SmartFunction: An Immersive Vr System To Assess Attention Using Embodied Cognition

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ABSTRACT

In traditional neuropsychological tests, executive functions (EFs) are typically evaluated using paper and pencil or computer-based sit-down tasks. However, a new assessment framework, the Automated Test of Embodied Cognition (ATEC), has been developed to measure EFs and embodied cognition through physical tasks. This paper proposes integrating the ATEC system with virtual reality (VR) to evaluate and diagnose attention-deficit disorders using embodied cognition (EC) principles. The VR system will utilize Meta Quest 2 VR headsets and controllers with motion sensors to accurately capture users' physical movements. The collected motion data will be transmitted to a remote server for evaluation through machine learning algorithms. By incorporating VR technology, the proposed solution provides an effective and affordable tool for assessing executive functions and attention-deficit disorders in real-life scenarios. The paper also presents the proposed solution's system architecture, which involves using a virtual avatar and visual and auditory cues to guide users during physical tasks.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

KEYWORDS

cognitive assessment, virtual reality, machine learning, ATEC, executive function, embodied cognition

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1 INTRODUCTION

Attention-Deficit Hyperactivity Disorder (ADHD) is a prevalent behavioral condition commonly observed in children and adolescents in the United States. It is characterized by symptoms of inattention, impulsivity, and in some cases, hyperactivity. The incidence of ADHD increases with age and affects approximately 10% of individuals between the ages of 4 and 17 [26]. Unfortunately, this condition often goes undiagnosed and can result from various neurodevelopmental disorders. Attention deficits are a common component of Executive Function (EF) difficulties throughout an individual's life. They have been linked to academic failure, problematic social functioning, increased risk of injuries, substance abuse, and challenges at work in adulthood [7]. ADHD is an EF disorder that includes several crucial functions: planning, cognitive flexibility, response inhibition, attention control, and verbal and visuospatial working memory [27].

Current assessments of EF are based on neuropsychological tests that involve paper and pencil or computer-based sit-down tasks, which do not reflect real-life scenarios. However, a previously funded study developed a new assessment system called the Automated Test of Embodied Cognition (ATEC) [1], which uses cognitively demanding physical tasks to measure executive function in action. It has been proven to be a more accurate predictor of children's functioning than conventional testing. The next step is to develop a low-cost and user-friendly VR commercial system to diagnose attention deficit and other EF deficits, which could benefit vocational rehabilitation, healthcare, education, families, and employers in various industries.

The Automated Test of Embodied Cognition (ATEC) is a clinically proven system developed to measure children's executive function and embodied cognition. It involves a set of physical tasks that require cognitive demands and concerns the physical movements of the participant. The ATEC system is based on Embodied Cognition (EC) principles, which propose that cognition is not only a function of the brain but also involves the body's interaction with the environment. It diagnoses attention disorders by analyzing the cognitive processes engaged during the performance of physical tasks. For example, it can identify deficits in attention control by measuring the accuracy and speed of a participant's response to a visual cue during a physical task. The automated system utilizes deep learning and self-supervised learning [12] to identify early symptoms of attention disorders.

This paper proposes the integration of the Automated Test of Embodied Cognition (ATEC) system with VR to evaluate and diagnose attention-deficit disorders while providing human expert interventions as necessary. The proposed integrated system utilizes Embodied Cognition (EC) principles, which involve the manifestation of cognition through various physical body movements [1]. The significant advantage of this integrated system is its potential to diagnose and assess ADHD levels remotely, making it accessible for a variety of applications, including addressing STEM disparities in education, inattention, memory impairments, coordination in Parkinson's Disease, early onset dementia, cognitive fatigue in multiple sclerosis, and other health conditions. Furthermore, by integrating ATEC with VR, we aim to provide a low-cost, easy-to-use, and effective tool for assessing executive functions and attention-deficit disorders in real-life scenarios. In addition, it can expand to assess other EF disorders by adding more tasks and assess cognitive flexibility, response inhibition, working memory, and other EFs.

ATEC uses motion capture of physical movements and applies computer vision algorithms to score performance and assess attention. However, we propose to build a VR system on top of ATEC that uses a VR headset and controllers to perform physical tasks and track physical movements rather than computer vision. This is the first time attention, and EFs can be scored and assessed using a VR system.

The proposed system has two major components:

- A VR version of the ATEC system to assess EF disorders.
- Data collection and analysis of EC motion data using VR headsets and controllers while the user performs the ATEC tasks.

