BRAIN WAVES AND LEARNING IN CHILDREN WITH ADHD: IMPACT OF EDUCATIONAL VIDEO GAMES VS TRADITIONAL METHODS

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ABSTRACT

The traditional learning method can be a challenging activity if the students are children with ADHD. There are studies that indicate that educational video games enhance the learning process in children. To objectively validate the aforementioned claim, this study aims to analyze and compare the brain waves activity of children with ADHD while learning scientific concepts through traditional methods and educational video games. To do this, the activity is monitored with an EEG headset while they learn. A pilot study has been conducted with 7 children aged 7 to 9 to evaluate the learning effectiveness of using video games versus traditional learning. The results support that playing educational video games makes the learning process more enjoyable and engaging for children with ADHD, thereby improving their study skills and knowledge acquisition.

KEYWORDS

ADHD, Learning, Serious games, Brain waves, Cognitive engagement.

1. INTRODUCTION.

Attention Deficit Hyperactivity Disorder (ADHD) is a mental health problem that is typically identified during childhood and is categorized as a neurodevelopmental disorder. Approximately 3-5% of school-aged children worldwide have ADHD (Rief, 2012). According to (Brito et al, 1995), ADHD causes disruptions in behavioral, cognitive, academic and social functioning. Children diagnosed with ADHD exhibit a range of behavioral and cognitive difficulties, including inattention, impulsivity, difficulty concentrating and memory problems that hinder the acquisition and retention of knowledge in both the short and long term. These children are unable to complete activities to a satisfactory standard and become bored easily (Wagner, 2000). There are studies that have further explored the importance of improving cognitive engagement (attention and concentration, mental effort, persistence, learning strategies, interest, and motivation in educational activities) as a means of overcoming these deficiencies (Lorch et al, 2006). Students who are cognitively engaged tend to perform better, have a deeper understanding of the material, and have a greater ability to apply what they have learned in different contexts (Fredricks et al, 2004).

Serious games (SGs), those that have targets different from only fun (Gee, 2003), have gained popularity in non-entertainment domains as they make tasks more engaging and appealing (Furió et al, 2013). This kind of game possesses significant educational potential, benefiting cognitive processes, executive functions, social skills, and the inclusion of students with specific educational support needs, especially with ADHD children (García-Redondo et al, 2019).

Electroencephalography (EEG) is a method used to evaluate brain waves. These are divided into multiple frequency bands: the δ-band, dominant in children during sleep, is linked to linguistic acquisition (Penolazzi et al, 2008); the θ-band predominates during drowsy states; the α-band indicates relaxation; the β-band is associated with fast activities; and the γ-band is related to problem-solving and memory (Wang et al, 2010). These measurements are made using devices that capture real-time data on brain activity, providing relevant information about cognitive processes and their response to different educational approaches. Studying brain waves will allow the identification of characteristic patterns during learning activities, evaluation of their effectiveness, and assessment of student participation.

Taking into account the above and aiming to quantify and contrast the brain waves measurements of children diagnosed with ADHD while learning with traditional educational methods and video games, this work proposes: to analyze and compare children's brain waves while learning with traditional methods and video games to explore differences in cognitive engagement between these approaches and assessing knowledge acquisition in both learning methods.

To this purpose, three objectives (O) were established:

- O1: Evaluate, by recording and analyzing brain waves, if video games offer ADHD students a more motivating learning method than traditional learning.
- O2: Identify brain waves patterns in ADHD children during traditional and GBL.
- O3: To assess knowledge acquisition in both learning methods.

Knowledge tests and brain waves measurements were used, and six research questions (RQs) were defined:

- RQ1: How does Game-Based Learning (GBL) impact the Attention levels of children with ADHD compared to traditional learning methods?
- RQ2: Does GBL promote higher levels of Appreciation and Enjoyment in children with ADHD compared to traditional learning methods?
- RQ3: How does GBL affect the Ease of Use and resulting stress levels for children with ADHD during learning activities compared to traditional methods?
- RQ4: How does the overall Quality of learning, reflected in Attention, Engagement, and Relaxation, compare between GBL and traditional methods?
- RQ5: Does GBL improve Cognitive Engagement more effectively than traditional learning methods for children with ADHD?
- RQ6: Is more knowledge acquired in the same period of time with GBL than compared to traditional methods?

RQs 1, 2, 3, 4, and 5 are aimed at supporting Objectives 1 and 2, while RQ6 is focused on supporting O3.

