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ICDVRAT Copenhagen 2026

16th International Conference on Disability, Virtual Reality & Associated Technologies

16th International Conference on Disability, Virtual Reality & Associated Technologies

Edited by:

Emil Rosenlund Høeg

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Welcome to ICDVRAT 2026

Dear delegates,

It is a great pleasure to welcome you to ICDVRAT 2026 in beautiful Copenhagen!

This year is particularly special as we celebrate 30 years of ICDVRAT. We are delighted to once again bring together researchers, clinicians, practitioners, technologists, students, people with lived experiences, and friends of the ICDVRAT community from across the world.

This year, we are especially happy to welcome participants from 17 countries: Canada, China, Czechia, Denmark, France, Hungary, Israel, Italy, Japan, the Netherlands, Norway, Portugal, South Africa, Sweden, Switzerland, the United Kingdom, and the United States. Bringing together people from so many different countries, disciplines, and perspectives is one of the things that makes ICDVRAT special and has been part of its spirit from the very beginning. We are delighted and honoured to have so many of you gathered here in Copenhagen.

True to this spirit, the work presented at ICDVRAT 2026 reflects the broad interdisciplinary nature of the field. This year's programme is organized around 11 themes:

AI, virtual humans and social interaction; stroke and neuromotor rehabilitation; physical and orthopedic rehabilitation; autism spectrum disorders; VR for anxiety, PTSD and OCD; biosensing, AI and neuroadaptive systems; embodiment, presence and immersion; ageing and methodology; cognitive assessment and training; accessibility and inclusion; and education and pedagogy.

As always, the conference is also an opportunity to reflect on how far we have come, and how far we still have to travel.

We hope ICDVRAT 2026 will provide space for these discussions alongside the scientific programme: for curiosity, disagreement, new collaborations, unexpected conversations, and new ideas.

Thank you for travelling from near and far to join us. We are very happy to have you here, and we warmly welcome you to ICDVRAT 2026.

The General Conference Chairs
Emil Rosenlund Høeg, Iveta Fajnerová, Pedro Gamito and David J. Brown

A Folk History of ICDVRAT

Once Upon A Time ...

When I was asked to put down a few words about the International Conference on Disability, Virtual Reality and Associated Technologies, I thought it would be easy to lighten my load by just asking an LLM to make it all up for me. I tried a few AI engines to see how much work I would have to put in to correcting all the hallucinations. As it turned out, there were not so many errors. In addition, there is also a wealth of information available on the ICDVRAT Archive site at www.icdvrat.com. What might be reasonably added, I wonder? A different approach was required. So, perhaps a kind of folk history might be of some interest.

In 1995, one of the doctoral students in my small research group – David Roberts, now Emeritus Professor at Salford University – happened to volunteer at a disability group. The group members were keen to learn more about virtual reality and how it might be applicable in their lives. Our particular VR specialism at that time was very much concentrated on the technical side of large-scale distributed VR, time delays, communications protocols, and so on. We didn't even have very much capability in graphics. Nevertheless, David persuaded me that we could put a workshop together.

Thus, with David's unstinting enthusiasm, we gathered about 30-40 people from academia, industry, communications, and, with the disability group, ran a workshop with presentations and an afternoon of brainstorming groups that truly mixed the different disciplines and users together. Following the seeming success of this workshop, we were able to persuade Harry Murphy, the then organiser of the CSUN Assistive Disability conference held in California, to advise on how we might mirror his US conference in Europe, as a complimentary event. The first conference was launched, billed as the "1st European Conference ..." in July 1996 and held in Maidenhead, UK. This conference was most helpfully supported by a financial grant from British Telecom who were very interested in advancing technologies for communications amongst this sector, by Harry Murphy who travelled to attend, and by industries both local and international such as Silicon Graphics and the General Reality Company also in attendance. We even had the audacity to enlist (with an honorarium, naturally) the well-known and respected media scientist Prof. Heinz Wolf to offer his words of wisdom at the conference dinner.

Looking at the author index at this event there will be many familiar names to those of you who have worked in the field, such as David Brown, Penny Standen, and Jaime Sanchez who had travelled from Santiago, Chile, each of whom would go on to co-chair one or more future conferences in the series.

One name that was missing was that of Dr Albert Rizzo. I had received a call from this American a month or two before run-time, but papers had already been reviewed and the schedule already confirmed. I explained with regret, that we could not include his paper on this occasion but, if we to run the conference again, I would be sure to let him know.

Hard To Get To Places ...

The success of 1996 led to the desire to run again in 1998, but how to organise? It seemed a good strategy to try and move the conference around Europe at the very least. The only real pragmatic way of doing so, however, was for me to enlist the organisational help of a much larger Mechatronics Conference being held in Skövde in September. A hard to get to – and even harder to pronounce – location certainly set a challenge. Helped by David Rose and Jan-Ingmar Linsdtrom, as academic and local co-chairs, this set in train a model for organisation that survived through to 2016.

David Brown turned up with a big User Group; how he funded all that travel still amazes me. Conference stalwart Sue Cobb also made her first appearance. It also saw the first paper presented by Skip Rizzo (I had learnt to drop the "Albert"), for I had remembered my promise from 2 years prior. He cut an interesting figure; perhaps the conference could get some extra attendees from the US if I were to put a half-Italian/half-Irish on the bill as a co-chair for 2000? What could possibly go wrong?

Going International ...

In 2000, the newly monikered "International Conference ...", where Skip Rizzo would join with Luigi Pugnetti as co-chairs, was held in Alghero, Sardinia. September became the de facto month for this now biennial event, which has remained to this day. Nothing went wrong (well, nothing much – ask me about it!) and, with the conference now no longer relying on a bigger event for logistics, true independence had arrived.

