VirTDAH: A Videogame to Improve Attention in Children with Attention Deficit Hyperactivity Disorder using Coordination Technique

Abstract. Attention Deficit Hyperactivity Disorder (ADHD) affects the daily life of children by impairing impulse control and attention. This paper presents the architecture design of a virtual reality videogame called VirTDAH, designed to improve attention in children with ADHD. The VirTDAH architecture design is based on the coordination technique, specifically on classification activities. VirTDAH is an alternative that aims to help children develop skills to order elements by establishing similarities and differences using a standard criterion. In addition, a case study applied to ten children diagnosed with ADHD is presented, in which a better level of attention and an improvement of cognitive abilities were observed through the measurement of metrics such as inhibitory control and quality of the attentional focus.

Keywords: ADHD, Coordination techniques, Sustained attention, Videogame, Virtual Reality.

1 Introduction

A disorder, it is associated with malaise or functional disability, which causes serious problems in people's daily lives [1]. According to World Health Organization [1] the Attention Deficit Hyperactivity Disorder (ADHD) has a prevalence in children of 5.3% worldwide. Among the main difficulties presented by children with ADHD are the lack of control of impulsive behaviors, lack of attention or concentration, relationship difficulties with other people, and emotional and cognitive problems [2]. Hence, the inattention is one of the most relevant impairments, so there are different techniques focused on improving it. Some of these techniques are: a) Auditory [3]; b) Memory Rusca [4]; c) Cognitive [5]; d) Visual perception [6]; e) Logic [7]; f) Selective attention [8]; h) Sustained attention [9] and, i) Coordination [10]. The literature reports different tools and software applications for improving attention in people with ADHD. Some of these tools are based on applications for mobile devices and Web environments that implement videogames [11], while other tools implement robot-assisted therapies [12]. However, most of these tools and applications do not implement techniques with a specific impact to improve attention in children based on the coordination technique. Therefore, it is essential to design new tools that take advantage of the characteristics of innovative technologies such as virtual reality to dynamically implement strategies such as coordination that improve attention in children with ADHD. In this sense, the coordination technique impacts motor skills related to the mobility of muscles and bones and learning tasks, making it one of the most important for improving attention. Therefore, this research aims to present the design of the architecture of a virtual reality videogame that uses a coordination technique, specifically classification activities. As a proof of concept of the design of the architecture, we present the design of VirTDAH, a videogame. VirTDAH was designed to improve attention levels in children with ADHD by assessing metrics that allow accurate tracking of the player's progress and provide concrete data on their performance. Classifying objects allows the child to develop the ability to order diverse elements through a common criterion by establishing similarities, differences, or relationships of belonging. Thus, classification is an activity that allows children with ADHD to expand their knowledge and improve their inhibitory control and quality of attentional focus. In addition, we present a case study to assess concentration levels in ten children with ADHD using VirTDAH through the metrics of inhibitory control and quality of attentional focus. The main contributions of this research focus on two aspects: 1) VirTDAH a videogame to stimulate attention in children with ADHD through coordination activities such as object classification, and 2) to promote the use of technologies such as videogames for the formal treatment of ADHD in children.

The remainder of the paper consists of five sections. The second section discusses state-of-the-art; the third section describes the design of the videogame architecture; the fourth section presents VirTDAH, the videogame based on the architecture design proposed in section three; the fifth section focuses on evaluating the videogame through a case study; and finally, the sixth section contains conclusions and perspectives for future research.

