Happy Shop: Development of a Virtual Reality Videogame Using a Memory Technique to Improve Concentration Levels in Children with ADHD

Abstract. Attention deficit hyperactivity disorder (ADHD) is a condition that affects approximately 5% of children and adolescents in Mexico and around 129 million children and adolescents worldwide. It leads to poor academic performance, difficulties in personal development, and challenges in socializing. Therefore, effective treatment of ADHD is crucial. This paper presents the architectural design and development of a videogame called Happy Shop, aimed at improving concentration levels in children with ADHD using a memory technique. The results indicated that Happy Shop helps enhance concentration levels in children with ADHD.

Key words: ADHD, Cognitive technique, Memory technique, Videogame, Virtual reality.

1 Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a neurological disorder that, according to the World Health Organization (WHO) [1], affects between 5% to 11% of children and 2% to 5% of adults worldwide. In Mexico, according to INEGI [2], approximately 5% of children suffer from this disorder, equating to 2 million children and adolescents across the country.

The characteristics of a child with ADHD include attention difficulties, impulsivity, and hyperactivity. In the scientific literature, several treatments for ADHD have been proposed. Among them, neuromodulation and transcranial electrical stimulation are notable, both mentioned in Moradi et al [3]. In addition, the use of interactive software, such as videogames, to improve concentration is explored. Mobile games are an effective complementary tool in the treatment of children with ADHD [4].

Currently, treatments such as therapies or medications have many shortcomings. Traditional therapies with a psychologist require that the child with ADHD and those who interact with them be involved to follow up on the case and for the specialist to supervise their development. Regarding medications, they are costly and often difficult to obtain. Therefore, it is important to propose new support for the treatment of people with ADHD. In this context, the use of new technologies, such as videogames, to improve concentration levels in children with ADHD will provide specialists with a tool for the automation of therapies and allow children to engage in their therapy in a fun way. In this light, the aim of this paper is to present the design of the architecture of a virtual reality videogame based on the object memorization technique to improve concentration levels in children with ADHD. This technique involves the ability to enhance the study environment and is essential for daily activities. It is also related to the concept of working memory, which is defined as the ability to briefly store specific information (whether visual or auditory) in immediate memory for processing. This means that the retained information is manipulated for our knowledge [5]. There are several techniques for developing memory in children, such as classifying information, learning pleasant songs, organizing daily activities, and object memorization. Due to these advantages, object memorization is the technique to be implemented in the videogame for this paper. Also, the design of a videogame called "Happy Shop" is presented as a proof of concept for the proposed architecture design. The use of Happy Shop to improve children's concentration levels was evaluated using two metrics: a) Vigilance and b) Processing Speed. Continuous use of Happy Shop demonstrated its ability to enhance concentration levels and encourage children to remain engaged in their ADHD treatment. This document is structured into five parts: 1) Introduction, which provides a brief explanation of the identified problem; 2) State-of-the-Art, which covers works based on the treatment of ADHD; 3) Design of the "Happy Shop" architecture, detailing its structure; 4) Gameplay, describing its dynamics; and finally, 5) A case study providing a detailed analysis of the findings from "Happy Shop".

2 State-of-the-Art

In this section, a review of works related to the treatment of ADHD using different technologies is presented. In this sense, Bahana et al. [6] studied children with ADHD playing a videogame, finding that visual cues were more effective than auditory ones. They concluded the game offers a viable therapy alternative to medication. Corrigan et al. [7] explored virtual reality's benefits for treating ADHD in children, showing improvements in cognitive function, attention, and working memory through rehabilitation studies. Meanwhile, Visone et al. [8] conducted a study on the application of a videogame and the benefits of virtual reality for children with ADHD. The results indicated that virtual reality improved cognitive performance, attention, and impulsive behavior in children with ADHD. Additionally, Goharinejad et al. [9] presented a study on the use of virtual, mixed, and augmented reality as a treatment for ADHD. They reviewed 30 studies employing these technologies in children with ADHD. The findings from these studies demonstrated that these technologies were effective in treating

ADHD. Wiest et al. [10] studied 43 school-aged children with ADHD using computerized cognitive training games aimed at improving working memory.

