Individualized Therapeutic Approaches for Children with ADHD in Virtual Reality (VR) Environments: Application and Evaluation of Game-Based Training to Facilitate Parallel Thinking

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Abstract. This study analyzed the behavior and adaptability of children with Attention Deficit Hyperactivity Disorder (ADHD) in a VR environment, evaluating the effects of individualized therapeutic approaches on attention and impulse control. The findings empirically demonstrated that VR-based programs effectively help maintain focus and drive positive changes in task performance for children with ADHD. Specifically, tailored goal settings and level designs played a critical role in enhancing engagement, with notable improvements in the children's self-efficacy. Additionally, the VR environment enables more effective, customized therapy by allowing individualized adjustments to address each child's specific conditions, such as hemiplegia or vestibular deficiencies. This study serves as an exploratory investigation into the potential of VR approaches for ADHD treatment, offering foundational data for future research developments.

Keywords: Human-robot interaction, Healthcare and medical robots, Perception

1 Introduction

1.1 Background and Motivation

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most commonly diagnosed neurodevelopmental disorders in children, characterized by symptoms such as inattention, hyperactivity, and impulsivity. ADHD can lead to various negative outcomes, including poor academic performance, interpersonal difficulties, and low self-esteem, which can significantly impact the child’s daily life and long-term development [5]. Currently, the primary treatments for ADHD include pharmacological interventions and Cognitive Behavioral Therapy (CBT). However, due to the unique characteristics of children with ADHD, applying and maintaining such treatments can be challenging, as they often require the assistance of specialized professionals, leading to spatial and financial constraints [1]. In this context, the recent advancements in Virtual Reality (VR) technology have garnered attention as a novel therapeutic tool for children with ADHD.

VR technology offers an immersive environment that has the potential to maximize a child's engagement and interest. Unlike traditional Cognitive Behavioral Therapy (CBT), which requires the presence of a professional therapist to achieve optimal results and may be limited by spatial and financial constraints, VR allows therapy sessions to be conducted anywhere with the use of a Head-Mounted Display (HMD). Moreover, VR-based therapy programs not only provide a safe environment for children to experience various situations that are difficult to replicate, but they can also be customized to each child’s specific symptoms and characteristics for rapid application. For instance, in this study, we developed haptic equipment that enables individualized training, such as exercises focused on using only one arm or specifically targeting the vestibular system. This personalized training approach allows children to effectively train target behaviors such as improving attention and managing impulsivity.

Due to these technical advantages, the development of VR-based programs aimed at alleviating ADHD symptoms is actively being explored in the field of ADHD treatment. Furthermore, VR’s visual and auditory feedback systems, along with its ability to track children’s actions, contribute to effective behavioral correction and improvement in self-efficacy for children with ADHD.

1.2 Research Problem

Research on VR-based ADHD treatment programs is still in its early stages, and there has not yet been sufficient scientific validation regarding their effectiveness and safety. While existing studies provide initial evidence that VR programs can have a positive impact on improving attention and reducing hyperactivity in children with ADHD, these findings are largely based on small-scale studies, limiting the generalizability of the results [2]. This study also represents an early-stage exploration into the potential use of VR technology for ADHD treatment, conducted with a limited number of participants. Through this approach, we aim to provide preliminary insights into the feasibility of personalized VR programs for children with ADHD, which can serve as foundational data for larger-scale studies in the future.

Furthermore, given the unique characteristics of children with ADHD, there is a possibility that the highly immersive VR environment may induce side effects. Therefore, it is essential to develop safe protocols that can prevent or minimize such adverse effects. Research is needed to verify the effectiveness and ensure the safety of VR-based ADHD treatment, as well as to develop individualized therapeutic programs based on these findings.

1.3 Research Objectives

The main objective of this study is to develop a VR-based treatment program for children with ADHD and evaluate its effectiveness in improving attention and impulse control, as well as investigate its impact on enhancing parallel thinking abilities. Specifically, this study sets the following three key objectives:

1. To design and develop a personalized VR treatment program that reflects the symptoms and characteristics of children with ADHD.

2. To conduct experimental research with children with ADHD to validate the effectiveness of the developed program. The VR environment in the program will provide controlled sensory experiences therapeutically appropriate, allowing a comprehensive evaluation of its effects on inattention, hyperactivity, impulsivity, and parallel thinking.

3. To assess the safety of the program, design appropriate safety protocols, and evaluate its long-term effects on children with ADHD even after the experimental period, determining the overall effectiveness of the program in treating ADHD.

Through this study, we aim to explore the potential of using VR technology for ADHD treatment and assess the effectiveness of VR-based learning interventions for children with ADHD.