2 State-of-the-Art

In recent years, the treatment of ADHD has involved using technologies as support tools to improve deficiencies such as attention. This section presents some works that address the contributions to treating ADHD. In this context, a randomized comparative study for children with ADHD to self-regulate their behavior and daily habits was proposed by Michelini et al. [13]. The results showed an increase in sustained attention in children with ADHD. From another perspective, a study on smartphone applications for people with ADHD, seeking to improve organizational and attention skills was conducted by Moëll et al. [12]. The results demonstrated that these applications help to organize the daily lives of children with ADHD. On the other hand, the use of multimedia and hypermedia mobile games to improve attention in children with ADHD was described in the research of Ahmad et al. [14]. The results highlighted the usefulness of games with rewards, short sound clips, and simple graphics for these children. While that a pilot study presented by Simone et al. [15], demonstrated that computerized home training improves cognitive functions and school performance in children with ADHD. Similarly, an interactive multiplayer videogames for short and long-term therapeutic use in children with ADHD was evaluated by Park et al. [16]. The semi-systematic evaluation observed an improvement in behavior and attention level. The study carried out by Barragan [2] included the design of a serious game for children with ADHD based on attention measures and performance observation, highlighting the importance of developing educational videogames. Similarly, educational puzzle videogames were evaluated by Suyami et al. [17], they found that children with ADHD who play these games develop unique skills and perceptual reasoning. From another perspective, a gamified educational system was implemented by Gomes et al. [18]. They identifyed 16 requirements for developing gamified applications that ensure better organization of daily tasks and education. In turn, Ivett Daniela Jácome et al. [19] proposed dividi2, a mobile application to improve attention through simultaneous stimuli. Dividi2 was found to increase motivation and attention in children with ADHD. With a different approach, a robot-assisted therapy (RAT) in order to attracting and maintaining attention in children with ADHD and ATHYNOS, a prototype that addresses attention in children with ADHD were proposed by Cibrian et al. [20]. On the other hand, Sandygulova et al. [12] reviewed scientific research-supported apps in mobile and desktop technology for children with ADHD. These apps aim to improve specific cognitive processes. From another perspective, e-tutor was proposed by Supangan et al. [21], e-tutor consisted in a gamification system that helps children with ADHD learn math, language, and basic hygiene. A statistical analysis showed that participants obtained a significant impact on learning tasks. On the other context, an applied study on cognitive health games using anecdotal records, which showed the importance of providing rewards or lives in games to children with ADHD was proposed by Landínez-Martínez et al. [22]. Finally, a set of exercises based on visual perception in children with ADHD was proposed by Abou Sleimana et al. [23]. The results indicated that children improved visuomotor integration and image recognition skills. As observed in the literature, thanks to the development of applications for mobile devices, there have been improvements in child behavior, cognitive processes, executive functions, and attention retention in children with ADHD. However, most of these applications focus on something other than a specific concentration technique, examining its validity and impact on managing inattention or inattention difficulties. Thus, although the development of applications with novel technologies, such as virtual reality, to treat ADHD represents an essential contribution to the health field, the efficacy of these technologies still requires research.

From this perspective, our proposal focuses on a technique to improve attention, specifically the coordination technique through object classification activities. This coordination technique has an impact on the quality of the attentional focus and inhibitory control, both essential to improve attention in children with ADHD.

3 VirTDAH Architecture

We present to the architecture of a videogame named VirTDAH. The architecture of VirTDAH is based on Virtual Reality (VR) features and a coordination technique that improves attention in children with ADHD. VirTDAH has a layered design due this architecture style allows better scalability, modularity, and maintenance. The layers and components of VirTDAH architecture are briefly described below:

Presentation layer. This layer controls the VirTDAH visual representation and the VR user interface. The component in this layer is the GUI component. The component displays the user interface elements in the VR environment, which allows the player to access the scenario of each level through the VirTDAH menu. This component communicates with the VR Controllers module, located in the VR component of the game engine layer so that the player can access the virtual environment.

Game Engine layer. This layer executes VirTDAH and manages player input from VR devices. The components in this layer are:

- ***Virtual reality component.*** It is responsible of VR-specific logic, VR configuration and calibration, player motion detection using virtual reality devices and cameras, and integration with Oculus hardware. It contains two modules: 1) a VR controller module and 2) a VR camera module. The VR controller module manages the player's input to the virtual environment and communicates with the VR camera module of the Virtual Reality component. Subsequently, the VR camera module communicates with the motion control component.
- ***Motion control component.*** This component manages the player's interaction in the virtual environment, such as touching, selecting, moving, and manipulating virtual objects, and communicates with the graphics engine module of the function's component.
- ***Function component.*** It is responsible for running the graphics, animation, and sound modules.
- ***The Graphics module.*** It is responsible for rendering high-quality graphics and supporting advanced visual effects.
- ***The Animations module.*** It executes the animations of the avatars and VirTDAH objects.
- ***The Sound module.*** It manages sound effects and background music. Once the sound module is executed, it communicates with the Avatar Control Scripts component of the game logic layer.

