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Virtual Reality Therapeutic Modules: Enhanced Cognitive Rehabilitation for Adolescents with Intellectual Disabilities

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Cognitive enhancement is becoming increasingly crucial for adolescents with neurodevelopmental impairments. This study highlights the evaluation and treatment of intellectual disabilities in adolescents who have difficulty with daily living activities despite having conceptual-based skills. To assess cognitive skills in these adolescents, the study utilized Virtual Reality (VR) approaches, integrating various modalities in the field of rehabilitation. The research aimed to develop virtual reality therapeutic modules that target two critical aspects of cognitive skills, using behavioral assessment scales tailored for Indian adolescents with intellectual disabilities, such as the Vocational Assessment and Programming System for Persons with Mental Retardation and the Functional Assessment Checklist for Programming. The results of this investigation showed the feasibility of implementing the virtual reality approach with intellectually disabled adolescents, with evaluations based on a single trial and the average time taken to complete the modules. The system was user-friendly, adaptable, and did not require any external hardware. A significant advantage of the developed therapeutic modules is their availability in multiple languages, tailored to the needs of intellectually disabled adolescents. Over time, these virtual reality therapeutic modules can provide a comprehensive rehabilitation program for these adolescents.

Keywords: Activities of daily living, Cognitive skills, Intellectual disability, Rehabilitation, Therapeutic modules, Virtual reality

Introduction

Neuro-developmental impairments[1], including intellectual disability, cerebral palsy, autism, specific learning disorders, and attention-deficit/hyperactivity disorder, are primarily associated with brain and neurological system[2] behaviors. Intellectual disability and autism are notably common among these conditions. Intellectual Disability (ID), historically known as mental retardation, is marked by reduced intellectual functioning and a decreased ability to adapt to everyday activities and social environments. Early diagnosis is vital, as it allows for ongoing management of the condition throughout a person's life. In India, it was projected that by 2020(3), there would be 55 million individuals with disabilities, many at risk of neurodevelopmental impairments. Studies have shown that the prevalence of intellectual disability ranges from 1.7 to 32 cases per 1000 people.[4]

In addition to intellectual challenges, adolescents with ID face significant rehabilitation obstacles due to a lack of conceptual behavior skills.[5] These skills include activities such as memory, mathematics, conceptual tasks, and the use of everyday items. Such adolescents struggle with planning, analyzing, and transferring information in working memory[6,7], impeding their ability to perform essential functions. The unemployment rate among individuals with ID ranges from 32% to 46%, with some studies reporting rates exceeding 70%, which is ten times higher than for non-disabled individuals. Over three-quarters of these individuals heavily rely on social support from family members or public assistance for daily living.[8] Government initiatives have focused on supporting employment to enhance the socio-emotional well-being and physical health of people with intellectual disabilities. Timely rehabilitation is one of the most prominent factors to enhance the growth of the affected person. Developing conceptual behavior skills is the first step towards achieving social autonomy and improving employment prospects, as

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below-average functioning and competency can severely limit job opportunities. Despite the importance of cognitive and conceptual behaviors, designing practical daily activities and rehabilitation programs for adolescents with ID remains challenging. Such programs are essential for helping these adolescents gain independence and reduce their social burden.

Using computer-assisted technology in adolescent rehabilitation programs has been explored[9] as an efficient and effective method. This approach integrates multimedia content such as text, diagrams, sound, and videos. With the advent of Virtual Reality (VR) technology, computer-assisted rehabilitation has advanced significantly.[10–12] Virtual reality enables users to achieve "immersion" through a human-computer interface that simulates visual, auditory, and haptic experiences. This makes real-world training more accessible and effective than conventional methods using words or pictures.[13] VR-based rehabilitation and education[14] are particularly appealing for adolescents with ID as they are more engaging, less challenging, and can help mitigate social anxiety. The nature of VR approaches positively impacts motivation and engagement, enhancing rehabilitation success by increasing active participation during therapy sessions. Moreover, caregivers benefit from reduced concerns regarding safety, social perceptions, and the logistical challenges of real-world training environments. VR provides a controlled and resource-efficient alternative that can significantly improve the quality and effectiveness of training programs[15–17] for adolescents with ID.

According to prior findings, VR-based therapeutic modules in rehabilitation and healthcare settings are designed to enhance the cognitive skills of adolescents with ID. These innovative techniques are being explored because the rehabilitation process can be prolonged.[18] Several examples of VR rehabilitation systems currently in use are highlighted below. One study focused on the visual-motor integration of ID adolescents, demonstrating significant improvements in cognitive functionality by combining VR and computer games[19] using a Nintendo Wii board. Adolescents with ASD[20] and ID aged 10–11 years participated in rehabilitation programs to enhance their psychomotor and intellectual performance. Despite the high efficiency of these technologies, their expensive equipment necessitates the development of low-cost alternatives. Another study evaluated the acceptability and efficacy of a remote home-based rehabilitation program using virtual apps installed on tablets. This program focused on independent aspects of quality of life for adolescents and young adults with ID. The study aimed to determine whether this technique could be used independently, enjoyable, and quickly and whether the skills learned could be applied to daily life. Several user-friendly VR therapeutic modules have been developed to simulate daily activities and environments. These modules often require training from bio-signals, including optical, auditory, and tactile signals. VR modules can be used for repetitive rehabilitation activities for individuals whose cognitive functions are still developing. By providing a suitable environment, defined duration and intensity of activities, and user-defined repeatability, these therapeutic modules offer a superior alternative for adolescents.[20]