The rest of the paper is structured as follows: we start by discussing some of the previous works that used VR for cognitive assessments. Then we explain the physical tasks from the ATEC system that will be integrated into the VR version. Finally, we present our planned study and data collection process, followed by our conclusion on the work done and future directions.

2 RELATED WORK

Traditional methods for the cognitive assessment and rehabilitation of attention usually include pencil and paper techniques, motor reaction time tasks in response to various signaling stimuli, and flat-screen computer programs [10, 14, 20]. The Stroop test [25] is arguably the best-known neuropsychological test to tap attentional (dys)function. It involves presenting a participant with a list of words that are printed in different colors. The participant is instructed to say the color of the ink as quickly and accurately as possible, while ignoring the word itself. Another well-known test is the flanker task [8]. In the arrow version of this task, subjects have to respond to the direction of a left or right pointing arrow, and ignore flanking arrows that point in the opposite direction as the target arrow [9] [24].

Traditional neuropsychological tests assess cognitive constructs without considering real-world context and have a modest predictive potential for everyday performance [18]. In fact, studies have demonstrated that the relationship between performance on paper and pencil EF tasks and performance in activities of daily living is weak [3]. Using a VR environment is one of the most promising new methods for developing function-led activities [6]. Participants are more likely to display usual behaviors when immersed in a virtual environment (e.g., activities that occur in daily life)[2]. To investigate the ecological validity and construct validity of VR measure of EF, Researchers in [19] conducted a study using the Virtual Library Task (VLT); a real life analogous task—the Real Library Task (RLT). Performances on the VLT and the RLT were significantly positively correlated, indicating that VR performance is similar to real-world performance.

Previous studies have shown that clinical assessment tasks in VR can be replicated successfully, as evidenced by [11], [16]. There are numerous instances of VR being effectively employed as an evaluation tool for EF-related abilities, such as task-switching and working memory [13], memory [23], and, most recently, cognitive function concerning attention switching and reasoning [28]. Researchers in [28] have designed a toolkit for building virtual interactions that can replicate traditional cognitive tests (such as the Wisconsin Card Sorting Task and Multitasking Task). Results of the preliminary validation study suggest effective replication of traditional tasks in VR, and suggest that the toolkit can be used to create new cognitive tasks in VR while producing measurements of performance that share mechanisms with traditional cognitive tests. In [21], the authors present modifications of the standard Simon and flanker tasks adapted to real-world settings using VR and human-like avatars as target stimuli. Their findings show that VR is a credible tool for testing inhibitory control with a high degree of transferability and generalizability to the real world. In [2], a study conducted on young and healthy adults, researchers used a VR-based function task with varying levels of executive function load to investigate its impact on performance. Despite finding that working memory capacity is not a complete predictor of performance, they discovered through quantitative analysis that as the load increased, task performance declined.

This paper proposes a novel framework for executive function assessment through body motion tracking. ATEC uses motion capture of physical movements and applies computer vision algorithms to score performance and assess attention [5, 17, 29–31]. The innovation here is to build a virtual reality system on top of ATEC using VR hand-tracking controllers to track movements rather than computer vision.

3 ATEC TASKS

3.1 Pass the Ball to the Beat (PBB) Task

This section outlines the "Pass the Ball to the Beat (PBB)" task in the Automated Test of Embodied Cognition (ATEC). The PBB task is a core component of ATEC with higher cognitive demand. It is designed to assess sustained attention and response inhibition using rhythmic upper body movements in response to commands. This task is more complex than traditional computerized continuous performance tests [4], as it involves a series of trials that increase in complexity. In each attempt, the participant is asked to pass a juggling ball from one hand to the other in rhythm to spoken cues of "Green Light," move the ball up and down to "Yellow Light," and not pass the ball when they hear "Red Light." The task is then repeated at a faster pace. The participant is also presented with the same set of trials but using a sequence of pictures of Green, Red,