The results showed significant enhancement in working memory after the training sessions. Zheng et al. [11] conducted a systematic review comparing videogames to traditional pharmacological therapies for treating ADHD in children. They categorized game-based devices by platform and found improvements in attention, time management, and social skills. Rodrigo-Yanguas et al. [12] studied "The Secret Trail of Moon" (TSTM), a virtual reality videogame designed to treat ADHD by focusing on cognitive brain training and reducing executive dysfunction. Results suggest TSTM could be an effective multi-modal approach for ADHD treatment. Pandian et al. [13] compared digital therapeutic devices, including games, for treating ADHD, highlighting positive cognitive effects and potential applications for anxiety and depression treatment. Ahufinger et al. [14] studied "Alien Attack," a videogame used as a cognitive treatment complement for children with ADHD. The game focused on enhancing executive functions, improving treatment engagement. Romero-Ayuso et al. [15] reviewed virtual reality treatments for children with ADHD using PRISMA and Cochrane Handbook standards and assessed them with the GRADE approach. Despite limited studies, they found virtual reality enhances cognitive improvement in individuals with ADHD Flogie et al. [16] developed and evaluated serious games to enhance personal development skills in children with learning difficulties, resulting in improved social and cognitive competencies. They recommended adapting the games to better meet individual student needs and training. Alqithami et al. [17] emphasized the importance of cognitive-behavioral therapy in treating ADHD. They designed a videogame using augmented reality as a generic cognitive model, showing increased attention among individuals with ADHD and supporting cognitive therapy treatment. Contreras-Espinosa et al. [18] reviewed the use of videogames for ADHD treatment, finding improvements in working memory, concentration, motor planning, and time organization skills. Their analysis of 12 studies showed that videogames effectively reduced hyperactivity, impulsivity, and inattention in ADHD patients. Salazar et al. [19] implemented neurocognitive strategies like attention training and memorization techniques in children with ADHD, using mathematical, visual, and memory exercises. The study found significant improvements in academic performance among children with ADHD as a result. Delgado et al. [20] studied behavioral intervention for a child with ADHD in school, using home-school cards for behavior modification. Data collected through direct behavior observation showed improved behavior and increased school attendance motivation.

The studies examined in this section have highlighted a range of research and contributions toward ADHD treatment utilizing virtual reality, augmented reality, mixed reality technologies, and memory techniques aimed at enhancing concentration. Notably, videogames have been identified as having potential auxiliary benefits in treating ADHD in children. Consequently, the application of virtual reality alongside memory techniques in ADHD treatment presents a promising area of opportunity, warranting further investigation. In this paper, a videogame is proposed that stands out for integrating memory technique, through exercises to memorize elements of a daily life environment.

3 Happy Shop Architecture Design

This section is dedicated to outlining the architectural design of Happy Shop. The architecture design is based on a layered approach, whose main advantage is the modularity that facilitates the development, testing, and maintenance of each layer independently. The following is a detailed description of each layer within the proposed architectural framework.

Presentation layer: This layer is tasked with the system's visual representation through the user interface component within the virtual reality environment. It contains the Graphical User Interface (GUI) component, enabling user interaction with both the virtual reality environment and its objects.

Virtual reality engine layer: This layer is responsible for operating Happy Shop and overseeing the player's interactions through VR devices. It comprises two primary components the component controller and the component of functions. Component controller: This component ensures the virtual reality functionality, overseeing the virtual environment's resources, player movement detection, and camera operations. It consists of two key modules: (1) the controls module, which facilitates player interaction, and (2) the camera module, designed to provide the player's perspective and communicate with the controller component for a cohesive experience. Component of functions: Tasked with handling multimedia functions, this component manages graphic animations and sound. Within the function component are two significant modules: the animation module, which is responsible for rendering graphics with optimized quality and executing animations for objects and players within the virtual environment, and the sound module, which controls the sound effects in Happy Shop, including ambient sounds and background music.