This study evaluated the feasibility of VR-based conceptual modules for rehabilitating adolescents with intellectual disabilities, aiming to restore their cognitive skills through therapeutic processes.[21] The approach involved adapting conventional skill training into a realistic VR environment, thereby integrating the familiar context of conventional rehabilitation into a virtual setting. The study focused on vital conceptual skills such as numerical understanding, daily living activities, and time management, recognizing their importance in rehabilitation. These therapeutic modules were designed based on learning theories to help adolescents regain concepts, items, arithmetic skills, self-efficacy, and decision-making attention. Through these modules, adolescents could develop the skills to confront their fears, manage irritations, and navigate a simulated world with increasing complexity and distractions. Furthermore, the therapeutic modules were aligned with the Functional Vocational Assessment for Persons with Mental Retardation[22] (VAPS) and the Functional Assessment Checklist for Programming[23] (FACP) to assess the adolescents' performance. The developed modules were adaptable for rehabilitating adolescents with cognitive skill deficits. To determine the feasibility of the VR system for adolescents with ID, the study examined three main factors: (a) whether the adolescents could independently manage these modules, (b) whether the modules were enjoyable, motivating, and easy to use, and (c) whether the acquired skills could be applied to real-world settings in everyday life.

Materials and Methods

Test Participants and Clinical Trial Procedure

10 ID adolescents (15–20 years) participated in data collection with informed consent between November, 2022-December, 2022. The single feasibility trials randomly took the adolescents from the National Institute for the Empowerment of Persons with Intellectual Disabilities (DIVYANGJAN). All the adolescents considered were diagnosed with ID based on standardized intelligence tests (IQ below 70) and adaptive behavior assessments. A minimum of two areas—communication, self-care, home life, social/interpersonal skills, use of community resources, self-direction, functional academic skills, work, leisure, health, and safety—must show indications of impaired adaptive functioning. However, adolescents with stable medical and psychiatric conditions and those who understand the language used in the study or have access to appropriate language assistance were included. Characteristics of adolescents's baseline clinical histories and demographics were presented (Table 1). The evaluation was conducted using IQ assessment scales tailored for Indian adolescents with mental retardation, specifically the VAPS and FACP. These assessments have been extensively utilized to evaluate various domains, including motor skills, activities of daily living, language proficiency, reading and writing abilities, understanding of numbers and time, social skills, pre-vocational readiness, financial burden, and behaviors related to violence and destructiveness.

Conventional Rehabilitation Clinical Examination

Therapists administrated an integrated approach in the conventional rehabilitation clinical assessment for adolescents with ID. They evaluate social integration, emotional stability, and physical and cognitive aspects. Through a thorough evaluation, each participant's distinctive abilities and problems were better understood, allowing for the development of customized rehabilitation therapeutic modules to improve their overall quality of life and level of independence. The Functional Vocational Assessment for Persons with Mental Retardation (VAPS) was a scale developed by the National Institute for the Mentally Handicapped (NIHM) specifically designed for individuals aged 18 years and older with ID. This assessment tool serves multiple purposes: it evaluates work readiness skills, assists in identifying appropriate job opportunities within the community, offers insights into selected job roles, identifies areas requiring additional training, emphasizes the importance of on-the-job training, assesses work-related skills and behaviors, aims to facilitate employment opportunities for all assessed individuals, and provides ongoing support to ensure job retention. Conversely, the FACP was developed by the NIHM specifically for adolescents with intellectual disabilities aged between 15 to 18 years. In transitioning from IQ-based to functional level-based grouping in special education evaluation and programming, the FACP ensures age-appropriate programming without compromise. This evaluation instrument was designed to yield training that suits the individual participant, allowing frequent internal evaluations to track growth and make necessary adjustments. It enables qualitative and quantitative assessment of the participant's development and facilitates uniform classification of adolescents, guiding their progression to the next developmental level. The components of the tool were designed to be easily understandable, involve tasks essential for daily activities, be readily observable, be as age-appropriate as possible, and ultimately be aimed at fostering successful societal integration. However, this conventional clinical examination was mapped with designed and developed VR therapeutic modules. By implementing such an approach, therapists enhance the participant's rehabilitation experience by adjusting the virtual environment to meet the participant's competence ability. Despite that, this approach has quantitative information on the participant's growth and effectiveness, enabling more accurate assessment and adaptation of the rehabilitation objectives.

Table 1 — Adolescents' demographic details

Participant ID	Age (in Years)	Neurological condition
I1	15	Mild ID
I2	16	Moderate ID
I3	16	Mild ID
I4	20	Mild ID
I5	15	Moderate ID
I6	20	Mild ID
I7	15	Moderate ID

Hardware Features

In VR-based rehabilitation, adolescents must be immersed in the computer-generated environments, disconnecting from the external world during therapy. The rehabilitation system utilized a tablet or Airbar (Touchscreen sensor) for PCs. Moreover, a tablet was running on Microsoft Windows 10, with a screen size of 10.1 inches. Alternatively, therapy modules could

be practiced on a PC or laptop by connecting an Airbar (15.6 inches) via a USB cable if a tablet was unavailable.

Software Features (VR-Based Cognitive Therapeutic Modules)

Therapeutic modules in the computer games framework were vital to developing interactive VR systems. This software application, consisting of libraries, enables the creation of digital rehabilitation tools and other applications with real-time graphics. To build 2D or 3D therapeutic modules, programmers can take advantage of various gaming mechanics, each of which has specific capabilities that aid with completing the task. Unity Game Engine (version 2019.1.10f1)[2] in this work shaped the VR application, utilizing C# scripts (Visual Studio 2017) and programming language to replicate all user interactions. The physical interactions between the fundamental components and their surroundings were significant. As depicted in Fig. 1, the VR System for Cognitive Rehabilitation (CORE) was indigenously designed and developed to monitor the growth of cognitive skills. The system includes three therapeutic modules with varying difficulty levels to assess and enhance the participant's performance.