Videogame logic layer. This layer contains the core logic of VirTDAH and it includes event management. The components of this layer are:

- ***Avatar control script component.*** This component controls the avatar's movement and actions in the game. It communicates with the videogame script component to implement the rules and mechanics of VirTDAH.
- ***Videogame script component.*** It implements of VirTDAH rules and mechanics in the three sublevels. For example, the first sublevel validates that ten objects are classified in two minutes, thirteen in sublevel two, and sixteen in sublevel three in 1:30 minutes. This component then communicates with the event management system component.

- ***Event management system component.*** This component allows the communication and coordination between different parts of VirTDAH. It sends collision and player interaction events when a sublevel is successfully completed and communicates to the sublevel transition scripts component.
- ***Level transition scripts component.*** Once that an event arrives in this component, it controls the loading and unloading of scenes in Unity. In addition, it communicates with the sublevel data component to store the data in the sublevel data component of the sublevel management layer.

Level management layer. This layer stores the player's information according to the results obtained in each sublevel.

- ***Level data component.*** This component stores information about the sublevel's current status, such as the number of objects classified and completed sublevels. Once this information is collected, this component communicates with the sublevel transition scripting component to trigger a new event in the VirTDAH logic layer's event management system component.

Figure 1 depicts the design of the VirTDAH architecture, where the interaction among the components and the different layers can be seen.

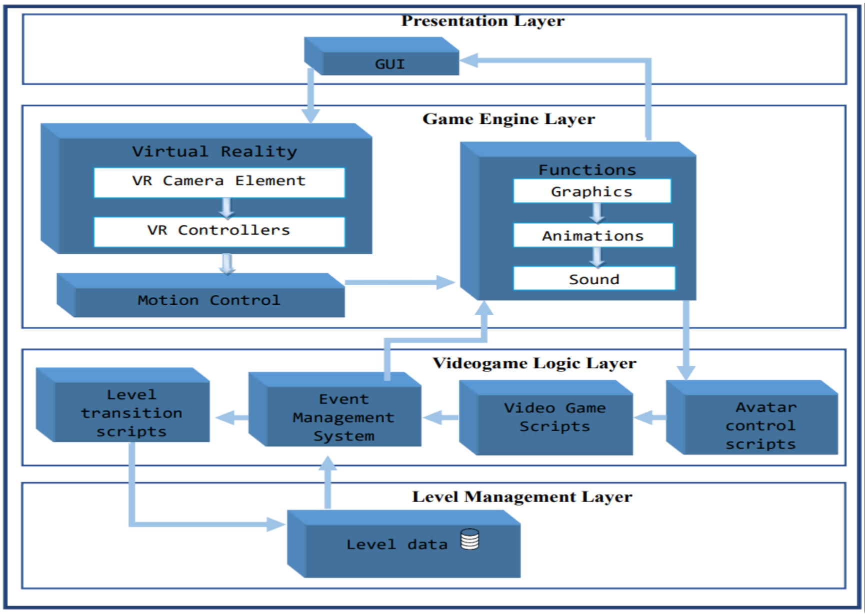

Fig. 1. Architecture of VirTDAH.

4 VirTDAH gameplay

This section presents the VirTDAH development process, which was developed in Unity® version 2021.3.21f1 and the C# programming language. In addition, Maya®

and Blender® were included for editing and modeling 3D objects, Photoshop® for object textures, and Illustrator® for developing the different icons.

VirTDAH was developed to help improve attention in children with ADHD. For this purpose, coordination was used as one of the main attention techniques. Coordination aims to help children with ADHD perform precise, efficient, and orderly movements [10]. Therefore, the development of coordination videogames focuses on physical activities or strategies and the acquisition of various skills such as reflex stimulation, lateralization, balance, construction, and classification. In this sense, the VirTDAH coordination strategy is classification. VirTDAH was developed to be deployed in a virtual reality environment to improve attention in children with ADHD. In addition, the selected scenarios, a bedroom, a classroom, and a kitchen, are part of the children's daily lives, thus strengthening real-world tasks from a dynamic perspective.