Game logic layer: This layer is responsible for the foundational logic of Happy Shop, orchestrating the game's event management across distinct components: the component of control, component of the game, event component, and level components. The component of control directs player movements, ensuring a seamless interaction within the game. The component of the game oversees gameplay, with Happy Shop featuring three main levels, each divided into three sublevels, to progressively challenge the player. The event component acts as a communication bridge for game states, such as concluding a sublevel. It evaluates player outcomes to determine progression to the next level or repetition of the current challenge and manages specific scenarios like sublevel repetition or pausing. This component also consults with the level component to unlock levels as needed. The level component prepares the upcoming sublevel or repeats the existing one based on the player's success in surpassing a level.

Data layer: Dedicated to preserving player information, this layer includes the data component, which stores the outcomes of the player's sublevel attempts in a database. This is crucial for tracking the player's advancement through Happy Shop.

The architecture of Happy Shop, as depicted in Figure 1, showcases the structured interaction between these layers and components, illustrating the game's design.

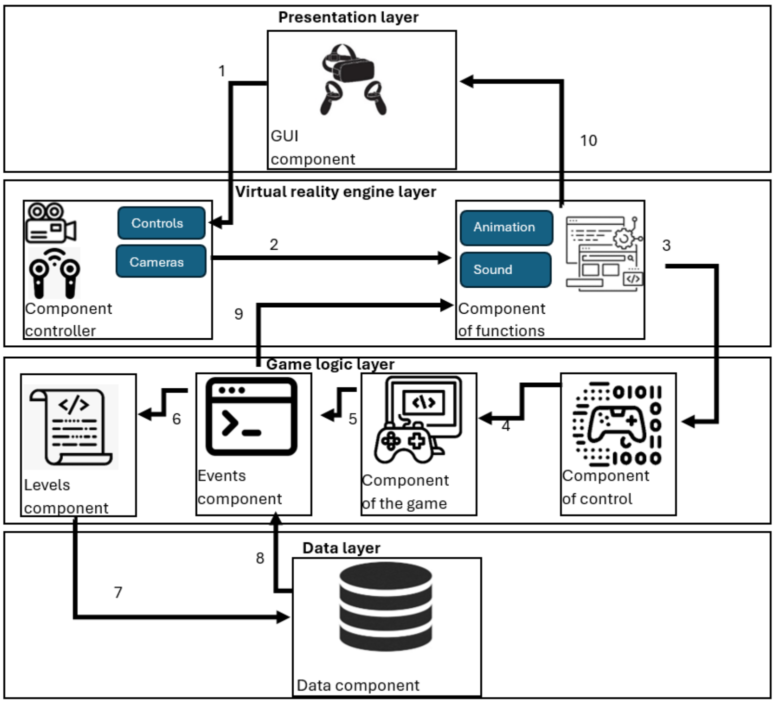

Figure 1 Happy Shop Architecture

Subsequently, the architecture's workflow is detailed to illustrate the mechanisms of communication between its layers and components:
(1) The process begins with the player engaging with the virtual reality device. The physical actions performed by the player are communicated to the component controller. (2) The component controller translates the player's actions into commands within the Happy Shop interface. It collaborates with the component of functions to trigger animations corresponding to the player's actions. (3) Based on the player's selected action, the component of functions instructs the control component to execute the appropriate response. (4) The component of control, responding to the player's actions, communicates with the game component to set up the interface for gameplay readiness. (5) With the component of the game set, the player's choices are forwarded to the events component. This component is attuned to the player's inputs, such as level selection. (6) Upon level selection, the levels component arranges the gameplay scenario and instructions for the forthcoming level. (7) Completion of the level triggers the saving of results within the data component. (8) The events component reviews the player's performance to ascertain if the level's objectives have been achieved. Based on the outcome, it decides whether the player advances to the next level or repeats the current one. (9) Receiving the results, the component of functions activates to present the player with the appropriate feedback screens. The outcome dictates whether the player progresses or remains at the current level. Finally, (10) the component of functions process culminates in the GUI component, which visually presents the player with options to either continue the game or revisit levels as needed.