Activities of Daily Living (ADL) *(VAPS and FACP):* This non-immersive VR therapy, designed as a learning activity, targets adolescents with ID. Comprising four sub-modules, it presents questions related to everyday items, aiming to enhance adolescents' learning capabilities through therapy. The sub-modules (Fig. 1 (b)) include 1) Daily Use Items I, 2) Daily Use Items II, 3) Number Identification, and 4) Shapes. Presented in a touchscreen format for ease of use, this module aids in training and skill enhancement for adolescents with ID. Adolescents were guided through the module with instructions from the instructor, choosing from the available modules. Each module was specifically tailored to enhance cognitive functionality, with the first two focusing on everyday items while the latter emphasizes number and shape identification. Adolescents engaged by analyzing items presented as buttons on the screen and answering corresponding questions through touchscreen interaction, with correct answers leading to score increases and progression.

Number Concept (NC) *(VAPS and FACP):* Developed to enhance cognitive learning and introduce the concept of time to ID adolescents

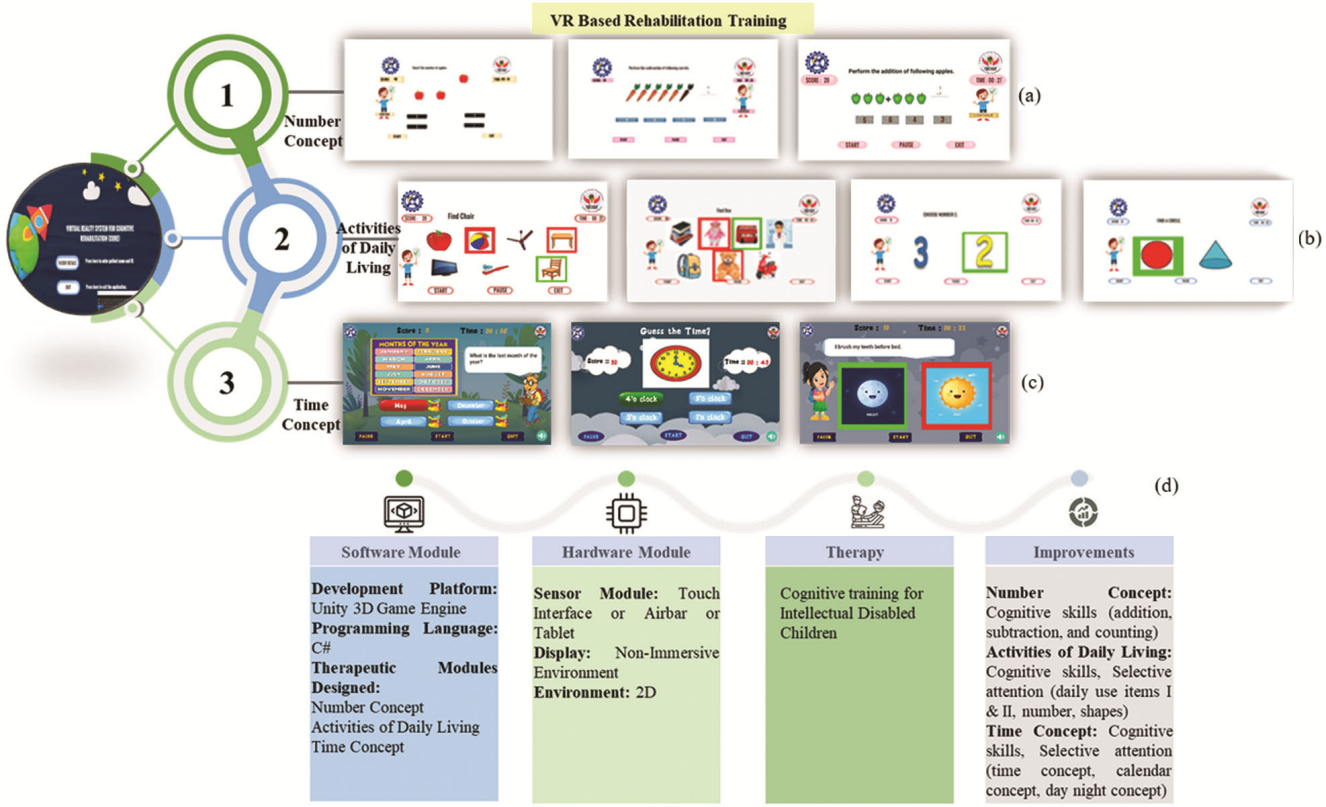

Fig. 1 — VR based therapeutic modules and development process for intellectual disabled adolescents

(Fig. 1 (a)), this module comprised three parts: 1) Clock Concept, 2) Calendar Concept, and 3) Day and Night Concept. The module prompts adolescents to select from the available modules and presents questions about time, date, month, year, and day and night. Adolescents were guided through instructions from the instructor, and touchscreen interaction was used to answer questions.

Time Concept (TC) *(VAPS and FACP):*Similar to the NC module (Fig. 1 (c)), this therapy aimed to enhance cognitive learning by introducing the concepts of time, clock, calendar, day, and night. It comprised three parts: 1) Clock Concept, 2) Calendar Concept, and 3) Day and Night Concept. Adolescents receive instructions from the instructor and choose from the available modules. Questions related to time, date, month, year, and day-night concepts are presented, with touchscreen interaction used for responses.