VirTDAH consists of three sublevels; in each sublevel, the child selects different objects and classifies them according to each type. Each sublevel has a degree of difficulty, and as the child advances, access is given to the following sublevels. Therefore, the first sublevel is the only sublevel available when starting the VirTDAH. Each of these sublevels is described below.

Sublevel 1. The purpose of this sublevel is for the child to learn to classification objects in a room and speed up the activity through a timer. In particular, clean clothes, dirty clothes, and toys are classified at this sublevel. The scenario of the first sublevel is a children's room and, at the beginning, a message with instructions appears. In this case, it is indicated that the toys are placed in a trunk, the clean clothes are in the closet, and the dirty clothes are in the hamper. When the start button is pressed, the timer counts to 02:00 minutes and notifies that the objects will begin to descend. Once the game starts, the objects descend linearly every 8 seconds. The classification containers have a counter that starts at zero; as the objects are classified correctly, a bell sound is emitted, and the container counter changes. If the child classifies an object incorrectly, an error sound is emitted. At the end of the game, the timer turns red color, and a message is displayed notifying that the results are evaluated. To pass sublevel 1, 10 objects in each container must be classified correctly. Figure 2 shows the sublevel 1 scenario. Figure 2 *(a)* shows how the objects to be classified descending, in this case, clean clothes, dirty clothes, and toys. Subsequently, Figure 2 *(b)* shows the classification of a sweater in the closet as clean clothes.

(a) *(b)*

Fig. 2. Sublevel 1 interfaces: a) Objects descending; b) Object classification

Sublevel 2. This sublevel aims to learn by classifying two or more objects in a classroom. In this case, numbers, letters, and figures are classified on a blackboard, so the setting in this second sublevel is a classroom. Upon entering the sublevel, a message indicates that letters are sorted to the left of the board, drawings in the center of the board, and numbers to the right. In addition, a start button is displayed to activate the countdown, which notifies that the objects will begin to descend in three seconds. The sublevel starts with a timer of 02:00 minutes and is displayed in white at the top of the stage. For this sublevel, objects descend linearly every six seconds, and the counters for each type of object are shown at zero. As the player classifies the different objects correctly, the blackboard changes color, a bell sound is emitted, and the counter on the blackboard changes when the object is classified correctly. Otherwise, an error sound is emitted. At the end of the sublevel, the timer turns red, and a message is displayed, notifying that the results have been evaluated. To pass this sublevel, the player must classify thirteen objects correctly in each blackboard section.

Figure 3 shows the sublevel two scenario, Figure 3 *(a)* shows how the letters, numbers, and figures descend, and Figure 3 *(b)* shows how to correctly classify the number seven on the right side of the blackboard.

(a) *(b)*

Fig. 3. Sublevel 2 interfaces: a) Objects descending; b) Object classification

Sublevel 3. This sublevel aims to learn by classifying kitchen items, mainly fruits, vegetables, healthy foods, and junk food.

The scenario of the third sublevel is a kitchen with basic utensils such as a refrigerator, a stove, a table, and storage drawers. A message with classification instructions and a button to start the game is displayed upon starting the sublevel. The instructions tell the child to place the fruits and vegetables in the fruit bowl, the healthy food in the refrigerator, and the junk food in the kitchen sidebar. Once the child selects the start option, the timer starts counting down, which is 01:30 minutes. For this sublevel, objects descend every 4 seconds linearly, and similar to the previous sublevels, a counter is displayed for each container that increments as the objects are classified. Each time the child places an object correctly, visual effects are shown. For example, the fruit bowl rotates in its place, the refrigerator opens its doors, and the junk food on the counter jumps in its place. In addition, a bell sound is emitted if the object is classified incorrectly, and an error sound is emitted if the object is classified into the wrong container. At the end of the game, the timer turns red, the videogame stops, and a message indicates that the results are evaluated sublevel 3 requires 16 objects to be correctly classifieds into each container to be passed.