With conference regular Cecilia Sik-Lányi taking the reins for Veszprém, Hungary (2002), I would like to also name-check local co-chairs for their huge contributions in the intervening years: Rachel McCrindle (Oxford, 2004); Tony Brooks, Esbjerg, Denmark (2006); Pedro Lopes-dos-Santos, Maia, Portugal (2008); Jaime Sanchez, Viña del Mar, Chile (2010); Evelyne Klinger, Laval, France (2012); Lena Pareto, Jurgen Broeren & Martin Rydmark, Gothenburg, Sweden (2014); and Skip Rizzo again, this time on home turf, in Los Angeles, USA (2016).

Passing the Baton ...

After retiring in 2016, I extend my heartfelt thanks to David Brown, Sue Cobb, Penny Standen, Pedro Gamito, Sebastian Koenig, Iveta Fajnerová, and Emil Roselund Høeg for holding the ship together, together with their substantial teams at each of their respective locations: Nottingham, UK (2018); Serpa, Portugal (2021, Covid delayed from 2020); Ponte Delgado, Azores, Portugal (2022); Prague, Czech Republic (2024); and the current host city of Copenhagen, Denmark (2026).

Now in its 16th edition and on its 30th anniversary, I believe this conference to be the longest established international conference series in the area of VR technology related to disability and rehabilitation. Deliberately interdisciplinary from its origins, the conference's community spans researchers in medicine, rehabilitation, psychology, education, computer science, engineering, and technology development, as well as practitioners and technology users, who would be left scratching away at their ideas in vain without integrating users and user groups to test out their new ideas and be told to go back to the drawing board when they don't quite live up to expectation. As indeed it should be.

I am sure that more superlatives are available from LLMs – or Word Calculators, as I like to call them – but the bottom line is that the subject areas covered by ICDVRAT remain a most interesting, rewarding and valuable space to be working in. And long may it continue.

– ***Paul Sharkey***

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Tuesday, September 15

9:00–12:00	**Cyber Workshop**
	Hands-on Training on the Application of VR in the Treatment of Anxiety and Related Disorders *Stéphane Bouchard Université du Québec en Outaouais,* *Ana Beato HEI Lab, Lusófona University*
12:00–13:00	**Lunch** *The lunch break on the first day is not included, as the conference opens at 13:00, but lunch can be purchased in the local canteen*
13:00–13:45	**Opening ceremony**
-	Welcome address from conference chairs *Emil Rosenlund Høeg & Ali Adjorlu*
-	Welcome with Head of department *Lone Malmborg*
-	Welcome from "Slusen" *The students from the student-driven bar "Slusen" make a short intro to the opening ceremony this evening!*
-	ICDVRAT Awards
13:45–14:45	**Keynote 1** *Louise Birkedal Glenthøj*
14:45–15:00	**Coffee Break**
15:00–15:45	**Session 1: AI, Virtual Humans & Social Interaction**
-	From Code to Care: Building AI Virtual Humans for Accessible and Ethical Healthcare Support *Sharon Mozgai, Russell Shilling, Brendon Hale*
-	Evaluating Metaverse Support Groups for Displaced Populations Albert Skip Rizzo, Cătălina-Maria Popoviciu, Saltanat Zhamaliyeva
-	One Format Fits All? Sensory Sensitivity and AI-generated Cyberbullying Narratives: A Study Protocol *Sofia Mateus Francisco, Cláudia P. Pires, Vera Pereira, Paula Paulino, Teresa Souto, Alexandre Rodrigues, Pedro Gamito, Jorge Oliveira*
15:45–15:55	**Discussion and Q&A**
16:00–16:15	**Coffee Break**
16:15–17:15	**Panel discussion - Accessibility in Technology: Progress, Gaps, and the Road Ahead** **Panelists:** *Valeria Borsotti, David Brown, Hafaz Shah, Tobias Nyhuus Jensen, Jenny Margrethe-Vej (moderator)*
18:00–24:00	**Welcome reception**

Wednesday, September 16

8:30–9:00	**Help-desk opens**
9:00–10:15	**Session 2: Stroke & Neuromotor Rehabilitation**
-	Virtual Reality for Upper Limb Stroke Rehabilitation: A Quality Improvement Study Evaluating Patient Outcomes and Clinical Feasibility *Emma Dunn, Caroline Wilson, Darryl Charles, Siobhan Poulter*
-	Integrating Shared Co-located Clinician-Patient Augmented Reality into Rehabilitation Tools *Ilan Vol, Shachar Maidenbaum*
-	Designing Multiuser VR Rehabilitation Games: Balancing Semi-Structured Play and Clinical Structure for Engagement and Care Support *Siobhan Poulter, Darryl Charles, Therese Charles*
-	Developing an Augmented Reality Tool for Walking and Attention Rehabilitation *Ilan Vol, Shachar Maidenbaum*
-	Virtual Reality-based and Conventional Cognitive Interventions in Community-dwelling Older Adults: The Moderating Role of Cognitive Reserve *Jorge Oliveira, Teresa Souto, José Bourbon, Catarina Alves, Cátia Coelho, Nuno Santos, Sofia Francisco, Ricardo Pinto, Vítor Hugo Silva*, Pedro Gamito*
10:15–10:35	**Discussion and Q&A**
10:35–10:50	**Coffee Break**
10:50–11:50	**Session 3: Physical & Orthopedic Rehabilitation**
-	Embodying the Phantom: A Low-Cost, Inclusive VR Mirror Therapy Driven by 2-Point Tracking *Jacob Loat, Andrea Aternali, Joel Katz, Sander Hitzig, Lora Appel*
-	Move, Enjoy, Interact: VR Dancing for Youth with Motor Limitations *Martin Lemay, Nawfal Chabibi, Margaux Hebinck*
-	Improving Functional Rehabilitation Through VR-based Physiotherapy: A Systematic Review and Meta-analysis *Denis Arsovski*
-	Saudi End-User Perception and Expectations Toward Using Virtual Reality-Based Physiotherapy Systems as an Exercise Tool for People with Knee Osteoarthritis: qualitative study *Duaa Sabbagh, Kate Button, Mohammad Al-Amri*
11:50–12:05	**Discussion and Q&A**