Study Procedure: Virtual Reality System for Cognitive Rehabilitation (CORE)

The CORE platform, a VR-based therapeutic module, significantly emphasized cognitive rehabilitation by providing targeted modules. To ensure the comfort and participation of adolescents with ID during rehabilitation, the therapist assists them in relaxing their muscles and sitting down before utilizing the non-immersive VR system, which has a tablet or PC. The therapist endorsed the participant to observe the questions and move their hand to select the correct option based on their thinking and the senses. A uniform approach disseminated cognitive instructions during the activities, ensuring the participant's effective engagement and understanding. Subsequently, it amalgamates three basic therapeutic modules triangulated with VAPS and FACP, highlighting (i) identification of daily use items to improve recognition and understanding and (ii) number identification, including addition, subtraction, and counting to enhance mathematics, calculations, arithmetical problems, and computation. (iii) Shape recognition enhanced cognition, visual skills, identification, and differentiation. For the clock concept, problems were analogous to understanding hours, minutes, and seconds. (iv) For temporal enlightenment, the therapeutic module incorporated the calendar concept to distinguish between dates, months, and years. (v) To understand the day-night concept, daily routine activities, and temporal orientation, the issues associated with time perception and the sequence of events have been addressed. The designed and developed VR system features instructions in diverse languages, enabling adolescents to follow along and complete the rehabilitation procedure efficiently. Each participant performed a feasibility trial lasting approximately 55–60 minutes by taking a rest of two to three minutes after completing each module. Trials allowed the recording of therapeutic module parameters, i.e., time and score achieved, for each activity.

Cognitive Rehabilitation Metric Properties

In cognitive rehabilitation, metric properties were essential for assessing and tracking progress effectively. Two key parameters widely used were time and score. Time refers to the duration individuals take to complete specific cognitive tasks, indicating their processing speed and efficiency. This metric helped measure how quickly adolescents perform cognitive activity, which is critical for monitoring changes over time. On the other hand, the score evaluated the accuracy and completeness of cognitive tasks performed. It measures adolescents' cognitive abilities based on predefined criteria or performance standards, considering task complexity, response accuracy, and goal achievement within set time limits. These metrics, time and score, together form a robust evaluation framework in cognitive rehabilitation. They enable therapists and researchers to objectively assess cognitive function, monitor improvements, customize interventions, and make informed decisions about the effectiveness of rehabilitation approaches. This structured approach aimed to enhance cognitive skills and improve adolescents' overall quality of life undergoing cognitive therapy. However, all scores and time measurements were stored in the database.

Data Storage Systems for VR Therapeutic Modules

A detailed flowchart outlining the process of cloud-based data sharing and dashboard creation for performance analysis is depicted in Fig. 2. Initially, data was accumulated from distinct VR therapeutic modules at different rehab centers and from remote tablets. This data was first stored locally on the C drive of a computer system. A Python application transfers this data to the cloud, which uploads it into an Amazon Web Services (AWS) S3 bucket, storing it as Excel files. Following this, a pre-designed URL is generated to facilitate data sharing. The Klipfolio website, an online Business Intelligence (BI) tool,

used this URL to retrieve data from the AWS S3 bucket. Within Klipfolio, the retrieved data was used to create "clips" (widgets) that were subsequently added to a dashboard. The final step involved conducting a performance analysis using the visualized data on the dashboard. This approach enabled efficient data sharing and thorough performance analysis by leveraging cloud storage and online BI tools.The system allowed for centralized, real-time management and scalable data storage from VR therapeutic modules, promoting collaboration and informed decision-making. It enhances efficiency, security, and user involvement with automated reporting and advanced data visualization.

Results

In the clinical trials depicted in Fig. 3, adolescents with ID interact with various modules in a VR setting. These modules include the Activity of Daily Living, Number Concept, and Time Concept modules. Unlike traditional pen-and-pencil tasks, which can be challenging and less engaging for adolescents with ID, the VR environment provides an immersive and interactive learning experience. In this VR environment, adolescents receive instant audio-visual feedback, significantly enhancing their engagement and motivation. Correct answers were met with positive reinforcement, such as "Sahijawab" (correct answer), while incorrect answers received feedback like "Galatjawab" (wrong answer). These auditory cues help reinforce learning by providing immediate clarity on their performance. The engaging sounds and interactive nature of the VR modules make the learning process more enjoyable and less intimidating compared to conventional methods. However, every correct answer increased the score by 10, and incorrect answers did not increase with time. This innovative approach improves comprehension of tasks and encourages active participation and sustained attention from the adolescents, effectively supporting their cognitive development.

As demonstrated in Fig. 4(a) and Fig. 4(b), the plots analyzed adolescents' ID performance in two therapeutic modules: "Daily Use Item I Module" and