Figure 4 shows the sublevel 3 scenario, and Figure 4 *(a)* shows that fruits, vegetables, healthy food, and junk food are descending. Figure 4 *(b)* shows the classification of a milk carton in the refrigerator.

(a) *(b)*

Fig. 4. Sublevel 3 interfaces: a) Objects descending; b) Object classification

VirTDAH offers an interactive and engaging game environment to capture children's attention to motivate them to participate consistently and enthusiastically. The following section describes a case study of VirTDAH applied to ten children with ADHD.

5 Case of study: Improving attention using VirTDAH

A case of study was conducted as a proof of concept for VirTDAH. In this regard, tests were conducted with ten children diagnosed with ADHD, five girls and five boys. The Oculus Quest 2 glasses were used for the tests. These tests were carried out in collaboration with a psychological center located in Cordoba, Ver. Mex. That specializes in treating childhood disorders under the supervision of its director and a team of psychologists.

Individual sessions were established in which each child was allowed to interact with VirTDAH. At the beginning of each session, participants were provided with a detailed explanation of the equipment they would be using. In addition, it was explained to them what VirTDAH consisted of, what types of challenges they would encounter in each sublevel, and what the goal they were to achieve in each sublevel was. During two months, participants played the three sublevels of VirTDAH exclusively on three occasions, with a duration of 10 minutes per session, carried out weekly. In this way, each child had three opportunities to interact with VirTDAH.

5.1 Evaluation

To effectively evaluate the contribution of VirTDAH to improving attention in children with ADHD, a detailed analysis was conducted to identify relevant variables and metrics. As a result of this analysis, the evaluation shown in Figure 5 was designed. It is essential to consider a variety of metrics that address different aspects related to attention. In this context, several metrics have been selected that cover critical factors such as sustained attention, selective attention, vigilance, processing speed, inhibitory control, and quality of the attentional focus. These metrics are based on NESPLORA AULA SCHOOL [24], a tool aimed at primary and/or secondary schools that provides objective information on students' attentional profiles through a cognitive test in virtual reality. In this case, the two specifically assessed will be inhibitory control and quality of the attentional focus, as they are fundamental to evaluating the use of VirTDAH as a therapeutic resource to improve attention in children with ADHD.

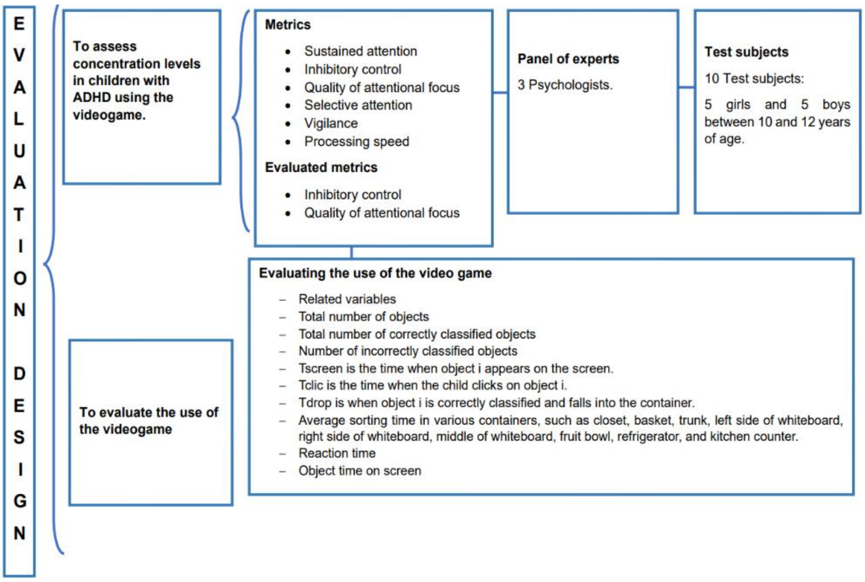

Fig. 5. Evaluation scheme

Each metric involves a set of specific variables, such as the total number of objects, the total number of correctly classified objects, and the number of incorrectly classified objects. In addition, variables were considered for the average classification time in the various containers, such as the closet, the basket, the trunk, the different positions of the blackboard (left, right, and center), the fruit bowl, the refrigerator, and the kitchen counter. The assessment of inhibitory control metrics and the quality of the attentional focus are fundamental in neuropsychological assessment and essential to effectively analyzing the attention progress of children with ADHD. The careful selection of these variables will facilitate the detailed analysis of the cognitive functions associated with attention, serving as a basis for implementing personalized interventions to improve the ability to concentrate in children with ADHD. The following we describes the relevant metrics, associated variables, and formulas for obtaining the VirTDAH evaluation results.