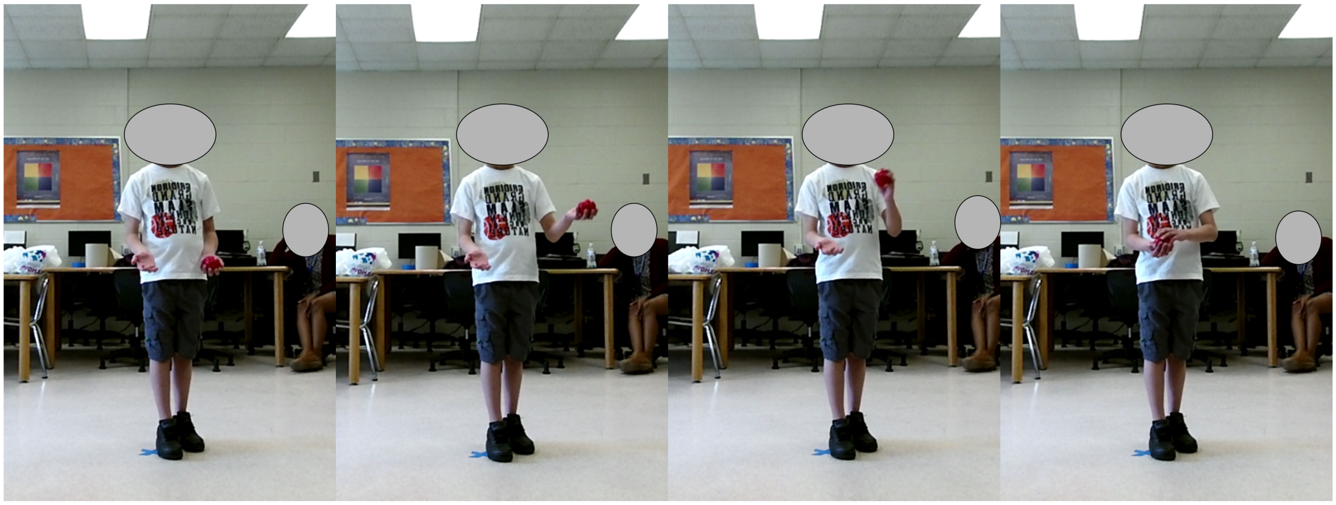

Figure 1: Sample image frames from the Pass the Ball to the Beat (PBB) Task. Here, the child performs a "PASS" action when the GREEN light turns ON or when they hear the keywords "GREEN LIGHT".

and Yellow traffic lights as visual cues, allowing for a comparison of sensory modalities. This task provides a more comprehensive assessment of executive function and attentional processes in children by incorporating embodied cognition principles.

3.2 Cross Your Body (CYB) Task

The second task from ATEC that will be translated to a VR setting is the "Cross Your Body" task. This task is a challenging cognitive and physical task that requires a combination of skills, including sustained attention, working memory, response inhibition, task-shifting, self-regulation, bilateral coordination, rhythm, and sensory integration. The task involves a sequence of movements that are performed in beat to a tune, where participants are instructed to touch their ears alternately with the opposite hand, followed by touching their knees, hips, and shoulders, respectively. In the final round, all four commands are given, and the person must remember to touch the correct body part when the corresponding word is heard, requiring them to cross their midline.

The task is based on the "Head Toes Knees and Shoulders (HTKS)" task [15], which has been widely used to measure self-regulation in children and has been found to be related to cognitive flexibility, working memory, inhibitory control, and academic achievement. The "Cross Your Body" task builds upon HTKS by adding a higher level of complexity and requiring participants to coordinate their movements across their bodies, incorporate rhythm, and integrate sensory information.

4 PROPOSED SYSTEM

The proposed solution is to convert the Automated Test of Embodied Cognition (ATEC), a physical assessment system, into a VR system. The VR system will consist of two ATEC tasks, Cross Your Body (CYB) and Pass the Ball to the Beat (PBB), that focus on various cognitive skills such as attention, response inhibition, working memory task-shifting, and self-regulation. The primary objective of this proposed VR system is to develop an experimental testbed that can accurately capture and analyze participants' physical movements while performing these tasks.

The proposed VR system is expected to offer a standardized, reliable, engaging, and motivating assessment experience compared to traditional physical assessment tasks. Additionally, the VR system will be accessible from anywhere, and its gamified nature will make it easier to standardize the assessment process. The VR application will include CYB and PBB tasks, providing a game-like feel to the assessment system.

The VR system will be designed using the Meta Quest 2 VR headsets and controllers equipped with an accelerometer, gyroscope sensors, and six degrees of freedom (DOF) tracking for accurately capturing users' physical movements. The VR environment will be developed using the Unity game engine, with each game containing multiple difficulty levels based on the speed of the physical activities and the time allotted to complete the tasks.

The system incorporates a virtual avatar and visual and auditory cues to instruct users during the performance of Cross Your Body (CYB) and Pass the Ball to the Beat (PBB) tasks. Figure 4 demonstrates the VR system. The VR controllers' sensors record the trajectory of each action performed by the user, and these actions will be analyzed and scored based on their validity. In addition, the VR system's motion controller and headset will capture the subject's upper body movements, which a server will evaluate. The captured motion data will be analyzed using machine learning algorithms to produce an ATEC score for each task.