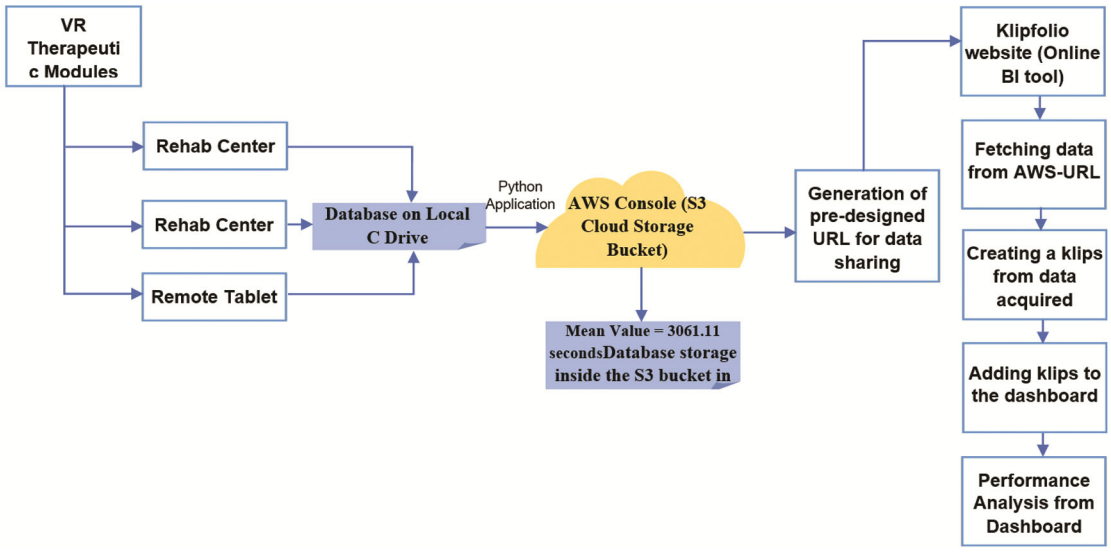

Fig. 2 — Flowchart of data sharing on cloud and creation of dashboard

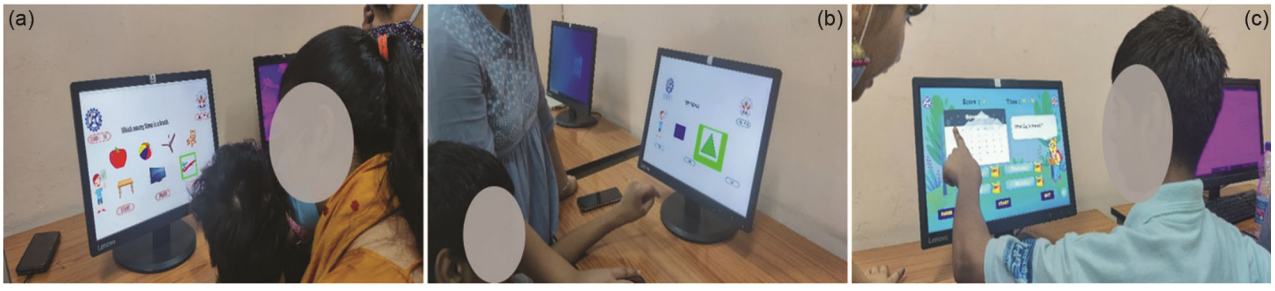

Fig. 3 — Intellectual disabled (a) adolescents performing activity of daily living module, (b) adolescents performing number concept module, and (c) adolescents performing time concept module

"Time Concept Module." In the Daily Use Item I Module, all adolescents achieved a maximum score of 70, indicating that they have the potential to understand and perform tasks accurately. However, there was significant variability in the time taken to complete the tasks, with the mean completion time being approximately 40 minutes and 55.55 seconds. Participant 3 took the least time (25 minutes and 50 seconds), while Participant 8 took the most (53 minutes and 20 seconds). Most adolescents took between 35 and 55 minutes, highlighting differences in processing and completion times despite achieving the same score.

In the "Time Concept Module", most adolescents achieved the maximum score of 55, except for Participant 8, who scored lower at 50. The mean time to complete the tasks was approximately 51 minutes and 1.11 seconds, with participant 7 taking the least time (32 minutes and 30 seconds) and participant 4 taking the most (56 minutes and 40 seconds). This module's broader range of completion times indicates even more significant variability than the Daily Use Item I Module.

The graphs illustrated in Fig. 5(a) and Fig. 5(b) have different therapeutic modules: "Daily Use Item II Module" and "Number Concept Module." In the Daily Use Item II Module, all participants achieved a maximum score of 70, indicating their potential to understand and perform tasks accurately. However, the time to complete the tasks varied significantly, with a mean completion time of approximately 34 minutes. Participants 5 and 8 took the least time (0 minutes), while participant 6 took the most (55 minutes), highlighting differences in processing and completion times despite the identical scores. In the Time Concept Module, most participants scored a maximum of 55, except for participant 9, who scored 50. The mean completion time was about 51 minutes, with participant 6 taking the least time (32.5 minutes) and participant 9 taking the most time (over 64 minutes). This broad range of completion times suggests significant variability in cognitive processing speeds.

In the "Number Concept Module", most participants achieved high scores, with a maximum score of 75 for most and slightly lower scores for participants 6 (35 minutes). The mean completion time was approximately 46 minutes, with participant 2 taking the least time (29 minutes) and participant 4 taking the most time (over 61 minutes). This variability reflects differences in how quickly participants process and execute tasks. The consistency in scores across the modules indicated that adolescents with ID can understand and perform tasks accurately, given sufficient time and support. However, the significant variability in time taken to complete tasks underscores the characteristic of cognition problems in ID adolescents, where cognitive processing speed can be slower and more variable.