Inhibitory control: In NESPLORA AULA SCHOOL [24] inhibitory control is the ability of an individual to control impulsive reactions in both the attentional and behavioral domains. To evaluate this metric, variables such as the Total number of objects that encompasses the total number of objects that fall during the videogame, regardless of whether they are classified or not, as well as the Total number of incorrectly classified objects that indicate the number of incorrectly classified objects in the garbage cans were taken into account. Based on the selection of these variables, the following formula was applied to calculate inhibitory control, where equation (2) is.

$$Inhibitory\ control = \frac{Total\ number\ of\ objects - Total\ number\ of\ misclassified\ objects}{Total\ number\ of\ objects} \quad (1)$$

Quality of the attentional focus: For NESPLORA AULA SCHOOL [24], this is a measure that allows us to assess the effectiveness of the visual focus of the evaluated person when faced with visual stimuli without looking away from the focus of the attention. In the evaluation of this metric, key variables have been considered, such as the total number of objects, which includes all the objects that fall during the videogame, regardless of whether they are classified or not, and the total number of correctly classified objects, which indicates the number of correctly classified objects in the containers. After a detailed selection of these variables, the following formula was applied to calculate the quality of the attentional focus. This process allows us to obtain a deeper understanding of the ability of the value to maintain accurate focus and avoid errors when interacting with the visual stimuli presented in the test, where equation (3) is.

$$Quality\ of\ the\ attentional\ focus = \frac{Total\ number\ of\ objects - Total\ number\ of\ correcly\ classified\ objects}{Total\ number\ of\ objects} \quad (2)$$

5.2 Results

The results obtained after the children's interaction with VirTDAH are described below, along with the associated metrics. Figure 6 shows graph showing the inhibitory control results of the five players with the best performance in the tests based on their performance in the three tests performed. These data represent the weighting of the mean per metric for each player during the three game sessions.

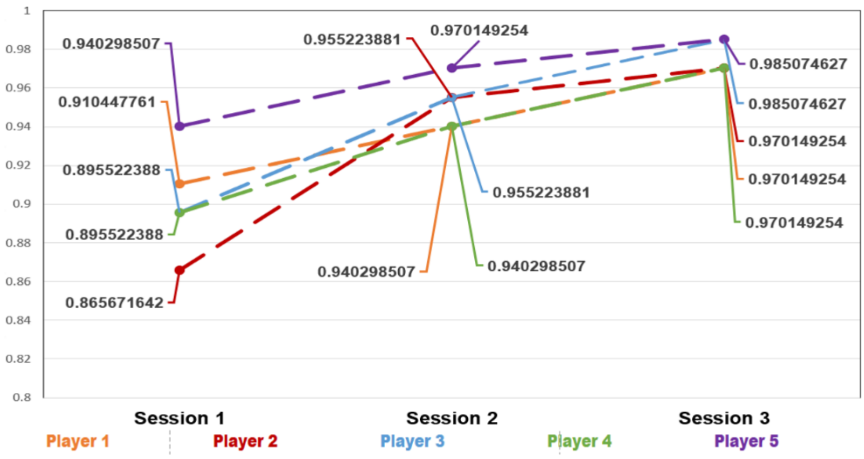

Fig. 6. Results of the inhibitory control metric.

The graph in Figure 6 shows that the players improved their inhibitory control in each session. Particularly in the first session, player 5 obtained 0.940298507 because he classified 4 objects incorrectly. Players 4, 3, 2 and 1 incorrectly classified 7, 7, 9, and 6 objects respectively. In the second session, player 5 misclassified 2 objects, thus his inhibitory control is 0.970149254. Meanwhile, players 4, 3, 2, and 1 misclassified 4, 3, 3, 3, and 4 objects respectively. Regarding the third session, players 3 and 5 misclassified only one object, and players 4, 2, and 1 misclassified two objects each.