The paper is structured as follows: Section 2 reviews publications that serve as a starting point for this research: Section 3 outlines the process from objective setting to experimental design. Section 4 evaluates the effectiveness of GBL versus traditional learning for ADHD children. Sections 5 and 6 present the conclusions and future work.

2. PREVIOUS WORK.

In the search for more effective educational methods, educators and researchers have become increasingly interested in Game Based Learning (GBL) methodologies (Boyle et al, 2015), which have been shown to have a high potential to increase student motivation (Hussein et al, 2019) (Rebollo et al, 2022). In the context of ADHD, the use of Serious Games (SGs), has emerged as a methodology for the increase of motivation, the retention of knowledge in educational contexts (Manero et al, 2016). In (Avila-Pesantez et al, 2018), results showed improved concentration in children who used ATHYNOS educational video game. In this sense, the comparison between learning through SGs and traditional learning is an aspect of considerable importance. The results of the work of (López-Fernández et al, 2021) show that GBL was as effective as traditional teaching for knowledge acquisition but was especially successful in increasing student motivation, preferring GBL over traditional teaching.

The brain characteristics of ADHD most often cited in the literature include an excess of θ-band, which are associated with sleep and decreased alertness, and a deficit of β-band, which are related to concentration (Moriyama et al, 2012). The study by (Juiter et al, 2021) aimed to measure the impact of music tones on the behavior of ADHD children aged 7 to 9 years, focusing on attention (θ-band), relaxation (α-band), and concentration (β-band). The results indicated that music tones had a significant impact on the behavior of ADHD children, as evidenced by significant changes in their brain waves scores across the three types of brain waves studied. Besides, various studies examine brain waves to enhance cognitive skills such as memory and attention while playing video games (Liu et al, 2014), (Alchalabi et al, 2018). In (Muñoz et al, 2015), neurophysiological signals in children with ADHD are monitored while playing a serious game to reinforce waiting ability, planning ability, ability to follow instructions, and ability to achieve goals. This work can discriminate between children with and without ADHD, aiding diagnosis.

Based on this literature review, it is valuable to explore the benefits of serious games in educational settings with children with ADHD, alongside analyzing their brain waves status as they learn.

3. USER EXPERIENCE DESIGN.

Prior to the experiment, essential tasks were conducted to ensure optimal conditions and precise implementation: Criteria for population inclusion, selection of the EEG headband meeting research requirements, selection of experimental games, material selection and procedure.

3.1. Criteria for population inclusion

Considering that ADHD is typically identified during childhood, children in early schooling stages were included. Selection was based on the criteria in Table 1, communicated orally to the families.

Table 1. Inclusion criteria.

Description	**Sample**
Children - diagnosed with TDAH - IQ (intelligence quotient) indices were normal. - aged 6 to 9 years - willingness to engage in both paper-based learning and gaming activities - were unaware of the knowledge they would acquire	7 (1 girl, 6 boys) 7-9 years old (M = 8.71; SD =0.70)

3.2. Selection of the EEG headband meeting research requirements

The selection of the headband is critical for the success of the research, especially when involving children with ADHD. Five EEG devices were evaluated: Emotiv Insight, Neurohead Band, NeuroSky, Muse 2 and Macrotellect BrainLink Pro. The choice of the Macrotellect BrainLink Pro headband was based on its ability to record and analyze brain waves, providing an effective platform for real-time monitoring of users' mental states. Its ergonomic design ensures user comfort during extended usage sessions, maintaining the quality of brain waves measurements. They are suitable for use with children. Its compatibility with various devices and platforms allows seamless integration with different operating systems and applications, enhancing its usability in diverse study and clinical contexts. Their advanced algorithms offer accurate feedback on the user's mental state, making it a comprehensive and user-friendly tool. Additionally, it provides high functionality and ease of use at an affordable cost.

3.3 Selection of experimental games

To select the suitable video games for the experiment, the Kokoro Kids commercial app was used, offering more than 200 games designed to enhance school activities and foster children's mental and cognitive skills. In 2024, Kokoro Kids received the PlayForAll award from the LEGO Foundation, recognizing solutions that facilitate learning through play, especially for neurodivergent children with ASD and ADHD. The selected games needed to provide educational content and enable the assessment of cognitive functioning, attention, and concentration.

Independent expert evaluators selected the games "*Flying through the Continents"* (FC) and "*Flying through the Solar System"* (FSS) (Figure 1). These enable the assessment of brain waves behavior during the learning of continent and planet names and locations. They help children locate these on a world or solar system map, guide them in navigating from one continent or planet to another by following instructions, and enable quick and efficient recognition of all continents and planets.