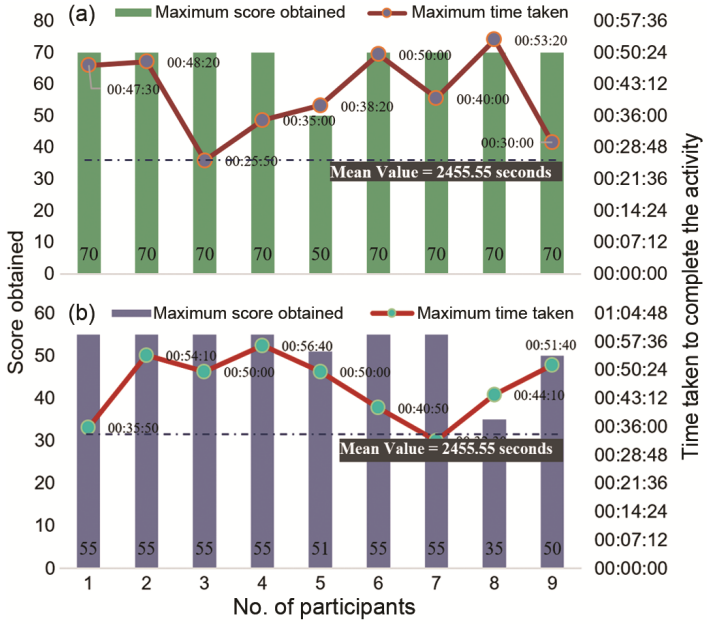

Fig. 4 — Average mean value of time with maximum score obtained by adolescents with: (a) activities of daily living module I, (b) number concept

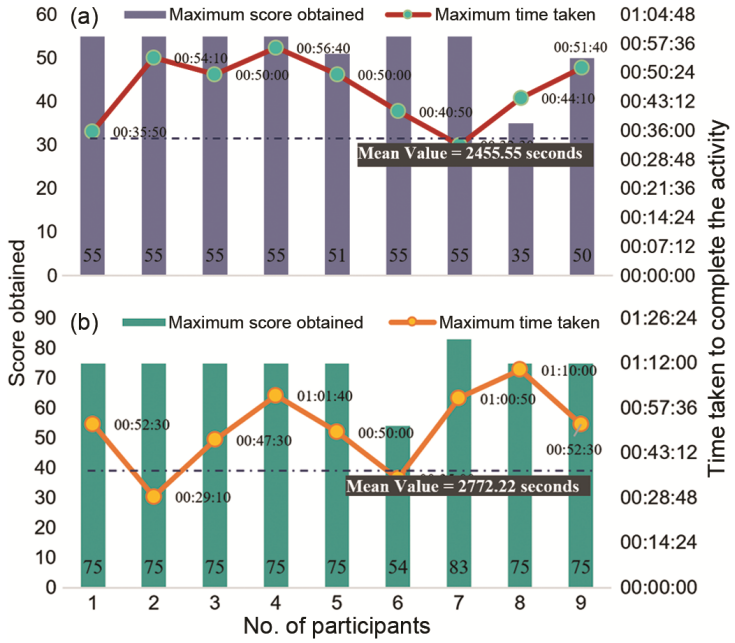

Fig. 5 — Average mean value of time with maximum score obtained by adolescents with: (a) activities of daily living module II, (b) time concept

Discussion

The feasibility trials demonstrated the benefits of using VR technology for cognitive development and learning in adolescents with ID. The National Institute took the behavior and enhancement of[14] adolescents for the Empowerment of Persons with Intellectual Disability (DIVYANGJAN) Regional Centre, Noida-201301, India. The Institution maintained all the confidential data of the adolescents and was accessible only to research team members. These trials involved three modules, Activity of Daily Living, Number Concept, and Time Concept, all conducted in VR. With a focus on enhancing the conceptually based skills[24] (cognitive and activities of daily living) of a participant with intellectual impairment, the authors of the proposed study examined the impact of VR therapeutic modules on the functional development of the brain. These VR modules assist users with precise hands or fingers[25] to touch by choosing the correct answer on the screen. Thus, adolescent's cognitive ability was shortened and required to enforce these therapeutic modules.[26] Typical VR therapeutic technologies were also easily accessible, including Nintendo WiiFit[27], Microsoft Kinect [28,29], Inertial Measurements Unit[30], and Leap Motion Device.[31] The precise functionality was not handled by adolescents with intellectual impairment, and the majority of mobile or computer game solutions do not directly address therapeutic objectives. Touch technology[41] was, therefore, one of the practical and most straightforward means to control cognitive functioning in adolescents. Conversely, research has shown that non-immersive VR rehabilitation was more motivational and practical than conventional rehabilitation. As a task-oriented process, visual and audio feedback on performance and progress were provided by interactive VR therapeutic modules used in VR-assisted therapy[32]; this further engages and motivates adolescents to intensify their recovery.

Immediate Feedback and Reinforcement

The ability of the VR modules to provide immediate feedback is crucial for reinforcing learning. Adolescents receive instant information on the accuracy of their responses, allowing them to adjust their understanding and approach right away. This immediate feedback loop helps to reinforce correct responses and offers opportunities to correct mistakes on the spot, which is often not possible with delayed feedback in conventional methods.

Variability in Cognitive Processing

Prior literature has shown that limited therapeutic modules based on conceptually based skills for knowledge, retention, and using knowledge were the best-determining method for activities of daily living and mental impairment with intellectually impaired adolescents. However, for adolescents who need

long-term provision of care, a therapeutic approach was not effective in achieving cognitive functionality. Similarly, according to the previous research, no system was based on VAPS and FACP (i.e., activities of daily living, numbers-time concept). With the present technology, our system determines that all the therapeutic modules developed with non-immersive VR were based on Behavioural assessment. The performance analysis across the different modules revealed significant variability in the time taken to complete tasks despite consistently high scores. This variability highlights the individual differences in cognitive processing speeds among adolescents with ID. The VR environment can more flexibly accommodate these differences than pen-and-paper tasks, allowing adolescents to work independently without feeling rushed or pressured.

