The Design of a Virtual Reality Environment for ADHD Intervention

Kholoud Nasser, Ahmad Ryad Soobhany
Heriot-Watt University, Dubai, U.A.E
kaan2000@hw.ac.uk, r.soobhany@hw.ac.uk

Abstract

Attention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental condition marked by inattention, hyperactivity, and impulsivity that significantly impacts daily functioning. This paper presents a novel ADHD intervention approach using immersive Virtual Reality (VR) technology and real-time performance data analysis to create a more engaging and responsive learning environment. The proposed system engages participants in VR tasks designed to challenge attention and impulse control, while monitoring user behaviour such as reaction time and accuracy to detect signs of inattention. When attention lapses are detected through these behavioral metrics, the system dynamically triggers adaptive interventions, such as prompts, rewards, or task adjustments, to re-engage the user. By leveraging an engaging VR environment with adaptive feedback, this approach offers a personalized and data-driven solution to improve attentional control in individuals with ADHD.

Introduction

ADHD is a prevalent neurodevelopmental disorder characterized by persistent patterns of inattention and hyperactivity-impulsivity. It affects millions worldwide, often leading to academic, occupational, and social difficulties. Traditional treatments for ADHD, such as medication and behavioral therapy, can be effective but do not fully address all patient needs, especially regarding sustained engagement and individualized feedback (Rodríguez et al. 2018). This gap has spurred interest in innovative technology-based interventions. In recent years, emerging technologies like *Virtual Reality* (VR) have opened new possibilities for ADHD therapy by creating immersive, interactive environments that closely mimic real-world settings (Mühlberger et al. 2020; Stokes et al. 2022).

VR is particularly promising because it can safely introduce realistic distractions and challenges in a controlled setting. Prior studies have used VR to both assess and train attention in ADHD. For example, VR versions of continuous performance tests have been shown to capture attention lapses and impulsivity with greater sensitivity than traditional methods (Adams et al. 2009). VR-based assessments can simultaneously measure multiple behavior dimensions (reaction times, omission errors, impulsive responses), providing a richer profile of the user's attentional state (Rodríguez et al. 2018). Building on this progress, we propose a VR-based intervention tool designed to improve attentional control and reduce impulsivity in individuals with ADHD. The key novelty of our approach is the use of an immersive and adaptive VR environment that dynamically responds to the user's performance in real time. By tailoring task difficulty and immediate feedback to the individual's needs, the system aims to keep participants in an optimal zone of engagement. Ultimately, this project seeks to develop a scalable, interactive, evidence-driven tool that bridges the gap between traditional ADHD therapies and modern technology-enhanced training.

The document begins by reviewing existing technological interventions in the Related Work section, highlighting the benefits of Virtual Reality (VR). The Proposed Methods outlines the design and implementation of the VR-based adaptive intervention, describing the VR application design, adaptive feedback mechanisms, and the overall system activity flow. The Expected Outcome section presents anticipated results based on previous research. Finally, the report concludes with Conclusion and Future Work, summarizing key findings and suggesting directions for further research enhancements.

Related Work

Technology-assisted interventions for ADHD have gained traction as complements or alternatives to conventional therapy. Various modalities have been explored, including mobile applications, social robots, and VR environments. Social robotic systems have demonstrated the value of interactive and engaging platforms for ADHD training. For instance, humanoid robots like *NAO* (Figure 1) have been used in educational games to help children practice attention and motor skills, delivering consistent feedback and maintaining engagement (Berrezueta-Guzman et al. 2022). However, robots can be cost-prohibitive and less scalable, highlighting the need for more accessible solutions. Mobile and tablet-based applications offer another route, smartphone apps equipped with sensors and machine learning have been designed to monitor attention in real time and provide just-in-time prompts to refocus the child when attention drifts (Barua et al. 2022). These apps are portable and inexpen-

Figure 1: Humanoid robots are used to treat ADHD. NAO, Pepper, Silbot, Sanbot Elf, and Bioloid. are pictured from left to right.

sive, but they lack the fully immersive context that VR can provide.