12:05–12:50		**Session 4: Autism Spectrum Disorder (Part 1)**
	-	A Game-Based Multimodal Data Capture Pipeline for Research on Emotional Regulation *Daniel J. Buxton, Mufti Mahmud, Jordan J. Bird*
	-	Feasibility Study of an LLM-Based Digital Social Interaction Programme to Improve the Social Communication Skills of Autistic Children in China *Vicky Yiran Zhao, William Farr*
	-	Game-Based Collaborative Interactions Among Moderately Functioning Autistic Adults *Orly Lahav, Tal Biro*
12:50–13:00		**Discussion and Q&A**
13:00–13:55		**Lunch Break**
13:55–14:55		**Keynote 2** Revolutionizing the research, assessment, and treatment of paraphilic disorders: the role of virtual reality and artificial intelligence *Kateřina Klapilová*
14:55–15:10		**Coffee Break**
15:10–15:55		**Session 5: Autism Spectrum Disorder (Part 2)**
	-	A Mixed Methods Study: Culturally Responsive Tangible Near Field Communication Brick Play for Facilitating Communication and Language Development in Autistic Young Children of West African Descent *Hannah Ackom-Mensah, Rupert Wegerif, William Farr*
	-	Bridging the Support Gap with Generative AI Enabled Learner Profiles for Adolescents with Autism *Isaac Lee, Will Farr*
	-	From Generic Guardrails to Pillars in the Structure of AI: Specificity in Paediatric Neurodisability & Neurodivergence *William Farr and Isaac Lee*
15:55–16:05		**Discussion and Q&A**
19:00–22:00		**Social Dinner** Restaurant HAPS Rådhuspladsen 57 1550 København *(Remember to book your ticket)*

Thursday, September 17

8:30–9:00	**Help-desk opens**
9:00–10:15	**Session 6: VR for Anxiety, PTSD & OCD**
-	Creation of a VR Application for Remote Exposure Therapy in Social Anxiety Disorder *Tereza Langová, Markéta Jablonská, David Jakeš, Katarina Adamcová, Veronika Trázníková, Pavla Stopková, Iveta Fajnerová*
-	Virtual Environments for Patients with Obsessive Compulsive Disorder in Outpatient Care *Karolína Zuzánková, Iveta Fajnerová, Pavla Stopková*
-	Detection and prevention of PTSD Risk in First Responders by means of a VR protocol *Ricardo Pinto, Hélder António, Pedro Gamito*
-	Virtual Reality Pre-Scan Simulation to Reduce MRI-Related Anxiety and Improve Scanning Efficiency *James Lewis, Adam Wallbanks, Daniel J. Buxton*
-	Virtual Reality Art Therapy and Trauma: A Pilot Study *Renata Cserjesi, Zsuzsanna Geréb Valachine, Anastasiia Lukoshyna, Bálint Vörös, Ádám Salamon and Cecilia Sik-Lanyi*
10:15–10:35	**Discussion and Q&A**
10:35–10:50	**Coffee Break**
10:50–11:50	**Session 7: Biosensing, AI & Neuroadaptive Systems**
-	Integrated VR & EEG - The Best Practices for Real-Time Data Collection in Research *Sean Haddick, Adam Wallbanks, Muhammad Arifur Rahman*
-	A Conceptual Mechanistic Framework for Biosensing-Enhanced VR Rehabilitation *Adam Wallbanks, Muhammad Arifur Rahman, David J. Brown*
-	VR & EEG - Mixed Computer Science Methods in the evaluation of Facial Emotion Expression Recognition *Sean Haddick, David Brown, James Lewis*
-	C&Look: A Platform Supporting Children with Oculomotor Difficulties *Ilona Heldal, Are Are Dæhlen, Carsten G. Helgesen, Qasim Ali*
11:50–12:05	**Discussion and Q&A**

12:05–12:35	**Session 8: Embodiment, Presence and Immersion**
-	Measuring embodied immersion through reactive and proactive postural adjustments during a telepresence cycling experience *Gabriel Baud-Bovy, Giulia Castagliuolo, Vittorio Dalmasso*
-	Repeated Immersion in a Virtual Forest: Stability of Benefits Across Multiple Sessions *Lukáš Hejtmánek, Karolína Rampová*
12:35–12:40	**Discussion and Q&A**
12:40–13:40	**Lunch Break**
13:45–14:45	**Keynote 3** Demystifying AI - in the context of its use within immersive and enabling technologies *David J. Brown*
14:45–15:45	**Session 9: Aging & Methodology**
-	Offline Onboarding as a Potential Contributor to Adherence in VR for Hospitalized Older Adults *Pál Tamás Szabó, Samuel Chovanec, Beáta Pintérné Sosity*
-	The technology works fine, but... Barriers of involving elderly adults in a co-design for digital health innovation *Ágnes Karolina Bakk, Pál Tamás Szabó, Samuel Chovanec*
-	Who Controls VR? A Thematic Synthesis of Studies That Directly Investigated Input Modality with Older Adults *Samuel Chovanec, Lora Appel, Varissara Vannawongpaisan, Pál Szabó, Beáta Sosity, Ágnes Karolina Bakk*
-	Rigour Meets (Virtual) Reality: Balancing Robust Methodology and Real-World Implementation in VR-Therapy Protocol for At-Home Dementia Care *Lora Appel, Samantha Lewis-Fung, Vanessa Geitz, Danielle Tchao, Barbora Darmová and Krisha Malik*
15:45–16:00	**Discussion and Q&A**
16:00–16:10	**Coffee Break**
16:10–17:45	**Demo Session**
18:00	**Copenhagen harbour Tour to Reffen Street Food**