Reduction of Motor Skill Barriers

Pen-and-paper tasks often require fine motor skills, which can be an additional challenge for adolescents with ID. The VR modules reduce the reliance on these skills, focusing instead on cognitive abilities. This reduction in motor skill demands allows for a more accurate assessment of the adolescent's cognitive capabilities, as their performance is less likely to be hindered by physical limitations.

Tailored Educational Approaches

The findings suggest that VR modules can effectively tailor educational approaches to the individual needs of adolescents with ID. The flexibility of the VR environment allows for personalized learning experiences, where tasks can be adjusted in difficulty and complexity based on the participant's performance and progress. This customization is vital for addressing the diverse cognitive profiles within this population.

Overall Implications for Educational Programs

Integrating VR technology in educational programs for adolescents with ID represents a significant advancement. It not only makes learning more accessible and enjoyable but also provides educators with detailed insights into each participant's cognitive strengths and areas needing improvement. This approach facilitates the development of more effective and individualized educational strategies, ultimately supporting better cognitive and developmental outcomes for adolescents with ID.

With increased cognitive functionalities, VR has the potential to improve conceptual-based skills along with activities of daily living to improve the impairments found in adolescents. However, in the future, this technique will be feasible with more intellectually impaired adolescents. When the number of trials, as well as the number of adolescents, is increased, it will show improved results and significantly impact rehabilitation.

Conclusions

This study proposed a conceptual-based approach for cognitive skill enhancement in adolescents with intellectual disabilities using non-immersive VR scenarios integrated with touch interfaces. The VR therapeutic modules, mapped to cognitive domains such as problem-solving, arithmetic, and visual recognition, were developed in a 2D environment and demonstrated the potential to improve cognitive functions. However, the study faced limitations due to its small sample size and focus on feasibility rather than clinical effectiveness. Additionally, the absence of standardized assessment metrics (FACP and VACP) and a lack of detailed characterization of disability types and rehabilitation intensity constrained the generalizability of the findings. Future work aims to extend the system to home-based applications, incorporating real-time data collection, routine diagnostics, and continuous monitoring. This expansion could facilitate remote rehabilitation, potentially improve IQ levels in disabled adolescents, and address broader neurodevelopmental impairments, including those in individuals with Cerebral Palsy and stroke, thereby enhancing motor, psychological, and cognitive outcomes.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

References

1 Edwards J, Jeffrey S, May T, Rinehart N J & Barnett LM, Does playing a sports active video game improve object control skills of adolescents with autism spectrum disorder?, *J Sport Heal Sci*, **6(1)** (2017) 17–24, doi: 10.1016/j.jshs.2016.09.004.

2 Thapa N, Park H J, Yang J G, Son H, Jang M & Lee J, The Effect of a virtual reality-based intervention program on cognition in older adults with mild cognitive impairment: A randomized control trial, *J Clin Med*, **9(5)** (2020) 1283, doi: 10.3390/jcm9051283.

3 Cheung J C W, Ni M, Tam A Y C, Chan T T C, Cheung A K Y, & Tsang O Y H, Virtual reality based multiple life skill training for intellectual disability: A multicenter randomized controlled trial, *Eng Regen*, **3(2)** (2022) 121–130, doi: 10.1016/j.engreg.2022.03.003.

4 Krysta K, Romańczyk M, Diefenbacher A & Krzystanek M, Telemedicine treatment and care for patients with intellectual disability, *Int J Environ Res Public Health*, **18(4)** (2021) 1–12, doi: 10.3390/ijerph18041746.

5 Tianwu Y, Changjiu Z & Jiayao S, Virtual reality based independent travel training system for adolescents with intellectual disability. *Proc - UKSim-AMSS 2016 10th Eur Model Symp Comput Model Simul. Published online* (2017) 143-148, doi: 10.1109/EMS.2016.034.

6 Singh N, Sehgal C A & Jena S, Effects of virtual reality approach in adolescents with learning disabilities in effects of virtual reality approach in adolescents with learning disabilities in India. (2022).

7 Panerai S, Catania V, Rundo F & Ferri R, Remote home-based virtual training of functional living skills for adolescents and young adults with intellectual disability: Feasibility and preliminary results, *Front Psychol* **9** (2018) 1–6, doi: 10.3389/fpsyg.2018.01730.

8 Volner R, Tichá D & Palásthy H, Computer-based cognitive and socio-emotional training in personal health information management. *Proc - Int Carnahan Conf Secur Technol. Published online* (2011), doi: 10.1109/CCST.2011.6095892.

9 Cheung J C W, Ni M, Tam A Y C, Chan T T C, Cheung A K Y & Tsang O Y H, The VESPA Project: Virtual reality interventions for neurocognitive and developmental disorders, *J Decis Syst*, **9(1)** (2021) 449–454, doi: 10.1109/EMS.2016.034.

10 Panerai S, Catania V, Rundo F, Ferri R, Justice S & Affairs D, Combined effects of virtual reality and computer game-based cognitive therapy on the development of visual-motor integration in adolescents with intellectual disabilities: A Pilot Study, *Proc-2021 3rd Int Conf Mach Learn Big Data Bus Intell MLBDBI 2021*, **9(2)** (2021) 553–556, doi: 10.1109/MLBDBI-54094.2021.00110.

11 Bifulco P, Narducci F, Vertucci R, Ambruosi P, Cesarelli M & Romano M, Telemedicine supported by Augmented Reality: An interactive guide for untrained people in performing an ECG test, *Biomed Eng Online*, **13(1)** (2014) 1–16, doi: 10.1186/1475-925X-13-153.