3.4 Material selection

The following materials were used in the experiment:

Traditional Learning (Figure 2):

- A printed sheet depicting the planets of the solar system, each labeled with its respective name.
- A printed map showing the continents, each labeled with its respective name.

Learning with Video Games (Figure 1):

- A video game designed to teach the continents and their names.
- A video game designed to teach the planets and their names.

Evaluation Instruments:

- An EGG device for recording brain waves (Macrotellect BrainLink Pro headband).
- A printed sheet of the solar system's planets with white labels for their names.
- A printed map of the continents with white labels for their names.



Figure 1: "*Fly solar system"* game from Kokoro Kids app (left) and child playing the game (right).



Figure 2: Printed sheets depicting the planets (left) and the continents (right)

3.5 Procedure

The research adhered to the 1964 Declaration of Helsinki and its subsequent amendments, approved by the Deontological Commission of Jaume I University under file number "CEISH/143/2023". Parents or legal guardians of participating children provided written informed consent after receiving an information sheet detailing the research objectives and participation specifics. The sessions were conducted in a quiet environment at Jaume I University. Age, gender, IQ and education level were collected through personal communication. Participant anonymity was ensured by assigning a Unique Identification Number (ID#) where "#" corresponds to the order number of the experience execution.

During the learning experience, each participant wore a Macrotellect BrainLink Pro headband to record EEG signals. Brain waves were continuously recorded throughout the learning process.

The experiment follows a structured format for each participant (Figure 3):

- **Paper-Based Learning Task:** Participants engage in traditional learning studying the contents using customized educational materials.

- **Game-Based Learning Task:** Participants switch topics; those who studied planets traditionally will learn continents through gameplay, and vice versa.
- **Knowledge Test:** Before and after each learning task, participants undergo a test to assess their knowledge. The tests involve identifying images and completing the names of planets or continents.
- **Gaming Task:** Participants play the game corresponding to their traditional learning topic, allowing for the measurement and analysis of brain waves activity for all games and children.

Each experiment lasted approximately two hours and it was divided as follows:

- 5 min. for a preliminary phase to understand both the traditional learning activity and the games' instructions and practice.
- 5 min. to complete the knowledge pre-test.
- 10 min. for the traditional learning task + 5 min. to respond to the learned concepts questionnaire.
- 5 min. to complete the knowledge post-test.
- 10 min. for the GBL task (game 1) + 5 min. to respond to the learned concepts questionnaire.
- 5 min. to complete the knowledge test.
- 10 min. to play the game 2.
- A 3-5 min. break was taken between each of the activities.



Figure 3: Learning the planets (top left) and continents (top right) using video games. Learning the planets using a traditional method (bottom left). Completing the knowledge test (bottom right).

4. EVALUATION.

To assess the effectiveness and experience of game-based vs traditional learning for ADHD children, this section evaluates both methods. Two studies are conducted: the first analyzes brain waves in both methods, and the second evaluates the knowledge acquired. A quantitative, comparative, cross-sectional design (Ato et al, 2013) is used for this exploratory study.

4.1 Analysis & Findings

This section describes the data collection process.

4.1.1 Brain Waves: Traditional vs. Game-Based Learning

The data collected comprise cognitive metric measurements from children aged 7 to 9 while engaging in activities such as studying planets on paper (PP), continents on paper (PC), or playing "Fly the Solar System" (FSS) or "Fly the Continents" (FC) games. These measurements encompass five main metrics: *Attention* (Att.),

Relaxation (Rel), *Appreciation* (App), *Mental Effort* (ME), and *Familiarity* (Fam.). A summary of the mean, maximum, and minimum values of these key variables is presented in Table 2.

Table 2. Means, Maximum, and Minimum Values of Key Variables.

	Mean				Maximums' means				Minimums' means			
	FSS	FC	PP	PC	FSS	FC	PP	PC	FSS	FC	PP	PC
Att.	44	49	45	48	82.1428	83	77	83,6667	18,4285	17	13	17
Rel.	51	56	57	59	75.2857	88	95.5	94,6667	13,1428	23	16,25	14,6667
App.	2	2	1	1	2.8571	3	2	2	0,5714	1	0	0
ME	18	15	13	3	40.8571	42	36.25	29,3333	-22,4285	-19	-38,5	14,6667
Fam.	-2	-7	-5	5	18.5714	13	23	33	-25,5714	-39	-32,5	-17,3333

These data provide an overview of how each group of children responded in terms of the measured variables while studying on paper and while playing. The values of the variables correspond to a scale varying between a minimum and maximum value as indicated Table 3.