4 Happy Shop Gameplay Overview

Below is the gameplay description of Happy Shop, this application was developed in Unity® [22] version 2022.3.18f1 and programmed using C#. Additionally, Maya® [23] was used for the development of scenarios and objects, which is dedicated software for 3D graphics development. Happy Shop aims to improve concentration levels by challenging players to memorize items on a shopping list and then locate the items in the aisles of a virtual supermarket. Players must complete the shopping list within a given time. Happy Shop is structured into three primary levels, each divided into three sublevels. Each level is in a different aisle. In this sense, the aisles are (1) snacks and drinks, (2) fruits and vegetables, and (3) groceries for levels one, two, and three respectively. In addition, each level is designed to challenge and progressively improve the player's memory and concentration by varying quantities and types of items. Here's a step-by-step description of the Happy Shop gameplay:

1) Game Initialization: Upon launching the game, player is greeted with a start menu that offers options to begin gameplay, modify player settings, and access gameplay data.

2) Progression Through Levels and Sublevels: Selecting the 'Start Game' option allows players to choose from one of three initial levels, each corresponding to a distinct section of the virtual supermarket. Within these levels, players encounter three progressively challenging sublevels, each equipped with an increasingly complex shopping list. Initially, all levels and sublevels are locked, except for the first level and its initial sublevel. Players unlock subsequent levels and sublevels by successfully completing the challenges presented in each sublevel.

3) Memorization of the Shopping List: Players are introduced to the game with clear graphical and verbal instructions. They view a shopping list in Figure 2, detailing products with quantities and visual references for ten seconds to aid memorization. This visual approach caters to various learning styles, enhancing game accessibility and effectiveness in memorization tasks.

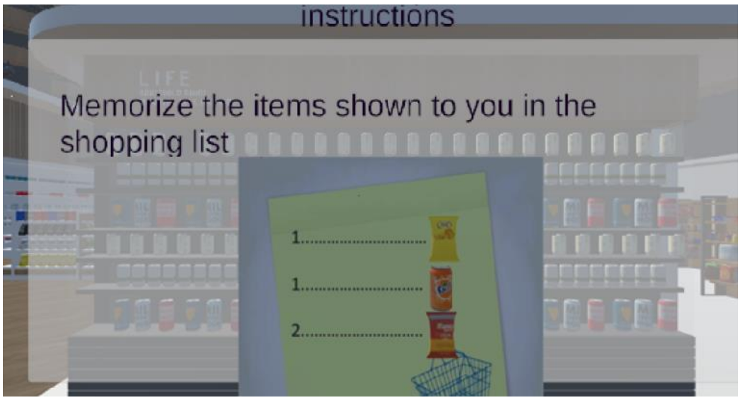

Figure 2 Shopping List

4) Engagement within the Virtual Supermarket Environment: Upon displaying the shopping list, the game seamlessly transports players to corresponding aisles in a virtual store (see Figure 3). Equipped with virtual reality gear, they navigate aisles to locate listed items, monitored by a timer and progress indicator. The interface allows for level restarts to correct errors or aid in recalling items, enhancing the overall gaming experience.

Figure 3 Shopping aisle

5) Item Selection Process: Participants are required to select desired items by pressing the corresponding button on the controller. Selection of the correct items is recorded and contributes to the participant's progress metrics.

6) Obstacles and Challenges: During gameplay, participants encounter obstacles or distractions, manifested as products not listed on the virtual shopping list. The requirement to discern and avoid these incorrect items introduces an additional layer of cognitive demand, emphasizing attention and concentration skills.

7) Sub-level ending: Upon completion of a level, the participant's performance is evaluated, and a feedback message is displayed on the end-of-level screen. This message provides immediate performance feedback, reflecting the participant's success in navigating the level's challenges. as observed in Figures 4 and 5.

Figure 4 Level Message Not Complete

Figure 5 Level Message Completed

5 Case Study

This study involved conducting tests with ten children, five girls, and five boys, all of whom had been diagnosed with ADHD. The Oculus Quest 2 virtual reality glasses were used for the test. These tests were conducted in collaboration with a psychological center for child development located in Córdoba, Veracruz, México. The study was conducted under the direct supervision of the center's director alongside a dedicated team of psychologists. This collaborative effort ensured that the tests were administered in a controlled and professional environment.

5.1 Test Design

Three sessions were conducted, and this allowed each of the participants to become familiar with Happy Shop. Before each session, a detailed briefing was provided on the equipment usage. Then, an overview of Happy Shop, including the challenges and the goals to be achieved.