VR-based systems offer unique advantages by placing users in realistic, controllable scenarios that can stimulate and train attentional skills. An example is the *Virtual Classroom* continuous performance test, where children with ADHD showed significantly more attentional errors in a VR classroom than in a traditional test environment, indicating that VR captured distraction and impulsivity more effectively (Adams et al. 2009). VR environments can present rich multisensory stimuli and record various performance metrics simultaneously, yielding a holistic view of a participant's attention profile (Rodríguez et al. 2018). Beyond assessment, VR is increasingly explored as a treatment modality for ADHD, particularly for attention training and impulse control exercises (Corrigan, Păsărelu, and Voinescu 2023). Ou et al. (Ou et al. 2020) developed a series of VR-based cognitive training games for children with ADHD using a head-mounted display; over a three-month program, participants exhibited notable improvements in attention span and impulse control, along with reductions in oppositional behaviors. Similarly, a recent systematic review by Corrigan et al. (Corrigan, Păsărelu, and Voinescu 2023) reported that immersive VR interventions led to meaningful gains in children's attention, memory, and overall cognitive function, with high engagement and minimal side effects. These findings underscore that VR can be an effective and safe tool for cognitive rehabilitation in ADHD, likely due to its ability to maintain motivation through gamification and presence.

In comparison to other technologies, VR provides a unique balance between engagement and ecological validity. While tablet apps are easily deployable, they cannot fully recreate complex real-life scenarios. Robotics offer physical embodiment and interaction, but VR can achieve comparable interactivity in software at much lower cost and greater flexibility. Moreover, VR allows real-time adaptation of the environment in ways not feasible in the real world. For example, an immersive therapy platform described by XRHealth (XRHealth 2020) automatically adjusts task difficulty based on moment-to-moment user performance, ensuring the experience remains challenging yet not overwhelming. This kind of adaptive feedback loop helps keep users in their "optimal engagement zone," providing personalized

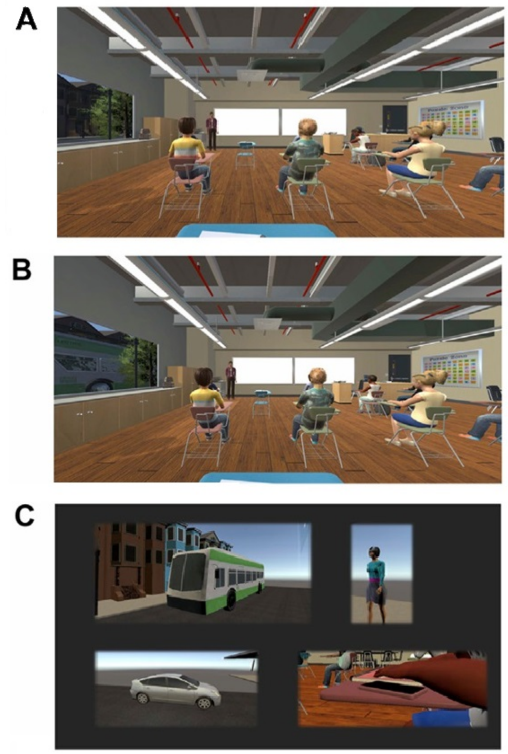

Figure 2: Example of a VR classroom environment for ADHD intervention tasks, shown in (A) a baseline state with no active distractions and (B) with a common distractor (a bus visible passing by the window). Such realistic virtual settings can simulate everyday classroom challenges (e.g., external vehicles, peer movement, ambient noise) in a controlled manner, allowing measurement of a child's attentional focus and distractibility under varying conditions. In research by Stokes et al. (Stokes et al. 2022), a similar VR classroom scenario was used to examine how environmental distractions impact children's attention.

difficulty progression that would be difficult to replicate in a static intervention.

Recent VR studies emphasize the importance of these realistic scenarios. Stokes et al. (Stokes et al. 2022) demonstrated that placing children in a distraction-rich virtual classroom (Figure 2) enables fine-grained observation of attentional lapses in real time. In their study, elementary school children performed learning tasks on a virtual board while typical distractions (cars driving by outside, a phone ringing on a desk, a classmate fidgeting) were introduced. This environment successfully elicited attention lapses similar to those in real classrooms, illustrating how VR can serve as a safe testbed for attentional training. Building on such prior work, our approach focuses exclusively on VR as the intervention medium, harnessing its immersive nature and adaptability to maximize engagement and therapeutic impact for children with ADHD.