Table 3. Scale of the maximum and minimum values for each of the variables measured,

Var.	Scala	Meaning
Att.	**0-100**	The higher the value, the greater the mental concentration.
Rel.	**0-100**	The higher the value, the greater the level of calmness and relaxation. The lower the value, the higher the level of stress.
App.	**0-4**	The higher the value, the greater the appreciation for the visual or auditory activity, while a lower value indicates neutrality.
ME	**-100-100**	The higher the value, the greater mental effort experienced during the activity.
Fam.	**-100-100**	The higher the value, the greater the learning progress during the activity. The lower the value, the less familiarity with the task.

4.1.2 Knowledge acquisition: Traditional vs. Game-Based Learning

Before and after each learning task, participants undergo a test to assess their knowledge. The tests involve identifying images and completing the names of 8 planets or 7 continents and their positions, as depicted in Figure 2. Each test is labeled with the child's identifier. (ID#). Table 4 presents the results from pre- and post-tests for each of the learning activities.

Table 4. Results from pre- and post-tests for each learning activity. Note: '-' indicates that the participant was not required to complete that part of the test.

	Pre-test				Post-test			
	Game		Paper		Game		Paper	
	FSS	FC	FSS	FC	FSS	FC	FSS	FC
1#	-	4	3	-	-	7	8	-
2#	2	-	-	1	6	-	-	4
3#	-	0	2	-	-	3	6	-
4#	2	-	-	3	7	-	-	4
5#	-	0	1	-	-	0	3	-
6#	-	2	4	-	-	5	8	-
7#	2	-	-	2	8	-	-	7

It is important to note the crossover design of the study: if a participant learned about the continents using traditional methods, they would learn about the planets through a video game, and vice versa. This approach ensured that each child experienced both types of learning methods, allowing for a direct comparison of their effectiveness.

4.2 Discussions

The analysis of the data collected for both experiments is given below.

4.2.1 Comparative Brain Waves Analysis: Traditional vs. Game-Based Learning

At first glance, the analysis of brain waves (Table 2) reveals an intriguing pattern: individuals who performed well in the paper-based learning mode also excelled in GBL, and vice versa. While initially suggesting similarities between the results of paper-based and GBL activities, further examination of the collected data uncovers nuanced differences in cognitive responses. These subtle yet significant variations warrant deeper investigation, as developed below.

Considering the dichotomy between relaxation and engagement, while paper-based learning appears to foster a slightly more relaxed learning environment, characterized by moments of tranquility and calm, gameplay shows an aura of heightened arousal and engagement. This heightened state of arousal during gameplay may signify a deeper level of cognitive stimulation, where learners are actively immersed in dynamic problem-solving scenarios.

Moreover, the differential responses in *Appreciation* underscore the profound impact of experiential learning on children's perceptions and attitudes towards educational content. GBL activities seem to evoke a deeper sense of appreciation and enjoyment, transforming learning from a passive endeavor into an enriching and enjoyable experience.

Finally, descriptive statistics were calculated for the brain wave measurements (Table 2). The analysis unveiled significant differences in brain activity during each game. Figures 4, 5, 6, 7 and 8 display the analysis results, comparing brain waves metrics across the two games and illustrating variations in attention, familiarity, and relaxation levels. These results indicate that:

- Both games showed similar mean appreciation levels (Figure 4), which aligns with the children's positive feedback. The higher variability for the FC game might suggest that individual preferences varied more for this game.
- Attention levels (Figure 5) were consistently higher for the FC game, suggesting that children were more engaged and attentive during this game.
- Familiarity levels (Figure 6) were higher and more variable for FSS, indicating that while some children learned with the game, others did not.
- Levels of mental effort (Figure 7) were similar between the two games, with the FSS game showing slightly higher effort levels, possibly indicating greater engagement or complexity.
- Relaxation levels (Figure 8) were slightly higher and less variable for the FC game, suggesting a more consistently relaxing experience, indicating that the FC game may have been perceived as less stressful or more relaxing.