12 Burdea G C, Grampurohit N, Kim N, Polistico K, Kadaru A & Pollack S, Feasibility of integrative games and novel therapeutic game controller for telerehabilitation of individuals chronic post-stroke living in the community, *Top Stroke Rehabil*, **27(5)** (2020) 321–336, doi: 10.1080/10749357.2019.1701178.

13 Unibaso-Markaida I, Iraurgi I, Ortiz-Marqués N, Amayra I & Martínez-Rodríguez S. Effect of the Wii sports resort on the improvement in attention, processing speed and working memory in moderate stroke, *J Neuroeng Rehabil*, **16(1)** (2019) 1–8, doi: 10.1186/s12984-019-0500-5.

14 Zhang M, Ding H, Naumceska M & Zhang Y, Virtual reality technology as an educational and intervention tool for adolescents with autism spectrum disorder: current perspectives and future directions, *Behav Sci (Basel)*, **12(5)** (2022), doi: 10.3390/bs12050138.

15 Chen W, Multitouch tabletop technology for people with autism spectrum disorder: A review of the literature, *Procedia Comput Sci*, **14(1877)** (2012) 198–207, doi: 10.1016/j.procs.2012.10.023.

16 Holden M K, Dyar T A & Dayan-Cimadoro L, Telerehabilitation using a virtual environment improves upper extremity function in patients with stroke, *IEEE Trans Neural Syst Rehabil Eng*, **15(1)** (2007) 36–42, doi: 10.1109/TNSRE.2007.891388.

17 Valenzuela V L & de Lucena VF, Remote monitoring and control of an electric powered wheelchair in an assisted living environment, *IFAC-PapersOnLine*, **49(30)** (2016) 181–185, doi: 10.1016/j.ifacol.2016.11.164.

18 Jialiang H, Haiyan Z & Huiying Z, Research on the auxiliary treatment system of participanthood autism based on virtual reality, *J Decis Syst*, (2021) 1–18, doi: 10.1080/12460125.2021.2003512.

19 Okahashi S, Seki K, Nagano A, Luo Z, Kojima M & Futaki T, A virtual shopping test for realistic assessment of cognitive function, *J Neuroeng Rehabil*, **10(1)** (2013) 1–13, doi: 10.1186/1743-0003-10-59.

20 Bozgeyikli L, Raij A, Katkoori S & Alqasemi R, A survey on virtual reality for individuals with autism spectrum disorder: Design Considerations, *IEEE Trans Learn Technol*, **11(2)** (2018) 133–151, doi: 10.1109/TLT.2017.2739747.

21 Swinnen N, Vandenbulcke M & Vancampfort D, Exergames in people with major neurocognitive disorder: A systematic review, *Disabil Rehabil Assist Technol*, (2020) 1–14, doi: 10.1080/17483107.2020.1785566.

22 Kutty A T T, NIMH vocational assessment and programming system for persons with mental retardation, *Published online* (1992), 16–19.

23 Justice S & Affairs D, National Institute for the Mentally Handicapped National Institute for the Mentally Handicapped, *Published online* (2013) 27751741.

24 Vandemeulebroucke T, Dierckx de Casterlé B & Gastmans C, The use of care robots in aged care: A systematic review of argument-based ethics literature, *Arch Gerontol Geriatr*. **74** (2018) 15–25, doi: 10.1016/j.archger.2017.08.014.

25 Pedraza-Hueso M, Martín-Calzón S, Díaz-Pernas F J & Martínez-Zarzuela M, Rehabilitation using kinect-based games and virtual reality, *Procedia Comput Sci*, **75** (2015) 161–168, doi: 10.1016/j.procs.2015.12.233.

26 Berton A, Longo U G, Candela V, Fioravanti S, Giannone L & Arcangeli V, Virtual reality, augmented reality, gamification, and telerehabilitation: Psychological impact on orthopedic patients' rehabilitation, *J Clin Med*, **9(8)** (2020) 1–13, doi: 10.3390/jcm9082567.

27 Lee S, Bae S, Jeon D & Kim K Y, The effects of cognitive exercise therapy on chronic stroke patients' upper limb functions, activities of daily living and quality of life, *J Phys Ther Sci*, **27(9)** (2015) 787–2791, doi: 10.1589/jpts.27.2787.

28 Verma S, Kumar D, Kumawat A, Dutta A & Lahiri U, A low-cost adaptive balance training platform for stroke patients: A usability study, *IEEE Trans Neural Syst Rehabil Eng*, **25(7)** (2017) 935–944, doi: 10.1109/TNSRE.2017.2667406.

29 van Diest M, Stegenga J, Wörtche H J, Verkerke G J, Postema K & Lamoth C J C, Exergames for unsupervised balance training at home: A pilot study in healthy older adults, *Gait Posture*, **44** (2016) 161–167, doi: 10.1016/j.gaitpost.2015.11.019.

30 Vogiatzaki E, Gravezas Y, Dalezios N, Biswas D, Cranny A & Ortmann S, Telemedicine system for game-based rehabilitation of stroke patients in the FP7-'Stroke Back' project, *EuCNC 2014- Eur Conf Networks Commun Published online*, (2014) 5–9, doi: 10.1109/EuCNC.2014.6882688.

31 Cui J, Yeh S C & Lee S H, Wearable sensors integrated with virtual reality: A self-guided healthcare system measuring shoulder joint mobility for frozen shoulder, *J Healthc Eng*, **2019** (2019), doi: 10.1155/2019/7681237.

32 Cikajlo I & Peterlin P K, Advantages of using 3D virtual reality based training in persons with Parkinson's disease: A parallel study, *J Neuroeng Rehabil*, **16(1)** (2019) 1–14, doi:10.1186/s12984-019-0601-1.