After the briefing, testing began. Each session spanned 10 minutes, during which participants interacted with Happy Shop, playing the assigned levels once per session. The test was conducted in a furniture-free classroom, ensuring that participants played in the virtual environment freely. Each participant had the support of a psychologist and their parents during the session to monitor the participants and take care of the equipment. At the end of the session, information from participants and parents who wished to share their experience with Happy Shop was collected.

5.2 Evaluation

To accurately evaluate Happy Shop's effectiveness in enhancing concentration levels among children with ADHD, a comprehensive analysis was undertaken. Following, we describe the relevant metrics, the associated variables, and the formulas used to obtain the results of the Happy Shop evaluation. The evaluation design is shown in Figure 6.

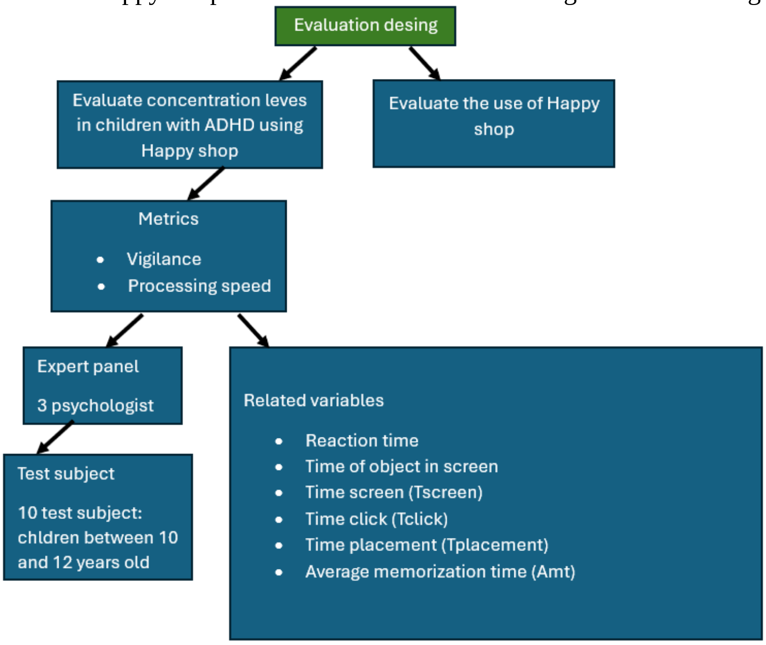

Figure 6 Evaluation Design

The evaluation metrics were carefully chosen to reflect critical dimensions of vigilance and processing speed in children with ADHD, drawing on the methodology of Nesplora Aula School – Nesplora [24], a tool. This tool was designed to be used in primary and secondary educational settings, offering insights into students' attentional profiles via a virtual reality assessment. In our case, we measured children's concentration levels using the metrics of processing speed and vigilance. Every metric utilizes a unique combination of variables. The metrics consider the mean response time to these objects.

Vigilance: According to Nesplora Aula School - Nesplora [24], vigilance refers to the capacity to sustain alertness over minutes to hours for the purpose of evaluation. The assessment of this metric involved variables such as *N*, representing the total number of objects memorized; *Tscreen*, the time at which object *i* is recognized by the player; *Tclick*, the moment the child clicks on object *i*; *Tplacement*, the time when the player accurately places object *i* in the shopping cart; and the *Average Memorization Time* (*Amt)* of each object per level, including specific times for snacks and soft drinks, fruits and vegetables, and groceries. Utilizing these variables, vigilance was calculated using the formula associated with equation (5).

$$Vigilance = \frac{1}{N} \sum_{i=1}^{n} \frac{Tclick - Tscreen}{Tplacement - Tclick} \ x \ Amt \tag{5}$$

Processing speed: In Nesplora Aula School - Nesplora, the processing speed refers to the rate at which information is captured, understood, and begins to be responded to. It encompasses the ability to efficiently perform simple or already memorized tasks. To assess this, variables such as Reaction Time, which accounts for the duration taken by the player to click on an object, and Time of the Object on Screen, which measures the moment the player places the object in the shopping cart, were selected. Based on these selected variables, the following formula was applied to calculate processing speed, utilizing equation (6).

$$Processing\ speed = Time\ of\ the\ Object\ on\ Screen - Reaction\ time \qquad (6)$$

5.3 Results

Table 1 shows the results obtained in the metrics during the three sessions by the five best players. The data in Table 1 reflects a weighted average of the results from these sessions. The findings from this evaluation offer vital insights into the concentration levels of children with ADHD.