Figure 3 provides an overview of the VR assessment module, which collects motion data from users performing the PBB and CYB tasks. The collected motion data will be sent to a remote server for evaluation. The remote server will use machine learning-based methods to provide cognitive performance scores for the users automatically. A human expert can provide recommendations or interventions based on these scores. Additionally, the development of the system will involve collecting vision data during task

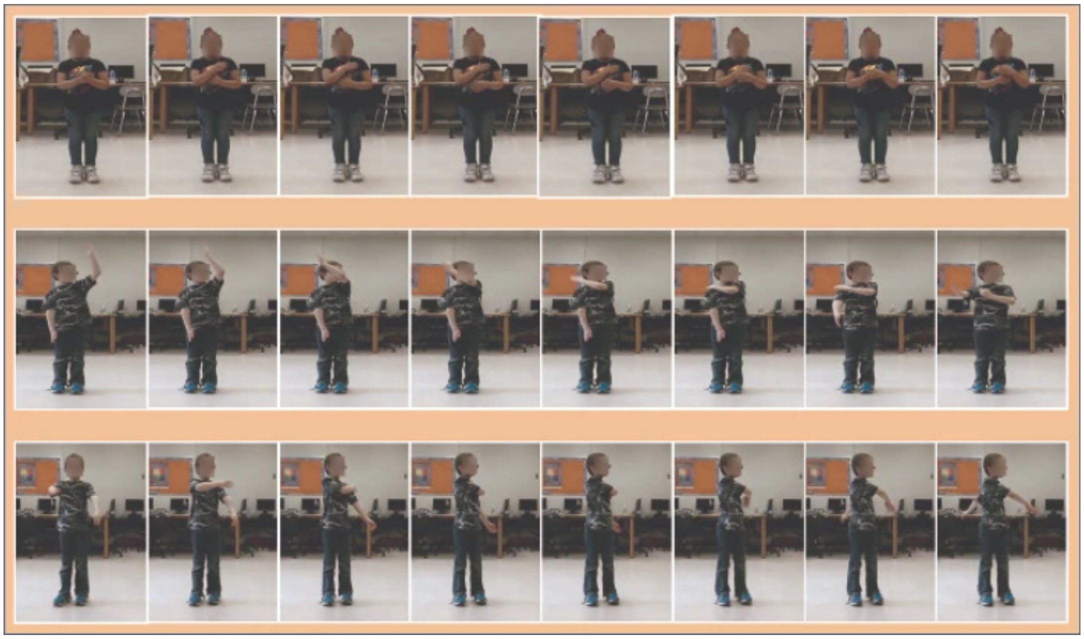

Figure 2: Sample image frames from the Cross Your Body (CYB) Task. The actions (top to bottom) performed are "right hand left shoulder", "left hand right shoulder", and "right hand left shoulder", illustrating the level of variations that the touching-shoulder action can have [22].