Friday, September 18

8:30–9:00		**Help-desk opens**
9:00–10:00		**Session 10: Cognitive Assessment & Training**
	-	Enhance VR Behavioural Metrics Capture Age-Dependent Reaction Time Delays *Nicolas Morgenstern, Toscane Revillard, Maiya Morgan*
	-	Towards a fusion of control and ecological validity in virtual reality based cognitive testing: pilot results from our QuestMarket game *Soma Zsebi, Cecilia Sik-Lanyi, Renáta Cserjési*
	-	Using Cognitive Map Theory to Create a Serious Game Assessment for Cognitive Dysfunction Post-Brain Injury *Jordan Tewell, Nicole Cruse, Khushali Bhatt*
	-	An Initial Study on Enhancing AR Physical Coaching: Multimodal Posture Feedback Using Local ML and LLMs *Johannes Nivala, Victor Månsson, Ali Geris, Günter Alce*
10:00–10:20		**Discussion and Q&A**
10:35–10:50		**Coffee Break**
10:50–12:05		**Session 11: Accessibility & Inclusion**
	-	Redesigning a VR Group Intervention to Support a Mentalising Stance in Professional Caregivers of People with Intellectual Disabilities *Veerle Andries, Suzanne Derks, Tanja Doodeman*
	-	Enemy Localization Tools for VR Games Accessibility to Blind and Visually Impaired Players *Florian Apavou, Tifanie Bouchara, Patrick Bourdot*
	-	An Interaction-Centered Perspective on Audio-Based Gameplay for Blind Players *Nicoleta Radu, Stine Froulund Astorp, Max Væhrens*
	-	Beyond Control: Access, Embodiment, and Therapeutic Interaction in VR for Older Adults — Insights from a Co-design Workshop *Beáta Pintérné Sosity*
	-	Examining the Technology Experience Profile of Individuals with Disabilities from Sexual and Gender Diversity in Quebec, Canada *Jhon Moreno, Mégan Dubois, Vasilisa Coveny, Célia Rigoulat, Pénélope Pelletier, Samuel Chourot-Ferland, Ashleigh Yule, Alan Martino, Andreas Neumann-Mascis, Carlota Caamano*
12:05–12:25		**Discussion and Q&A**

12:25–13:05		**Session 12: Education & Pedagogy**
	-	Student-Developed Podcasts as an Accessible Pedagogical Model for Teaching Rehabilitation Technologies *Karen Francis*
	-	Teacher Perspectives on Social Virtual Reality for Remote School Participation: An Exploratory Study *Scott Naylor, Emil Rosenlund Høeg, Ali Adjorlu*
	-	REPLICA: Development and Evaluation of an Immersive First-Person Simulation Platform for Psychiatric Education *Iveta Fajnerova, Pavel Srp, Markéta Jablonská*
13:05–13:15		**Discussion and Q&A**
13:15–14:00		**Lunch Break**
14:00–15:00		**Award Ceremony and closing remarks**

Keynote Speakers

David J. Brown

David Brown is a professor from Nottingham Trent University whose work focuses on making technology inclusive and accessible, especially via interdisciplinary systems like virtual reality, serious games, affective computing, and robotics for education and rehabilitation.

Professor in Interactive Systems for Social Inclusion, Nottingham Trent University

Demystifying AI – in the context of its use within immersive and enabling technologies

Within our contexts of use – including education, social care and rehabilitation, AI can be understood as (predominantly) a set of pattern-spotting and generative tools that we are using within and alongside virtual and mixed-reality experiences in real time to transform assessment, treatment, education, care and opportunity for those who need it most. Our basic premise is that an algorithm does not have to make the same choice as a human would make, but a human should at least be able to understand the process by which the decision is made. Understanding the process provides transparency and clarity about how decisions are made – which builds trust, protects rights, and allows for challenging and greater understanding of outcomes that significantly impact lives. We put co-designers (persons directly affected by our research) and co-researchers with disabilities more formally and centrally into the human centric design approaches to these technologies. When we reframe our community partners as co-researchers, then we are much more likely to develop AI-enhanced enabling systems which are trustworthy, unbiased, privacy preserving and will go on to being used and create impact.

AI isn't just a tool—it's a responsibility.

Louise Birkedal Glenthøj

Associate Professor Louise Birkedal Glenthøj is a clinical psychologist and research leader at the VIRTU Research Group at the University of Copenhagen. Her research is dedicated to advancing the use of VR in the clinical assessment and treatment of mental health disorders including psychosis, eating disorders, autism, and anxiety, as well as the application of VR in general clinical practice. She also explores the innovative use of VR-based eye tracking to support the diagnostic process for specific mental health disorders. Additionally, her research aims at identifying biomarkers, such as EEG and MRI, as potential predictors of therapy outcomes with the goal of improving the efficacy of VR interventions.

Associate professor and research leader
Mental Health Center Copenhagen,
University of Copenhagen

Virtual reality in clinical psychiatry: Evidence and experience from recent trials

Virtual reality (VR) is increasingly used as a clinical tool in psychiatric treatment, particularly in areas where real-world exposure, social interaction, or behavioural change are difficult to achieve through traditional therapy. In this talk, I will present findings from five clinical VR studies conducted across several psychiatric populations, with a primary focus on psychosis and additional work within eating disorders.

The talk will describe how VR has been applied to address key clinical challenges, including distressing symptoms, perceived social threat, avoidance, reduced engagement in everyday activities, and difficulties in emotional and interpersonal functioning. Drawing on data from both larger trials and pilot studies, I will discuss clinical outcomes, feasibility in routine clinical settings, and patterns of engagement across repeated VR sessions.

Beyond outcomes, the presentation will focus on processes that appear important across interventions, such as presence, emotional engagement, and patients' interaction with virtual social environments. I will conclude by reflecting on common challenges and lessons learned, and what these experiences imply for the future development and implementation of VR-based interventions in psychiatry.

Kateřina Klapilová

Kateřina Klapilová, Ph.D. (ECPS) is a researcher at the Center for Sexual Health and Interventions at the National Institute of Mental Health and Charles University in the Czech Republic. Her research focus on sexual health and human sexual behaviour. Her work spans large-scale national studies of sexual behaviour and health, as well as experimental and psychophysiological research on sexual reactivity, preferences, and dysfunctions. She contribute to the development and evaluation of preventive and intervention programs targeting problematic and paraphilic sexual behaviour, and is involved in advancing evidence-based approaches to the prevention of sexually motivated crime, alongside educational initiatives for professionals in the field.

