Virtual reality and machine learning techniques may be used in serious games to assess youngsters with ADHD. Virtual reality, on the one hand, creates a compelling environment that can deliver a realistic sensory experience throughout the diagnostic procedure. Machine learning, on the other hand, can classify the data collected throughout the game and improve diagnostic accuracy. The discussion among the scientific community on the assessment methods of ADHD has been of concern for a long time. Therefore, it is necessary for researchers to constantly try to find the most appropriate method, in order to identify the cognitive and metacognitive deficits of children with ADHD and to integrate them as soon as possible in a therapeutic environment.

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