Table 1: Evaluation results by session.

Failure Metrics Analysis						
Sessions	Session 1		Session 2		Session 3	
Player	V	PS	V	PS	V	PS
Player 1	0.54	0.48	0.62	0.49	0.84	0.82
Player 2	0.27	0.23	0.49	0.43	0.72	0.85
Player 3	0.32	0.48	0.38	0.53	0.68	0.63
Player 4	0.21	0.42	0.39	0.48	0.75	0.70
Player 5	0.42	0.32	0.51	0.37	0.73	0.59

V: Vigilance; PS: Processing Speed

A thorough examination of the data presented in Table 1 reveals key insights into the players' performance across various metrics designed to assess concentration levels. Notably, Player 1 demonstrated exceptional memorization skills, correctly recalling the highest number of objects. This player was identified as the best of the group. Meanwhile, Player 2 also showed commendable results but fell short of Player 1's benchmark. Conversely, Players 3, 4, and 5 exhibited comparable performances, as evidenced by their closely aligned data, as observed in Figures 7 and 8.

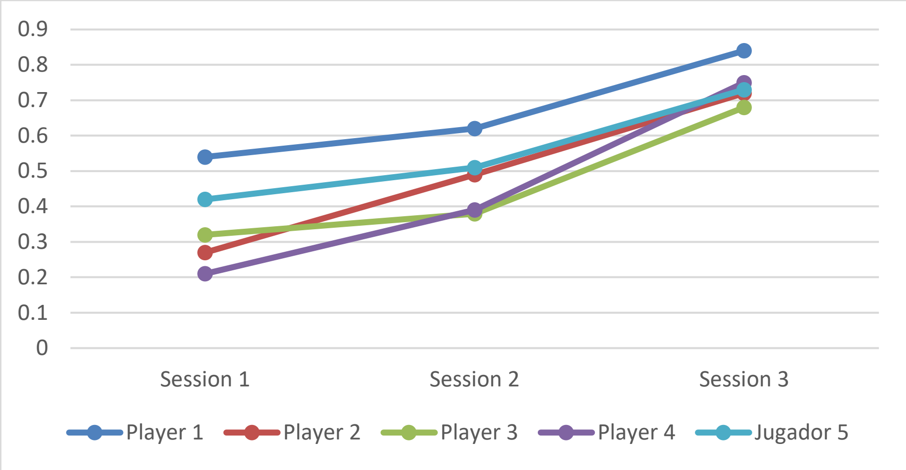

Figure 7 Vigilance Metric Results

The results showed that all players improved their vigilance metric. In session one, all players had issues with time placement as they did not recognize the location of the shopping cart. Thus, the times placement results were 5.82, 6.58, 6.91, 5.52, and 5.82 seconds for players 1, 2, 3, 4, and 5 respectively. Regarding the average memorization time, the players struggled to locate the items on the shopping list, with times of 4.27 (player 1), 5.41 (player 2), 5.73 (player 3), 4.58 (player 4), and 4.92 seconds for player 5. In session two, players identified the location of the items and improved their average memorization times, achieving 3.79, 4.84, 5.36, 4.27, and 4.73 seconds for players 1, 2, 3, 4, and 5 respectively. For time placement in this session, the players recognized the location of the shopping cart and achieved times of 5.63, 6.20, 6.52, 5.39, and 5.54 seconds respectively. By session three, players had become familiar with the dynamics of object movement and the locations of the items on the list, resulting in improved average memorization times of 3.57, 4.24, 4.89, 3.64, and 3.85 seconds for players 1, 2, 3, 4, and 5 respectively. For time placement, players 1, 2, 3, 4, and 5 had times of 5.12, 5.85, 6.17, 4.89, and 5.27 seconds respectively.