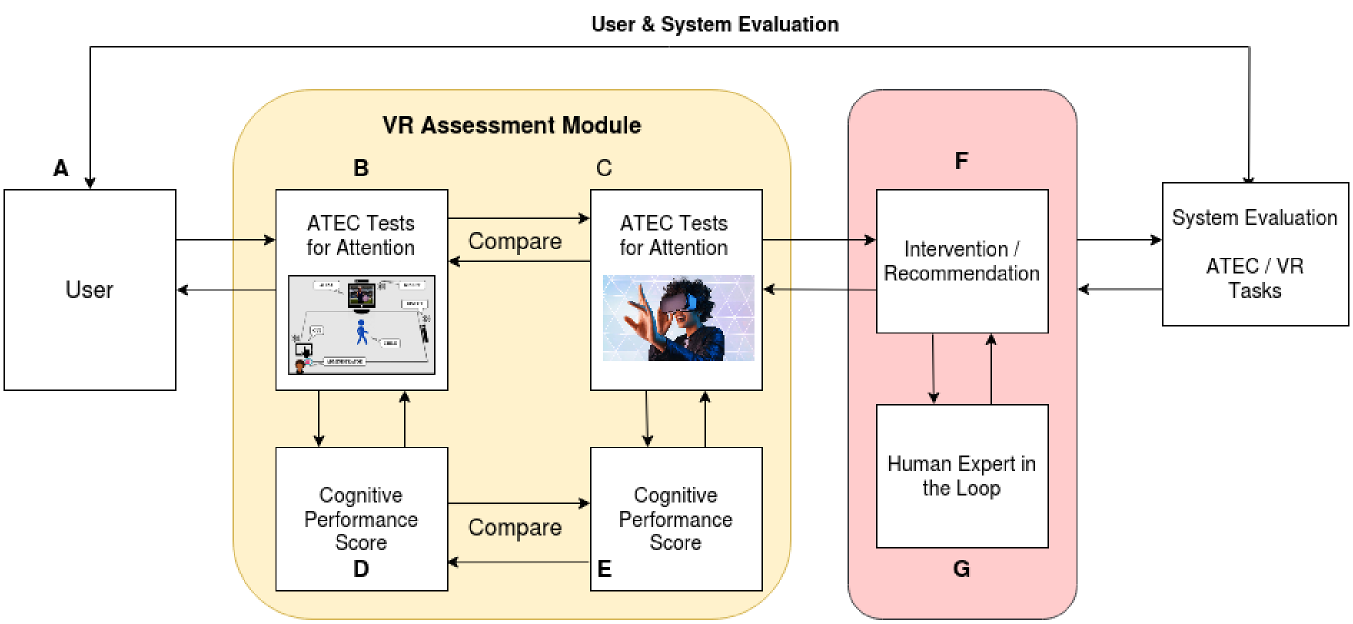

Figure 3: System Architecture

performance to generate cognitive performance scores using the traditional Computer Vision (CV) based ATEC system. The scores from the CV-based ATEC system and the proposed VR-based system can be compared to improve the VR-based system.

In summary, the proposed VR-based solution offers a promising approach to enhancing the ATEC assessment system. This system will provide a standardized, accessible, and engaging cognitive assessment tool for research and educational settings.

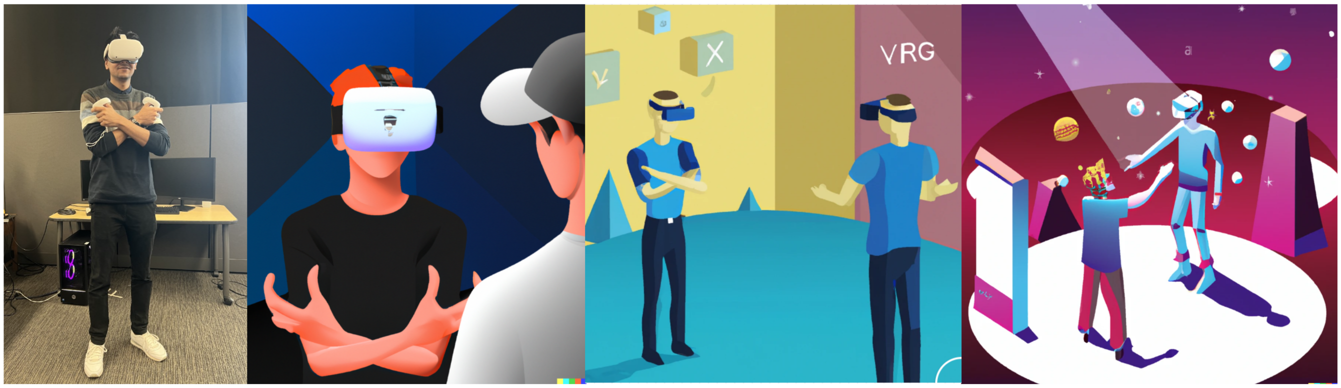

Figure 4: Proof of Concept (PoC) Design of the VR system based on ATEC: (a) Subject engaged in playing the "Cross Your Body (CYB)" game (b) Close-up view of the user playing "CYB" inside the VR game under the guidance of a human avatar (c) Two players playing different versions of the VR game - the first player playing "CYB" and the second player playing "Pass the Ball (PTB)" (d) Game view of a player engaged in playing PTB while being instructed by a human avatar.

4.1 VR Environment Demo

A VR demo of the PBB task is developed in the Unity game engine using the Oculus Quest 2 headset and controllers. The game environment is set in a classroom with a traffic light situated in front of the user. In this demo, the user is asked to pick up the ball and pass it from one hand to the other when the light turns green and not pass it when the light is red. Using the Oculus quest 2 controllers, the user has the ability to pick up the ball from the desk and hold it until a green light is observed and then pass the ball to his other hand. A screenshot of the demo can be seen in Figure 5.