The comparison between "F*lying through the Solar System*" (FSS) and "*Flying through the Continents*" (FC) is crucial to assess how different learning contexts impact the brain waves of children with ADHD. While both games are designed to teach names and locations, their unique contexts may affect attention, relaxation and other cognitive aspects differently. Evaluating both allows for a broader understanding of how different types of educational content influence learning and cognitive engagement in these children.

Overall, the evaluation of brain waves data reveals that both games were well-received and enjoyable. FC games required more attention and were more consistently relaxing, while FSS games showed more variability in *Appreciation* and *Familiarity*, suggesting different learning curves. Both games were generally easy to understand, with the FSS game requiring slightly more mental effort.

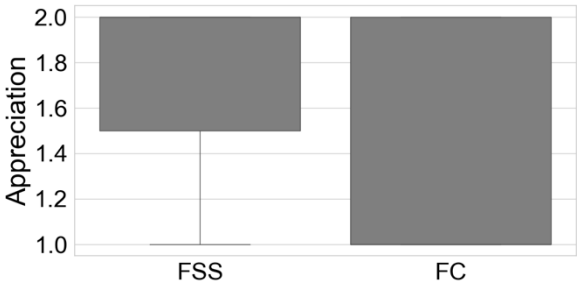


Figure 4: Appreciation Levels by Game

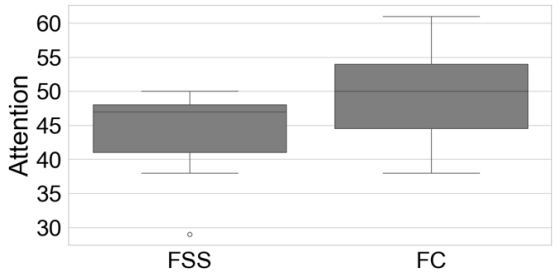


Figure 5: Attention Levels by Game

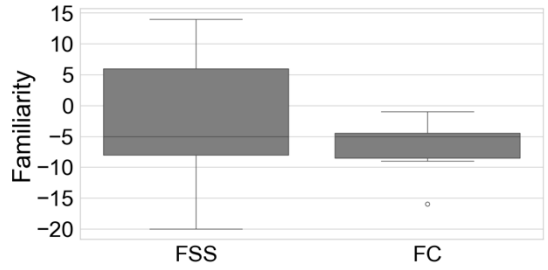


Figure 6: Familiarity Levels by Game

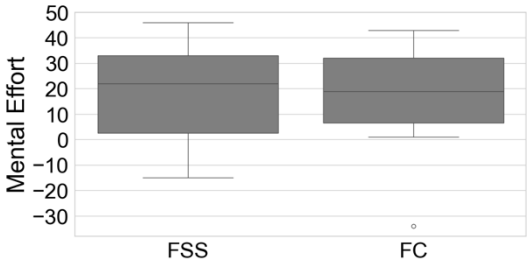


Figure 7: Mental effort Levels by Game

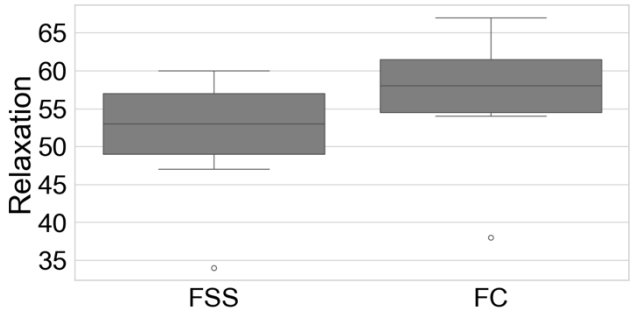


Figure 8: Relaxation Level by Game

4.2.2 Knowledge Acquisition Analysis: Traditional vs. Game-Based Learning

The data shown in Table 4 were merged using each child's unique identifier (ID#), enabling the integration of the results from the pre- and post-tests. This enabled an analysis of the extent to which children learned with each of the methods.

The results indicate substantial improvements in post-test scores for both learning methods (GBL and traditional). However, most participants showed greater progress when using the "*Flying through the Solar System*" (FSS) game. This game not only captured the children's attention more effectively but also promoted greater appreciation and mental effort, suggesting a more interactive and stimulating learning environment. Specifically, the data showed that attention levels were consistently higher during the FSS game, which indicates that this type of content may be more effective in keeping children focused. Moreover, the variability in familiarity suggests that while some children quickly adapted and learned effectively with FSS, others performed better with traditional methods, underscoring the importance of tailoring educational strategies to the individual needs of each student. This finding highlights that while FSS can significantly enhance learning for many students, traditional methods still hold value for others, emphasizing the need for a diverse approach in educational practices.