On the other hand, graph in Figure 7 shows the attentional focus quality results of the five best-performing players in the tests.

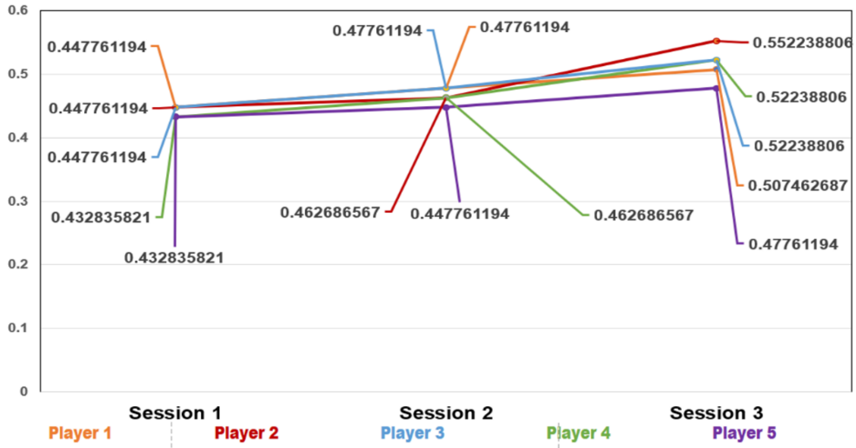

Fig. 7. Results of the quality of the attentional focus metric

The results of the attentional focus quality metric in Figure 7 show a progressive improvement in each player. Unlike the inhibitory control metric, the number of correctly classified objects is the relevant variable to measure the quality of attentional focus. From this perspective, in the first session, player 5 obtained 0.47761194, and we can infer that it is because he classified 35 objects correctly. Players 4, 3, 2, and 1 (32, 32, 30, and 33 objects respectively) classified fewer objects correctly than player 5. In the second session, players 1 and 4 classified the same number of objects correctly as player 5 in the first session. While players 2 and 3 correctly classified 33 objects each; and player 5 classified 31 objects. Finally, in the third session, players 3 and 5 correctly classified 38 objects, and players 4, 2, and 1 incorrectly classified 37, 37, and 37 objects respectively.

The advantage of obtaining detailed results from player metrics lies in the VirTDAH ability to deliver personalized interventions. By accurately measuring vital cognitive functions, the approach facilitates the design of VirTDAH strategies that aim to improve attention effectively and are tailored to the individual needs of children with ADHD.

6 Conclusion

As conclusion, the VirTDAH evaluation allowed to confirm its effectiveness as a therapeutic resource to improve attention in children with ADHD. During the tests, it was observed how VirTDAH influences several cognitive areas, which allows the conclusion that VirTDAH represents an effective contribution to treating ADHD, specifically in improving attention. It is worth mentioning that the active participation of specialists in the different stages of the process facilitated the design of VirTDAH and the application of the tests.

It is relevant to note that while videogames are available to improve attention in children with ADHD, VirTDAH offers excellent potential. This is due to its meticulously designed approach, specifically tailored to the needs and characteristics of children with ADHD. In addition, VirTDAH stands out for its ability to maintain children's interest and engagement during videogame sessions, which facilitates long-term treatment. The results underline the VirTDAH videogame's potential as an effective and engaging therapeutic tool to address attention challenges in children with ADHD. It offers a promising option for treating this condition, providing children with an enriching and encouraging videogame experience that contributes significantly to their cognitive and emotional development.

However, it is important to note that there are future work. We are considering to increase the number of levels and sublevels in the classification videogame is important, as it will allow players to offer greater options and expand the diversity in the therapy sessions.

On the other hand, we are considering to implement other complementary techniques to improve the attention such as auditory, memory, cognitive, visual perception, logic, and focused attention, to mention but a few. By integrating these additional techniques could provide a more holistic and comprehensive perspective to address attention challenges in children with ADHD, thus maximizing therapeutic benefits.

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