Researcher in sexual health and behaviour, National Institute of Mental Health and Charles University, Czech Republic

Revolutionizing the research, assessment, and treatment of paraphilic disorders: the role of virtual reality and artificial intelligence

Paraphilic disorders represent a heterogeneous group of conditions in which atypical sexual interests may cause distress, functional impairment, or harm to others. Despite decades of clinical and forensic work, significant gaps remain in their assessment, treatment, and prevention. Traditional approaches are constrained by methodological, ethical, and legal limits, while many at-risk individuals remain undetected and difficult to engage.

Emerging technologies offer ways to address these challenges. Artificial intelligence (AI) enables the creation of legally compliant, standardized, and demographically tailored visual stimuli for psychophysiological testing (e.g., penile plethysmography).

Projects such as the Philippe-Pinel virtual character generator and recent Czech initiatives with AI-generated static and dynamic stimuli—including nonverbal behavioral cues—improve ecological validity while respecting legal boundaries. Virtual reality (VR) adds immersive environments that support individualized risk assessment, treatment monitoring, and the development of "training arenas," where patients can safely rehearse strategies and clinicians can observe change. Early feasibility studies in forensic psychiatry suggest benefits in anger regulation, impulsivity, and behavioral control.

Digital tools also show promise for prevention and outreach. Chatbots and avatars have been piloted as deterrence and redirection tools, for instance the reThink chatbot on Pornhub UK, which was associated with reduced CSAM searches and increased contacts with support services. Online CBT programs (e.g., Prevent It) and pilot motivational interviewing courses further illustrate how digital platforms can engage non-disclosing individuals, CSAM users, and incarcerated populations. Together, AI and VR innovations herald a transformative future for sexology, providing ethically sound, ecologically valid, and scalable tools for assessment, intervention, and prevention.

ICDVRAT Panel discussion

Accessibility in Technology, how can technology assist people with disabilities

Panel chair / Moderator

Jenny Margrethe-Vej

Panel

Prof. David Brown, NTU
Valeria Borsotti, Postdoc, KU
Hafaz Shah, author
Tobias Nyhuus Jensen, Accessibility Expert

Overview

Join us at ICDVRAT 2026 for a 60-minute panel debate on "Accessibility in Technology: Progress, Gaps, and the Road Ahead." How far have we come in using technology to empower people with disabilities, and where do we still fall short? With new EU accessibility rules on the horizon, are organizations ready, or is this just another compliance hurdle?

Our panel, featuring Hafaz Shah (author), David Brown (Professor, NTU), Valeria Borsotti (Postdoc, KU), and Tobias Nyhuus Jensen (Accessibility Expert), will explore co-creation, innovation, and the ethical dilemmas of emerging tech. Moderated by Jenny Margrethe-Vej. Be part of the conversation at ICDVRAT 2026!

Panelists

Jenny-Margrethe Vej (Moderator) (She/her)

Founder of Diagnoseklubben, University of Copenhagen

Jenny-Margrethe is a speaker, educator, and researcher working at the intersection of neurodiversity, gender, inclusion, intersectionality, and computer science. She is the founder of Diagnoseklubben and is affiliated with the NeuroGen Computing project at the Department of Computer Science, University of Copenhagen. With a background in computer science and IT project and programme management, she combines research, professional experience, and lived experience as a late-diagnosed autistic person with ADHD. Her work is characterised by humour, directness, and a willingness to challenge established ways of thinking.

David J. Brown

David is Professor of Interactive Systems for Social Inclusion at Nottingham Trent University. His research involves the use of VR for children and young people with disabilities for over 30 years.

In addition, he is both a Principal and Co-Investigator on a range of Horizon Europe, British Council and UKRI projects investigating the role of multimodal affect recognition, eXplainable and privacy preserving AI to promote inclusive education, and the positive mental and clinical wellbeing of students with Intellectual Disabilities and Autism. He is Associate Editor for Frontiers: Virtual Reality in Medicine (https://www.frontiersin.org/journals/virtual-reality/sections/virtual-reality-in-medicine) and Editorial Board Member for Virtual Worlds (https://www.mdpi.com/journal/virtualworlds/editors). He has a lifelong obsession with the late, great musician – Janis Joplin.

Valeria Borsotti (she/her)

University of Copenhagen, Denmark. Public Health Department

Valeria Borsotti is a digital anthropologist and HCI scholar researching equity and accessibility in science and technology. Her recent research explores challenges and opportunities related to neurodiversity and accessibility in Danish computer science education. She is co-author of “Diversity in computer science - Design artefacts for equity and inclusion” and co-editor of “Universal Design as a Tool for Change”

Tobias Nyhuus

Principal Accessibility Program Lead, Siteimprove

Tobias Nyhuus Jensen is Principal Accessibility Program Lead at Siteimprove, where he helps teams build accessible, resilient digital products. He is also Denmark’s national expert for the European Commission’s AccessibleEU initiative and co-chair of the Nordic Accessibility Community Group under W3C. His work focuses on making accessibility practical across product development, organisational change, and the implementation of accessibility requirements.

Hafaz Shah

Author and inclusion-advocate, A Life on 4 Wheels

Hafaz Shah is a Danish entrepreneur, author and inclusion advocate with more than 15 years of experience in recruitment, sales, marketing and business development. He is the author of A Life on 4 Wheels, which reflects on his life as a wheelchair user and his experiences with education, employment, entrepreneurship and inclusion. Through his work, Hafaz promotes greater awareness of disability inclusion and encourages organisations to turn good intentions into meaningful action.