2 Experiment

2.1 Participants and Experimental Setup

This study was conducted with four children diagnosed with ADHD. The participants exhibited varying neurodevelopmental stages and sensory sensitivities, necessitating individualized therapeutic approaches. The experiment was conducted in a quiet and controlled indoor environment and the equipment used included a Head-Mounted Display (HMD) and controllers. To ensure the comfort and safety of the children during the experiment, side effects such as motion sickness from wearing the VR devices were regularly monitored, and the experimental process was adjusted as necessary.

Additionally, individualized goal settings and level designs were tailored to each child's characteristics and abilities. These goals and level designs were adjusted to ensure that each child could engage in challenges appropriate to their skill level. This approach was designed to keep the children engaged in the experiment and allow them to experience the program at their own learning pace.

Fig. 1. A scene in the VR environment where a child practices parallel thinking by shooting a web towards a donut target.

Fig. 2. The experiment was designed to be conducted with assigned roles for the facilitator, cameraman, and recorder.

2.2 Procedure

Pre-question. Prior to the start of the experiment, basic information about the children was collected. This process involved gathering data on the child's name, age, prior experience with VR games, frequency and severity of motion sickness, and expectations for the experiment. This information was used to assess each child's readiness for the experiment and to design a tailored approach that would best suit their individual characteristics.

Usability Testing. After wearing the VR devices, the children's comfort and any occurrence of motion sickness were monitored at 5-minute intervals. This testing primarily focused on evaluating any discomfort experienced by the children while using the VR equipment. Specifically, real-time monitoring was conducted to assess the ease of device operation, discomfort while wearing the headset, and any physical reactions such as motion sickness. The following questions were posed during the usability testing:

- Is there any discomfort while wearing the VR equipment?
- Are you experiencing any motion sickness?
- Are there any difficulties in performing specific movements or operations?

These questions were used to assess the children's conditions during the experiment and to make necessary adjustments to the experimental procedures.

User Testing.

Week 1. A basic tutorial was provided to help the children adapt to the VR environment. The tutorial was designed with the overall user experience (UX) in mind, incorporating voice guidance and a graphical interface. Each child performed basic actions such as moving, rotation, object targeting, and grappling, depending on their initial abilities, allowing them to become familiar with the VR equipment.

Week2. Building on the achievements of the first week, additional training was conducted to address the specific needs of each child. During this phase, the children practiced more complex actions, with those who had weaker balance focusing on stair-climbing exercises. The success of these actions and the corresponding feedback were used to evaluate the overall user experience.

Week3. The children were encouraged to perform more varied VR game actions, according to their abilities. The difficulties encountered during gameplay and the subsequent experiences were analyzed, and the difficulty of specific actions was gradually adjusted based on their performance.

The children’s game performance and experiences varied each week, and the experiment was adjusted flexibly according to the individualized training and goals set for each child. Furthermore, the children's progress and user experience were continuously evaluated through the following detailed questions:

- Are there difficulties in using the grappling line to accurately connect to the target?
- What challenges are encountered when swinging on the grappling line?
- Did you experience any difficulties while climbing stairs or changing directions?
- Were there any difficulties in performing specific actions? Which actions were particularly challenging?
- Was the speed of the game instructions too fast or too slow?
- Are you motivated to continue participating in the game?

These detailed evaluations and questions played a critical role in providing customized treatment tailored to each child's developmental stage and allowed the experiment to be appropriately adjusted based on the child’s characteristics.

3 Experimental Result

3.1 Participant A

Background. Participant A exhibited difficulties in spatial and body awareness, frequently experiencing nausea and dizziness due to spatiotemporal distortions during running tasks.

First Experiment. Participant A experienced difficulties with spatial awareness and hand controller usage during the first trial. The participant struggled to press buttons while navigating the screen and also had issues with adjusting the head angle, causing the HMD to slip off. The experiment was discontinued after 5 minutes and 15 seconds when the participant reported dizziness.

Second Experiment. The participant demonstrated some improvement in body movement in response to screen navigation but continued to have trouble using both controllers while ignoring instructions. The participant terminated the session after 2 minutes and 33 seconds due to dizziness.

Third Experiment. Body movements became smoother during screen navigation, but the participant still struggled with button operations. The participant disregarded the researcher’s guidance, and the session was ended after 3 minutes when the participant complained of dizziness.

Individual Results. Although Participant A initially struggled with spatial perception and sensory integration, the participant showed a reduction in dizziness and increased interest in activities as the trials progressed. The participant's parents reported a significant improvement in the child's ability to integrate visual, motor, and sensory input, and expressed great interest in future sessions even after returning home. Interviews confirmed that dizziness had markedly decreased compared to earlier trials, and there was a notable improvement in the participant's task performance.

3.2 Participant B

Background. Participant B exhibited a high level of anxiety, leading to difficulties in independently completing tasks. During independent training at the partner center, the participant frequently requested assistance.