Additionally, a pilot study by Cunha et al. (Cunha et al. 2023) demonstrated significant cognitive improvements

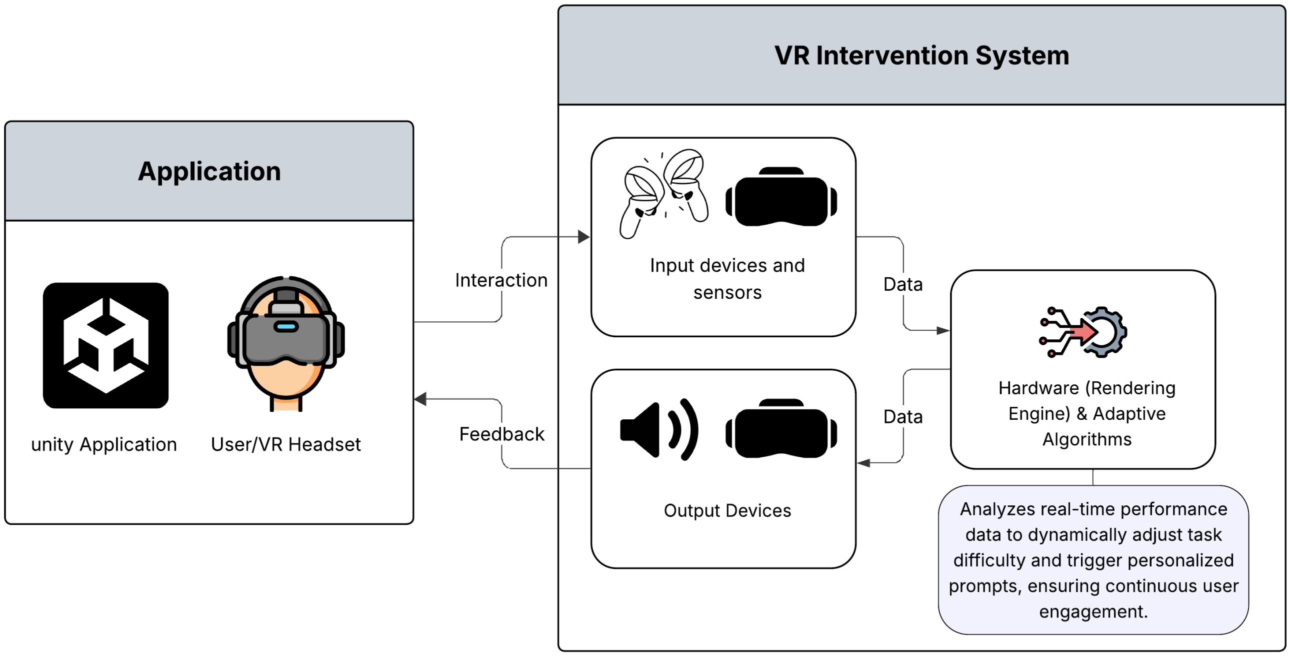

Figure 3: System Component Diagram

from VR-based training in adults with ADHD, highlighting VR's potential to enhance processing speed and working memory. Another randomized controlled trial (Wong et al. 2024) found substantial benefits from VR-based social skills training in children aged 6–12 with ADHD, significantly improving social skills, self-control, initiative, and emotional control. These recent studies reinforce the efficacy of VR interventions, providing foundational support for our proposed adaptive VR system aimed at personalized attentional training and improved cognitive outcomes in children with ADHD.

Proposed Method

We propose a VR-based ADHD intervention system comprising an immersive VR application that delivers adaptive training tasks in a simulated environment. The system Component diagram, illustrated in Figure 3, emphasizes interaction between the user and the VR environment, enabled by input devices and sensors that capture user interactions, and output devices providing adaptive feedback directly within the VR headset

VR Application Design: The VR application is developed in Unity3D and deployed on a Meta Quest Pro head-mounted display, providing six degrees-of-freedom tracking and an untethered experience. Within the VR app, users are placed in interactive scenarios that mimic real-world settings important for attention training. In the current design, two modes are featured: a *Virtual Classroom* and an *Arcade Game* mode. In the classroom mode, the user assumes the role of a student who must pay attention to instructional content on a virtual whiteboard and respond to prompts such as answering a math problem or memory quiz, while typical classroom distractions occur. These distractions can include auditory and visual events such as classmates whispering, objects moving, or outdoor noises. The arcade mode provides a gamified environment for impulse control training, where the user plays a fast-paced game (for example, a "whack-a-mole" style task or a go/no-go reaction game) that requires quick responses to target stimuli and inhibition of responses to non-targets. The variety of tasks is intended to exercise both sustained attention (in an academic context) and impulsivity control in a fun, engaging manner.