Interestingly, the effectiveness of each method varied among participants. Some children showed remarkable progress with GBL, while others achieved similar or even better results with paper-based methods. For instance, while some participants using the "*Flying through the Solar System"* (FSS) game saw substantial

score improvements, others using the traditional method (PP) also showed significant gains. This underscores the importance of tailoring the learning medium to the individual preferences and strengths of each student.

5. CONCLUSIONS.

The purpose of this section is to present the conclusions derived from comparing the cognitive and emotional engagement of children during traditional paper-based learning and GBL.

5.1 Effectiveness and Brain Patterns in Learning Methods

After thorough analysis, we conclude that the study successfully achieved its objectives. The data provides clear evidence regarding the effectiveness and motivational aspects of GBL (O1) and reveals distinct patterns in brain waves behaviors among children with ADHD (O2):

- **O1:** The results indicate that educational video games enhance the learning experience for children with ADHD. Brain waves analysis revealed higher levels of engagement during GBL compared to traditional methods. The *Familiarity* values obtained confirm that, for the most part, children acquire more knowledge in a shorter period of time with GBL.
- **O2:** The EEG data analysis showed distinct brain waves patterns between traditional and GBL methods. GBL resulted in higher mean and maximum values of *Attention* and *Relaxation*, suggesting enhanced focus compared to traditional methods. *Appreciation* and *Mental Effort* were also higher in GBL, indicating that children found the games more engaging. While some children experienced occasional higher stress levels during GBL overall, the data suggests this method creates a more stimulating environment for ADHD children.

Regarding the Research Questions (RQ1, RQ2, RQ3, RQ4, and RQ5) that support these objectives (O1 and O2), we can confirm that all of them are met, as demonstrated below. We can conclude that the results indicate that the playability of GBL is well accepted by children with ADHD, showing higher levels of attention and engagement during gameplay (**RQ1**). The brain waves data demonstrated greater appreciation and enjoyment during GBL, indicating positive sympathy and enjoyment factors (**RQ2**). The consistent concentration and low stress levels observed during gameplay suggest that the ease of use of these video games is positive (**RQ3**). Higher overall quality, reflected in better attention, engagement, and relaxation, suggests that the percentage accuracy quality factor of these video games is high (**RQ4**). Brain waves data showed higher cognitive engagement during GBL compared to traditional methods, suggesting that video games do improve cognitive engagement (**RQ5**).

In summary, GBL shows advantages over traditional methods in sustaining children's attention and engagement. The higher levels of appreciation suggest that GBL offers a more enjoyable and less stressful learning environment.

5.2 Knowledge acquisition in Learning Methods

We can conclude that the study successfully achieved assess knowledge acquisition in both traditional and GBL methods (O3):

O3: The results in Table 4 indicate significant post-test score improvements for both methods.

Regarding the Research Question (RQ6) supporting objective (O3), the results show that GBL often led to greater knowledge acquisition within the same period of time compared to traditional methods for many participants. However, traditional learning also resulted in substantial improvements. This indicates that both methods can be effective in facilitating knowledge acquisition, depending on the individual learner's needs and preferences. Furthermore, the *Familiarity* variable evaluated, closely related to RQ6, reflects the learning curve. The analyzed data indicates that children became proficient more quickly with GBL, suggesting greater knowledge acquisition within the same timeframe. However, as mentioned earlier, the effectiveness of each method varies based on individual preferences and learning styles.

As a general reflection from this research, it can be said that this study provides compelling evidence that GBL offers significant benefits over traditional methods, enhancing an effective and motivating learning

environment. Additionally, the distinct brain wave patterns observed during GBL suggest it is more cognitively stimulating. In conclusion, GBL can serve as a valuable supplement to traditional educational methods, providing personalized and engaging content that addresses the unique learning needs of children with ADHD. By leveraging the strengths of both approaches, educators can create a more inclusive and effective learning environment that fosters academic success and holistic development.

6. FUTURE WORK.

Given the small sample size of seven children aged 7 to 9, future studies should expand the sample to improve the reliability and generalizability of findings.

Subsequent research will involve including non-ADHD children and diverse serious video games targeting cognitive skills like attention and memory. This approach aims to identify brain wave activity patterns in children with ADHD compared to typically developing children, across various game-related abilities. These patterns could potentially serve as diagnostic markers, enhancing clinicians' ability to diagnose ADHD more effectively.

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