01

AI, VIRTUAL HUMANS & SOCIAL INTERACTION

From Code to Care: Building AI virtual humans for accessible and ethical healthcare support

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Abstract

This paper presents the evolution of clinical virtual reality (VR) systems toward AI-driven virtual human (VH) agents for healthcare support. Building on decades of research, we describe the progression from early VR exposure systems to conversational VH platforms such as SimCoach, Battle Buddy, and the Sidekick platform. We highlight user-centered design efforts, mobile deployment strategies, research, and ethical challenges, including safety, bias, and clinical scope. The work demonstrates how VH systems can improve access to care while emphasizing the need for responsible design and human oversight.

1. Introduction

Over the past three decades, clinical virtual reality (VR) has evolved from experimental laboratory systems into scalable tools for assessment, training, and intervention across a wide range of healthcare applications. Early work focused on immersive environments for clinical targets including exposure therapy targeting anxiety disorders and post-traumatic stress disorder (PTSD), cognitive and motor assessment/rehabilitation for orthopaedic/central nervous system dysfunction, acute/chronic pain management, and clinical training (Bell et al., 2024; Rizzo et al., 2023). However, recent advances in artificial intelligence (AI) – particularly large language models (LLMs) – have accelerated the development of conversational virtual human (VH) agents capable of engaging users in naturalistic dialogue (Rizzo et al., 2026).

This shift represents a fundamental transition in clinical VR: from immersive environments as the primary therapeutic medium to intelligent agents that can operate both within VR and on non-immersive platforms such as mobile devices. These agents are increasingly capable of delivering psychoeducation, guiding structured self-help strategies, supporting clinical training, and facilitating access to care. As such, VH systems are now positioned as scalable tools to address persistent gaps in healthcare access, particularly in mental health domains.

This paper provides an overview of this evolution, drawing on a lineage of systems developed over nearly two decades, including SimCoach, Battle Buddy, and the Sidekick platform. We describe the design principles, user-centered findings, research strategies, and technological inflection points that enabled this progression. We also examine the ethical, clinical, and regulatory challenges associated with deploying AI-driven VH systems at scale.

2. Evolution of clinical virtual reality and virtual humans

2.1. Early clinical VR foundations

Clinical VR emerged in the mid-1990s as a promising approach for creating controlled, immersive environments for behavioral healthcare. Early systems targeted domains such as exposure therapy for phobias, cognitive assessment, physical rehabilitation, and pain distraction. Despite technological limitations at the time, these systems demonstrated the value of immersive simulation for eliciting ecologically valid responses while maintaining experimental control. Advances in computing power, graphics rendering, motion tracking, and interface devices – driven in part by the gaming industry – enabled increasingly sophisticated VR environments. These developments laid the groundwork for integrating virtual humans into clinical applications. Virtual humans during this period were mainly instantiated as props to add to the context of a VR simulation (e.g., virtual audience members for fear of public speaking exposure therapy) but rarely for natural language interaction.

2.2. From scripted agents to interactive virtual humans

Thus, early virtual humans were limited in their interactivity, often functioning as static or scripted elements within VR environments. Over time, research in embodied conversational agents introduced systems capable of perceiving user input (e.g., speech, facial expressions) and generating contextually appropriate responses. These systems began to incorporate multimodal sensing, allowing VH agents to analyze vocal prosody, gaze, and gesture to infer psychological states. This marked a transition from VHs as environmental props to active participants in clinical interaction, enabling applications in clinician training, social skills development, and patient engagement.

2.3. The AI inflection point

The recent emergence of LLM-based AI has dramatically expanded the capabilities of VH systems. Modern VH agents can now engage in fluid, natural language dialogue, maintain contextual awareness, and generate responses that approximate human conversational patterns. This has enabled deployment beyond laboratory settings into mobile and web-based platforms, supporting "anytime, anywhere" access to healthcare information and support. Despite these advances, VH systems remain at an early developmental stage. While they demonstrate impressive fluency and adaptability, they are still prone to inaccuracies, overconfidence, and occasional confabulation. This duality – high capability paired with persistent limitations – defines the current state of AI-driven VHs and underscores the importance of responsible design.

3. Case studies in VH system development

3.1. SimCoach: Reducing barriers to care

SimCoach was developed in 2009-2011 to address barriers to mental healthcare among military service members and veterans, including stigma, access limitations, and concerns about confidentiality. The system provided an anonymous, VH-mediated interface through which users could explore mental health concerns, complete screening measures, and receive information about treatment options. (see Figure 1).

User-centered evaluations demonstrated that individuals were more comfortable disclosing sensitive information to a VH compared to traditional web-based tools. However, the system's lack of persistent memory limited its ability to build longitudinal engagement and trust. While Sim-

Coach improved user experience and engagement, it did not significantly increase help-seeking behavior, highlighting the importance of continuity and personalization in VH interactions (Meeker et al., 2015).

3.2. Battle Buddy: Mobile VH for Veteran safety planning and mental health psychoeducation

Battle Buddy represents a transition from static, web-based VH systems to mobile, user-initiated interactions. Designed as a prototype mHealth application, Battle Buddy supports suicide prevention through structured safety planning. The system guides users in identifying warning signs, coping strategies, and sources of support, emphasizing preparation rather than real-time crisis intervention (see Figure 1).

A key design principle was minimizing interaction burden. Sessions were intentionally brief, modular, and repeatable, aligning with real-world mobile usage patterns. The system also leveraged existing smartphone features (e.g., music, photos, messaging) to support coping strategies, reducing friction and increasing usability during periods of distress. Development followed a user-centered rapid assessment process, incorporating feedback from veterans, clinicians, and researchers. Findings emphasized the importance of predictable interaction flow, non-judgmental tone, and clear system boundaries (Mozgai et al., 2023).

3.3. Sidekick platform: Scalable VH deployment

The Sidekick platform (which evolved from the Battle Buddy concept) represents the current generation of VH systems, designed for scalable deployment across multiple domains. It provides a cloud-based infrastructure that allows subject-matter experts to author, curate, and manage VH interactions without requiring deep technical expertise. (see Figure 1).