5 CONCLUSION

This paper proposes integrating the Automated Test of Embodied Cognition (ATEC) system with VR to assess and diagnose attention-deficit disorders using Embodied Cognition principles. The significant advantage of this integrated system is its potential to analyze and evaluate ADHD levels remotely, making it accessible for various applications. The proposed method has two major components: a VR version of the ATEC system to assess EF disorders and data collection and analysis of EC motion data using VR headsets and controllers. At the same time, the user performs the ATEC tasks. Previous works in cognitive assessment and rehabilitation of attention have been discussed, and traditional neuropsychological tests have been found to have a modest predictive potential for everyday performance. Therefore, the proposed integrated system has the potential to provide a low-cost, easy-to-use, and effective tool for assessing executive functions and attention-deficit disorders in real-life scenarios. In addition, it can expand to assess other EF disorders by adding more tasks and assess cognitive flexibility, response inhibition, working memory, and other EFs. The future direction includes conducting studies on the proposed system to evaluate its efficacy and usability.

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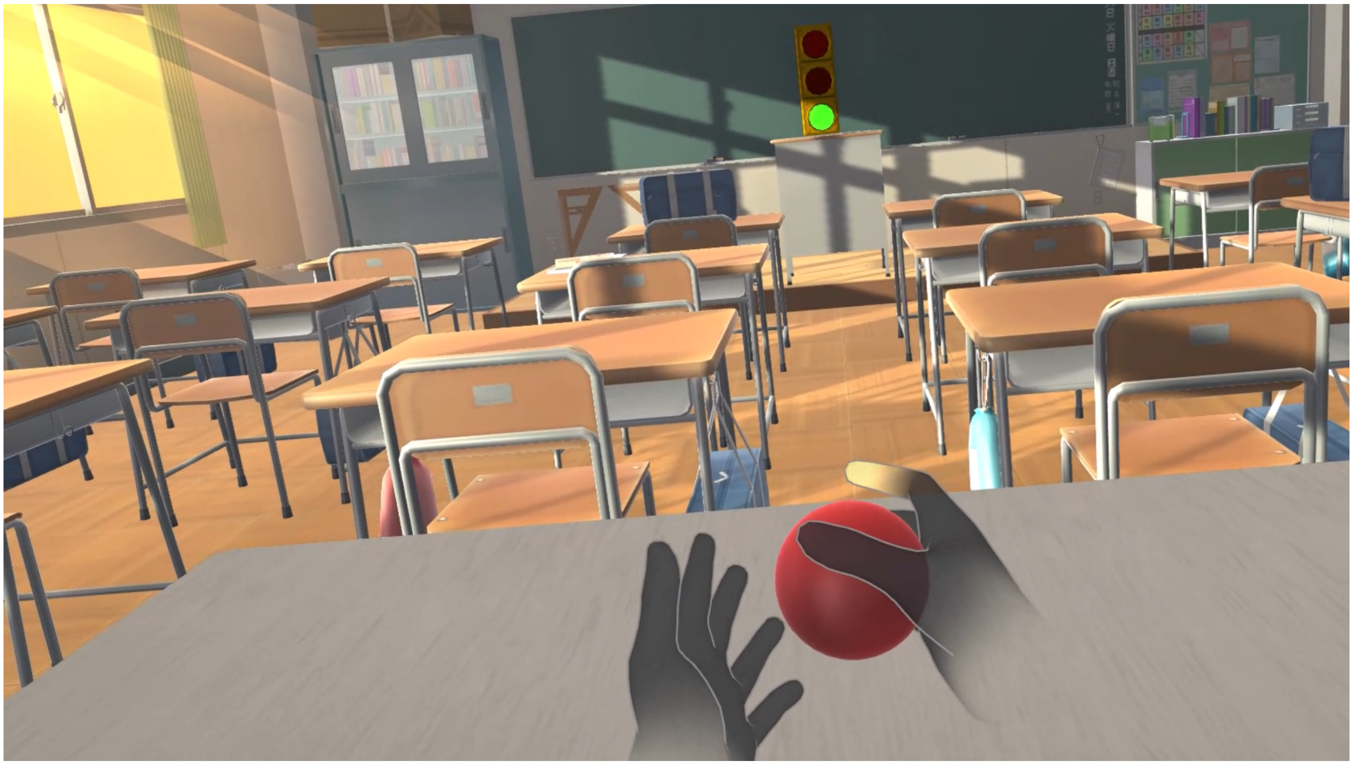

Figure 5: Demo of the VR Environment where a user performs the PBB task, passing the ball from one hand to another during a GREEN light.

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