First Experiment. Participant B encountered difficulties with hand controller operations and body coordination during the screen movement. After failing to complete the task within the first couple of attempts, the participant removed the HMD after 5 minutes and 50 seconds, in frustration and discontinuing the session.

Second Experiment. The participant's body movements improved slightly, especially when turning, but they were unable to concentrate on the audio instructions. The trial was stopped after 7 minutes and 6 seconds due to the participant's continued struggles.

Third Experiment. During the third trial, Participant B moved fluidly and ignored background noises, completing the task within 2 minutes and 20 seconds. The participant expressed satisfaction with the accomplishment.

Individual Results. Initially, Participant B struggled with high anxiety and a lack of independent task performance. However, as the trials progressed, the participant's anxiety decreased and parallel tasking skills improved through the VR program. This resulted in a notable increase in the participant's independence and self-efficacy. The participant's parents also observed that their child expressed pride in their achievements and demonstrated a sustained interest in participating in the program. Furthermore, assessments conducted at the center showed significant improvement in the participant's performance.

3.3 Participant C

Background. According to the partner center, Participant C exhibited right hemiplegia, which significantly limited the opportunity to experience the developmental movements that are typical of human growth. The participant had only recently achieved independent walking.

First Experiment. Participant C's body did not respond naturally to screen navigation, and coordination was poor during the first trial. The participant frequently went off the designated path and complained of dizziness, leading to the session being stopped after 5 minutes and 25 seconds.

Second Experiment. The participant attempted to complete tasks that required the use of the right hand but failed, and body movements remained uncoordinated. The session was ended after 6 minutes and 40 seconds due to complaints of dizziness.

Third Experiment. The participant used the right-hand controller but lacked the strength to continue, eventually dropping the controller. The session was stopped after 5 minutes and 29 seconds upon the participant's request, who later stated that the experiment was not enjoyable.

Individual Results. Although Participant C initially found the VR program unfamiliar and intimidating due to right-sided hemiplegia, the participant gradually adapted to the environment and reported feeling more satisfied with the program over time. The participant's parents noted that the VR environment, which was modified to accommodate one-handed control, greatly improved the child's self-confidence. While progress was slower compared to other participants due to the hemiplegia, Participant C still showed consistent improvement as the trials progressed.

3.4 Participant D

Background. Participant D exhibited reclusive tendencies, avoiding going outside due to issues with emotional expression, distractibility, and difficulty in emotional regulation.

First Experiment. The participant quickly adapted, displaying a high level of proficiency in both body movements and hand controller use. However, the participant occasionally peeked through the gaps of the HMD. The session lasted 7 minutes.

Second Experiment. During tasks requiring body rotation, the participant moved naturally and successfully completed them. After 8 minutes and 40 seconds, the trial ended, and the participant reported experiencing dizziness but stated that he managed to continue until the end.

Third Experiment. Participant D excelled in the web-swinging task during the third trial and completed all tutorial objectives. Despite excelling in direction-changing tasks compared to other participants, the session was halted after 4 minutes and 40 seconds due to dizziness and nausea, likely caused by a gastrointestinal issue.

Individual Results. Through the VR program, Participant D showed significant improvements in emotional regulation and task performance. Despite experiencing dizziness and nausea, the participant maintained a positive attitude toward the program throughout the sessions.

3.5 Common Observations

ADHD children's tendency to lose interest quickly and struggle to adapt to unfamiliar situations poses challenges in applying non-pharmacological treatments. The multitasking required in this experiment—moving with the left hand while simultaneously operating the web with the right hand—was initially considered a limiting approach for children with ADHD. However, throughout the three trials, no participants exhibited impulsive behaviors such as throwing equipment or leaving their assigned positions without instruction. Additionally, the participants maintained focus on task execution, even when faced with auditory distractions like other children's voices or questions from the facilitator.

As the trials progressed, participants became more engaged in providing feedback during Q&A sessions and maintained focus even after the program concluded. Interestingly, this focus was independent of their interest in VR; even when some participants expressed that the program was not enjoyable or that certain tasks were difficult, they continued to concentrate on completing the tasks until asked whether they wished to proceed further.

The effects of personalized settings were reflected in the increased focus and goal achievement rates of the children over the course of the trials. Notably, children who initially struggled to complete tasks within the target time showed an improvement of over 30% in success rates following the implementation of tailored goals, demonstrating that the individualized approach contributed to enhancing the children’s self-efficacy.