Key features include:

- Role-based VH agents (“Sidekicks”) tailored to specific domains
- Expert-curated knowledge sources and constrained response parameters
- Multi-agent coordination for complex user needs
- Integration of multimedia resources to support actionable outcomes

The platform emphasizes a human-in-the-loop approach, enabling experts to define system scope, enforce boundaries, and ensure alignment with clinical and organizational standards. Applications being developed thus far include veteran resource navigation/clinical access, caregiver/special needs parent support, and mental health resource access and management for police and other first responder populations.

In a recent evaluation conducted within the United States Department of Veterans Affairs, 1,005 Veterans were given early access to a non-clinical version of the Sidekick/Battle Buddy application (results to be presented in the full paper and conference presentation). Findings from this study were highly encouraging: 92.5% of participants indicated they would recommend Sidekick/Battle Buddy to a friend or use it regularly when available; 85.1% reported improved ability to *identify* VA resources; 83.7% reported improved ability *to connect to* appropriate resources; 80.5% reported improved ability to *access* VA staff and services; and 78.4% expressed satisfaction with the navigation experience.

Participants also reported high levels of engagement with the virtual human (VH), noting the value of conversational, personalized guidance and reduced frustration when navigating multiple VA systems. Although derived from an early-stage prototype, these findings suggest that the platform represents a scalable, patient-facing AI support approach that can enhance Veterans' awareness of and access to resources – while complementing, rather than replacing, live human clinicians.

4. User-centered design and accessibility implications

Across all systems described, user-centered design has been critical to success. Iterative testing consistently revealed preferences that shaped system design, including:

- Clear privacy protections and transparency
- Reduced authority cues (e.g., avoiding military uniforms in VH design)
- Customization of agent characteristics (e.g., gender, age)
- Informal, conversational language
- Low-friction interaction models

These findings are particularly relevant for disability and accessibility contexts. VH systems offer unique advantages for individuals who face barriers to traditional care, including those with mobility limitations, social anxiety, or neurodivergent communication preferences. For example, some users prefer text-based interaction or simplified language structures, highlighting the need for adaptable communication modalities. Co-design with target populations remains essential to ensure accessibility, usability, and cultural relevance.

5. Ethical and clinical considerations

5.1. Scope and role definition

A central principle in VH design is that AI systems should augment – not replace – human clinicians. VH agents are best suited for structured support functions such as psychoeducation, screening, and skill-building. They should not perform diagnosis, treatment planning, or crisis management independently. A rich detailing of these ethical and professional guidelines can be found in (Rizzo et al., 2025).

5.2. Safety and crisis response

Ensuring safe responses to users in distress is a critical challenge. Current AI systems can detect explicit indicators of risk but often struggle with indirect or ambiguous signals. Effective design requires conservative escalation strategies, clear pathways to human support, and avoidance of autonomous risk management.

5.3. Privacy and data protection

VH systems collect sensitive data through user interaction and, in some cases, multimodal sensing. This raises significant concerns regarding privacy, consent, and data governance. Compliance with regulatory frameworks (e.g., HIPAA, FERPA) is necessary but not sufficient, as these frameworks were not designed for AI-driven systems.

5.4. Bias and inclusivity

AI systems may reflect biases present in training data or design decisions. This can disproportionately impact underserved populations, including individuals with diverse linguistic, cultural, or cognitive profiles. Addressing bias requires diverse datasets, inclusive design practices, and ongoing evaluation.

5.5. User attachment and dependency

VH agents can foster strong user engagement and self-disclosure. While this can reduce stigma and increase access, it also raises concerns about over-reliance or substitution for human relationships. Design strategies should encourage connection to real-world support networks.

6. Discussion

The progression from early VR systems to AI-driven VH platforms reflects a broader shift in healthcare technology toward scalable, user-centered solutions. VH systems offer a promising approach to addressing global mental health needs, particularly in contexts where access to care is limited. However, the transition from research prototypes to real-world deployment introduces new challenges. The increased fluency and realism of AI systems can lead to overestimation of their capabilities, necessitating careful design of scope, transparency, and safety mechanisms. Lessons from both clinical VH systems and consumer AI applications highlight the risks of deploying systems without adequate guardrails (Rizzo et al., 2026). The most effective approach appears to be hybrid design models that combine generative AI with structured constraints, expert oversight, and curated knowledge sources. This allows systems to leverage the strengths of AI while maintaining control over safety-critical interactions.

7. Conclusion

AI-driven virtual humans represent a significant advancement in clinical VR, enabling scalable, accessible support for a wide range of healthcare applications. Systems such as SimCoach, Battle Buddy, and the Sidekick platform illustrate the potential of VH agents to enhance engagement, reduce barriers to care, and extend the reach of expert knowledge. At the same time, these technologies must be developed and deployed with careful attention to ethical, clinical, and regulatory considerations. The future of VH systems will depend not only on technological progress but also on the establishment of robust frameworks for safety, accountability, and human oversight. When designed responsibly, VH agents can serve as powerful tools for bridging gaps in care – supporting, rather than replacing, the human relationships at the core of healthcare. These elements will be discussed in more detail in the final paper and conference presentation, if accepted.

Figure 1: Simcoach, Battlebuddy, Sidekick.

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Evaluating metaverse support groups for displaced populations: A randomized controlled trial with Ukrainian refugees

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Abstract

This randomized controlled trial (N = 152) evaluated the efficacy of immersive, avatar-based metaverse support groups for Ukrainian refugees. Participants were randomized to metaverse, in-person, or waitlist group therapy conditions. Significant reductions were observed in depression and anxiety with concurrent improvements in well-being and social support. Metaverse outcomes were comparable to in-person groups and superior to waitlist. Therapeutic alliance significantly moderated outcomes, particularly in immersive settings. Findings support metaverse-based interventions as scalable and effective approaches for displaced populations.