Adaptive Feedback Loop: A core feature of the VR system is its adaptivity. During each session, the application continuously logs performance metrics that serve as proxies for the user's attention level and impulsivity. Key metrics include task reaction times, accuracy (percentage of correct responses), omission errors (missed responses), commission errors (responses when none were required), and head orientation or position changes (as an indicator of distractibility or fidgeting). These metrics are analyzed on the fly to infer when the user's focus is waning or when a task may be too easy or too difficult. Based on this analysis, the system can adjust the intervention in real time. For example, if a user begins missing consecutive targets or shows slowed responses (potentially indicating loss of focus), the system might issue a gentle prompt or cue within the VR environment (such as a virtual teacher saying the child's name, or a highlight on the task area) to bring their attention back. If the user continues to struggle, the task difficulty can be reduced adaptively—e.g., slowing down the pace of an arcade game or temporarily pausing new distractors in the classroom scene.

Conversely, if the user is performing very well with sustained accuracy and fast responses, the system can introduce additional challenge (for instance, increase the speed or frequency of stimuli, or add a new distractor) to keep them appropriately engaged. This closed-loop design of monitoring and feedback ensures that each session is individualized, keeping the participant in an optimal state of cognitive effort (neither bored nor overwhelmed). Such adaptivity is informed by the principles used in intelligent tutoring systems and biofeedback therapy, translated here into the VR context for ADHD intervention.

Implementation and Trial Plan: A pilot study will be conducted with individuals diagnosed with ADHD to explore the system's usability and initial impact. Each participant will complete a single VR training session, designed primarily to evaluate the proof of concept and gather preliminary data on user interaction and system responsiveness. The single-session approach is intentionally selected to establish initial feasibility and identify critical usability aspects before proceeding to more extensive studies. Prior to the session, brief assessments will measure attention and impulsivity. During the session, the system will monitor engagement and performance through integrated metrics. After the session, participants will provide feedback via a questionnaire regarding the system's enjoyment, difficulty level, and any discomfort experienced. Insights from this session will inform subsequent refinements. Future research will incorporate multiple sessions, control conditions, and detailed adaptive-algorithm specifications, alongside considerations of long-term outcomes, statistical power, potential VR-induced discomfort, and accessibility barriers to support robust clinical adoption.

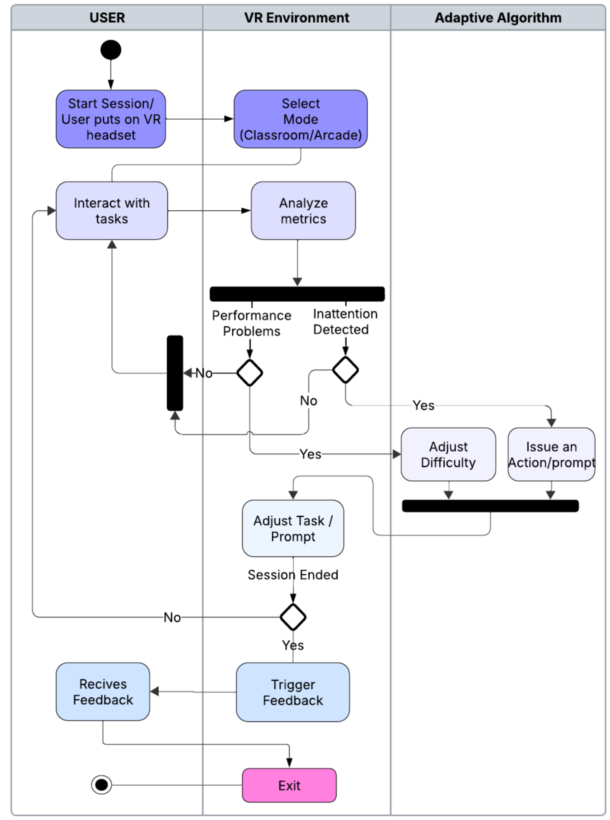

Figure 4: Activity Diagram

System Activity Flow

Figure 4 illustrates the activity diagram representing the dynamic workflow between three core entities of the proposed system: the **User**, the **VR Environment**, and the **Adaptive Algorithm**. This structured representation outlines the real-time flow of interaction, analysis, and adaptation during a typical training session.