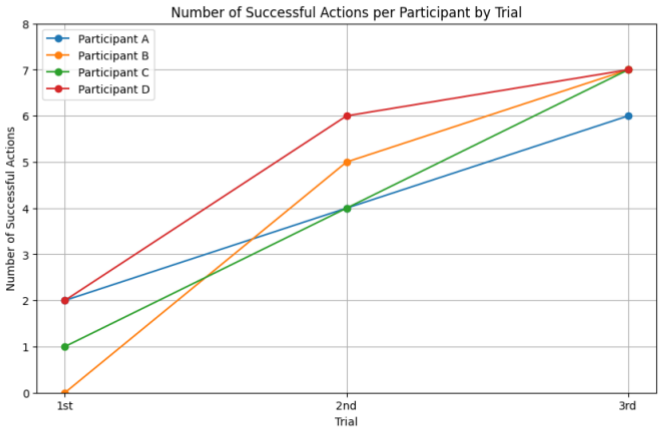

Fig 3. Number of Successful Controls per Participant by Trial (Moving straight, Web shooting, Object aiming, Moving up and down, Jump, Releasing web, Web Swinging)

4 Discussion

4.1 Immersive Effects of the VR Environment

A notable finding of this study is that the VR environment did not act as a hindrance for children with ADHD; however, it contributed to their participation and engagement in the program. Most participants expressed interest rather than discomfort with the VR environment, and even those who experienced difficulties in operating the equipment showed anticipation for the next training session. This suggests that the children perceived the training program not as a task but as an enjoyable activity, viewing the challenges and failures encountered during task execution as part of the play. The effect of this perception, without the use of gamification techniques such as instant rewards, was evident. Children engaged in routine activities such as following a path viewed these actions as novel experiences in the VR environment. This indicates that, for some children, simply transferring the same therapeutic programs into a VR setting may help sustain their interest and increase participation in treatment.

4.2 Enhancing Focus through the Use of HMDs

The use of HMDs appears to have played a role in reducing external distractions, allowing the children to maintain focus on the training program. During the experiment, even when the facilitator asked questions or unexpected noises occurred, the children did not turn their heads in the direction of the sound. They were observed focusing on controller manipulation while responding to questions, even in children previously reported to have weaknesses in sustained attention to response tasks. The isolating effect of the HMD may also be beneficial for children with dependent tendencies. For example, Participant D, who was reported to have difficulties in performing independent tasks, did not express physical affection towards others while wearing the HMD. As the sessions progressed, the participant began solving tasks independently, like other participants. The fact that the facilitator's voice could be heard but not seen likely reduced the participant's anxiety and encouraged independent problem-solving. This isolation effect provided by the HMD aligns with strategies like Body Doubling, which are often employed to improve work efficiency in ADHD patients. The situation where the child is isolated from visual distractions but can still hear the facilitator's voice may have promoted greater focus and independence [3].

4.3 Future Research

This study was conducted with a small sample size over a relatively short period [4]. Given the chronic nature of ADHD, it is necessary to conduct long-term studies with larger sample sizes to evaluate the long-term effectiveness and sustainability of VR-based treatments.

This study confirmed positive changes in the participants' attention span through pre- and post-experiment evaluations conducted by collaborating institutions. However, a limitation of this study is that the analysis of the impact of individualized goal setting on emotional development was based solely on qualitative data and observational outcomes. Future studies should incorporate standardized evaluation tools and objective quantitative measures to strengthen the reliability of the clinical effects observed.

5 Conclusion

This study empirically confirmed that children with ADHD can maintain a high level of focus and make continuous progress in task performance through individualized therapeutic approaches within a VR environment. In particular, the individualized goals and customized level design for each child played a crucial role in enhancing program engagement and positively influencing emotional changes. The results of the study showed that children who initially struggled with task execution significantly improved their control abilities after the implementation of tailored goals, and their self-efficacy also increased. This suggests that individualized approaches are key to maximizing the effectiveness of training programs for children with ADHD.

Additionally, contrary to traditional perceptions of the characteristics of ADHD, the children who participated in this study demonstrated a high level of focus within the VR environment, successfully completing tasks without giving up. This indicates that even short-term VR-based training can be effective for children with ADHD.

By designing the study to account for the diverse characteristics of ADHD in each child, the research revealed significant progress in areas where participants had previously struggled. Despite the high level of motor skills required to use a Head-Mounted Display (HMD) and dual-hand controllers, none of the children exhibited impulsive behaviors or lost interest in the tasks during the experiment. This suggests that contrary to the common belief that children with ADHD struggle to adapt to new situations, the VR environment can actually play a positive role in maintaining focus [6].

Furthermore, this study holds significance as an important case that empirically demonstrates the potential and effectiveness of applying VR technology to ADHD treatment. While previous studies have discussed the potential of VR, this research provides concrete evidence through actual experiments. The results show that children with ADHD are capable of adapting to new technology and environments, providing valuable insights into the potential use of VR in future ADHD treatment program development.

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