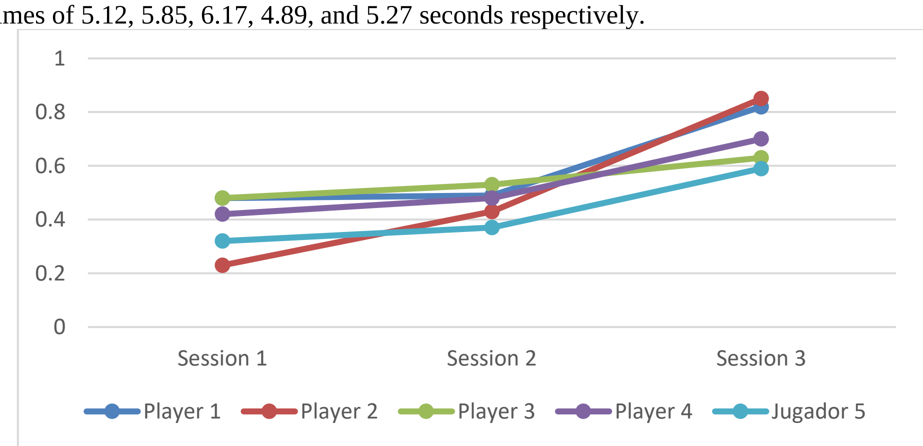

Figure 8 Processing Speed Metric Results

Regarding the processing speed metric, players showed promising results. In session one, all players experienced difficulties with reaction time as they were not yet familiar with the virtual reality headset controls, resulting in times of 3.67, 3.82, 4.71, 4.83, and 4.92 seconds for players 1, 2, 3, 4, and 5 respectively. Additionally, the time of the object on screen were affected because players could not locate the items on the shopping list on the store shelves, with times of 4.58, 4.65, 5.26, 5.76, and 5.95 seconds for players 1, 2, 3, 4, and 5, respectively. In session two, as players became familiar with the graphical user interface, the time of the object on screen improved to 4.14, 4.35, 4.79, 5.24, and 5.25 seconds, respectively, for players 1, 2, 3, 4, and 5. The reaction times for players 1, 2, 3, 4, and 5 were 2.75, 2.78, 3.21, 3.56, and 3.75 seconds, respectively. By session three, players had become accustomed to the virtual reality headset controls and the store aisles, leading to improved reaction times, with player 2 standing out with a time of 2.53 seconds. Players 1, 3, 4, and 5 had reaction times of 2.42, 2.93, 2.96, and 2.89 seconds, respectively. The on-screen object times for players 1, 2, 3, 4, and 5 were 3.54, 3.95, 4.25, 4.75, and 4.87 seconds, respectively.

In summary, the data provided in Table 1 offers a detailed view of the players' performance in terms of concentration levels. These results highlight the importance of concentration and identify areas for improvement for those players whose performance did not meet the optimal level observed in other players.

The advantage of obtaining detailed results from player metrics lies in Happy Shop's ability to offer personalized interventions. By accurately measuring concentration effectively and adaptively to the needs of children with ADHD, tailored support can be provided.

6 Conclusions

Most treatments for ADHD often hamper timely and adequate support for individuals with this disorder, leading to challenges in their social, academic, and professional lives. Virtual reality holds the potential to simulate environments conducive to ADHD treatment, offering innovative avenues for managing symptoms. Additionally, the application of memory techniques is emphasized for their role in mitigating ADHD symptoms such as hyperactivity and enhancing concentration. On the other hand, the works reviewed in this paper reported therapeutic advantages over the use of videogames for the treatment of ADHD. However, to underscore that videogame usage for ADHD treatment necessitates professional supervision, with careful monitoring of children's gaming duration. Moreover, the findings from the reviewed studies suggest that incorporating these techniques into virtual reality videogames could significantly enhance the resources available to specialists in treating ADHD.

In the development of Happy Shop, a layered architecture was implemented to delineate clear responsibilities and simplify the system's structure. This architectural choice not only streamlines development but also enhances the game's effectiveness in integrating therapeutic strategies. Furthermore, the importance of employing memory techniques in treating ADHD in children was recognized. These techniques not only improve academic performance but also support daily life activities successfully. The evaluation of the video game treatment showed significant improvements in the children's concentration levels, underscoring the effectiveness of the approach. Future work will involve further testing and assessing players' performance using other metrics. In addition to increasing the levels and scenarios and including other memory techniques.

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