The process begins with the user initiating the session and wearing the VR headset. The system then prompts the user to select the training mode—either a Classroom scenario or an Arcade game. Once a mode is selected, the user begins interacting with tasks presented within the virtual environment.

As the interaction progresses, the VR system continuously analyzes performance metrics, such as response time and accuracy. Based on these metrics, decision nodes determine whether the system should adjust task difficulty or issue supportive prompts to the user. This decision-making process is driven by the adaptive algorithm, which evaluates the user's attentional state and provides tailored adjustments to either increase or decrease task difficulty or introduce adaptive feedback (e.g., visual/auditory prompts).

The adjusted task or feedback is then triggered in the VR environment, which the user experiences in real time. The cycle continues with updated metrics being analyzed and further adaptive decisions being made until the session concludes.

This diagram emphasizes the closed-loop nature of the system, highlighting its ability to provide personalized, responsive training through continuous monitoring and adjustment. The division into swimlanes also helps clarify the responsibilities of each system component in the overall intervention pipeline.

Use Case Diagram

Figure 5 outlines the VR intervention in which the user initiates a session to engage in structured tasks aimed at improving focus. As the user interacts with these tasks, the system collects key performance metrics—such as completion time, accuracy, and engagement level then delivers adaptive feedback in response. This includes adjusting task difficulty and providing real-time cues to create a personalized and effective experience for managing ADHD symptoms.

Expected Outcome

We anticipate that the VR-based intervention will enhance attention and self-regulation skills in participants with ADHD. By providing a highly engaging platform, the system is expected to sustain users' motivation to complete attention exercises in a way that traditional settings often fail

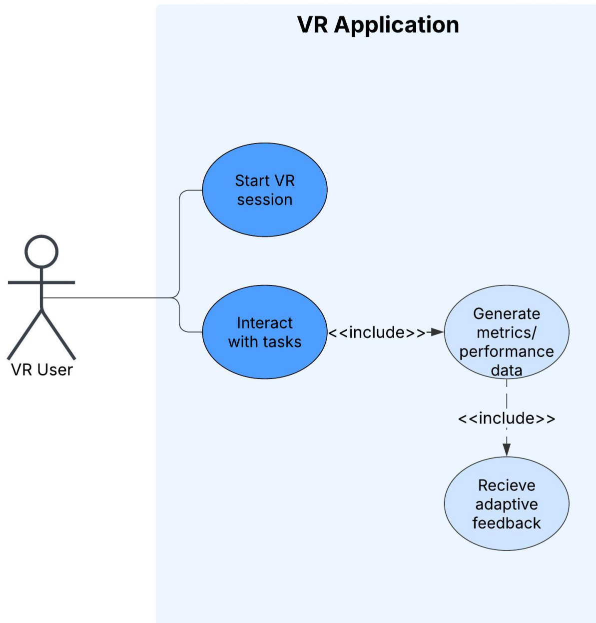

Figure 5: Use Case Diagram

to achieve. We expect to observe improvements in objective measures of attention in line with earlier studies that have reported gains from VR training (Ou et al. 2020; Corrigan, Păsărelu, and Voinescu 2023).

Conclusion and Future Work

In conclusion, this work introduces a novel VR-based intervention designed to enhance attentional control and reduce impulsivity in individuals with ADHD. The immersive and adaptive nature of the system aims to provide a highly engaging, personalized experience that can complement traditional therapies. Preliminary implementation efforts suggest promising outcomes in terms of user engagement and adaptability.

For Future work we recommend to build on this initial pilot study by conducting larger trials to more thoroughly assess how well the VR intervention works in diverse groups. Enhancing the system with advanced machine learning algorithms could further personalize experiences for each participant, making interventions more effective and engaging. Additionally, implementing multi-session data logging will allow the system to adapt dynamically across sessions, continuously improving based on previous interactions. Partnering with clinical experts will be essential to integrate this VR approach with traditional therapies, ensuring it meets the needs of both practitioners and patients, ultimately supporting better outcomes for individuals with ADHD.

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