1. Introduction

The war in Ukraine has created a large-scale humanitarian crisis, placing a substantial mental health burden on displaced populations (Buchcik et al., 2023). Access to care is further limited by logistical, linguistic, cultural, resource, and stigma-related barriers. Support groups are a well-established, low-cost intervention for promoting psychological well-being, particularly among individuals facing shared adversity (Worrall et al., 2018); however, traditional in-person groups are difficult to scale in humanitarian contexts due to geographic dispersion and limited resources. Online virtual environments – particularly those described as "metaverse" platforms – offer a promising middle ground. These systems allow users to interact via avatars in shared, three-dimensional spaces, combining accessibility with embodied social presence. Emerging research suggests that such environments may enhance engagement, reduce stigma, and foster meaningful interpersonal connection (Cerasa et al., 2024; Vila et al., 2024). However, research is needed to determine whether this approach can provide the sense of presence, engagement, and interpersonal connection that underpin effective face-to-face group interventions and produce positive outcomes. The present study addresses a critical gap in the literature by conducting a randomized controlled trial (RCT) to evaluate the efficacy of metaverse-based support groups compared to both in-person groups and a waitlist control condition. This work provides one of the first rigorous empirical tests of immersive group interventions for refugee mental health.

2. Methods

2.1. Study design

A three-arm parallel-group randomized controlled trial was conducted to compare:

1. Metaverse-based support groups
2. In-person support groups
3. Waitlist control

Participants (N = 152) were randomized in a 1:1:1 ratio and assessed at four time points: baseline, mid-intervention (after session 2), post-intervention, and 3-month follow-up . Mixed-effects linear models were used to analyze longitudinal changes.

2.2. Participants

Participants were Ukrainian refugees residing in Romania, recruited through NGOs and refugee centers. The sample was predominantly female (98%) with a mean age of 47.3 years. Inclusion criteria required participants to be adults not currently engaged in formal mental health treatment. Recruitment yielded approximately 1,000 initial contacts, with 152 participants meeting eligibility criteria and randomized. Retention was 44% at post-intervention and 43 participants at follow-up.

2.3. Intervention

Both metaverse and in-person groups followed an identical structure: five weekly 90-minute sessions facilitated by licensed psychotherapists. Sessions included check-in, discussion, psychoeducation, and group sharing, grounded in cognitive behavioral therapy (CBT) and trauma-informed principles. The metaverse condition was delivered in a browser-based immersive environment modeled after a Kyiv location (using spherical photoreal imagery), where participants interacted via avatars using spatialized voice communication. This setup enabled real-time group interaction while preserving anonymity and reducing social inhibition.

2.4. Outcome measures

Primary outcomes:

- Depression (PHQ-9)
- Anxiety (GAD-7) Secondary outcomes:
- Well-being (WHO - Five Well-Being Index (WHO, 1998))
- Perceived social support - Multidimensional Scale of Perceived Social Support (Zimet et al., 1988)
- General psychological distress (DSM-5-TR Level 1 Cross-Cutting Symptom Measure (LeBeau, 2014)
- Gender-based violence (GBV) awareness (NGO-developed)

Therapeutic alliance (The Working Alliance Inventory – Short Form (Munder et al., 2010)) was assessed as a moderator of outcomes.

3. Results

3.1. Main effects

Active Metaverse and in-person intervention conditions showed comparable improvements and both outperformed the waitlist condition. Across the pooled sample, significant improvements were observed from baseline to post-intervention:

- Depression decreased significantly ($\beta \approx -4.99$, $p < .001$)
- Anxiety decreased significantly ($\beta \approx -4.47$, $p < .001$)
- Well-being increased significantly ($\beta \approx +7.18$, $p < .001$)
- Social support increased significantly ($\beta \approx +10.69$, $p < .001$)
- Psychological distress decreased significantly ($\beta \approx -15.66$, $p < .001$)

Critically, metaverse-based groups achieved comparable outcomes to in-person groups across all primary and secondary measures. This finding supports the viability of immersive digital environments as an alternative delivery modality for group-based interventions.

3.2. Follow-up effects

At the 3-month follow-up, most treatment effects attenuated, though reductions in general psychological distress remained significant. This suggests that while short-term benefits are robust, maintenance strategies may be necessary to sustain gains.

3.3. Therapeutic alliance

Therapeutic alliance emerged as a significant moderator of outcomes, particularly for:

- Depression
- Well-being
- General distress

Notably, alliance effects were strongest in the metaverse condition, suggesting that meaningful therapeutic relationships can be formed in immersive digital environments – and may even be enhanced under certain conditions.

4. Discussion

This study provides one of the first rigorous demonstrations that metaverse-based support groups can produce clinically meaningful improvements in mental health outcomes among displaced populations. The results are notable for several reasons. First, the magnitude of improvement across outcomes is consistent with prior research on in-person, group-based psychosocial interventions, suggesting that metaverse delivery does not compromise efficacy. Second, the equivalence between metaverse and in-person groups challenges assumptions that digital interventions are inherently less effective or less engaging. The metaverse environment offers unique affordances that may contribute to these effects:

- Anonymity through avatar representation
- Reduced salience of identity markers
- Increased psychological safety

- Enhanced sense of presence compared to traditional online platforms
- Enhanced access to care

A key mechanism underlying these findings appears to be therapeutic alliance. Despite the mediated nature of interaction, participants in the metaverse condition formed strong relational bonds with facilitators and group members. This aligns with prior work suggesting that avatar-mediated environments can reduce stigma and facilitate self-disclosure by minimizing social evaluation pressures. Previous research suggests that interactions with virtual human representations often elicit a heightened sense of safety and lower perceived stigma when individuals disclose personal concerns, compared to direct encounters with human providers (Lucas et al., 2014, 2017; Mozgai et al., 2017). This effect has been attributed to the reduced salience of social identity markers, the perception of anonymity, and the minimization of impression management pressures in avatar-mediated settings. Drawing on classic theories of stigma and self-presentation (Goffman, 1959, 2022), the Metaverse may provide a unique environment in which participants can explore sensitive topics without the same fear of negative evaluation or social judgment that often arises in face-to-face groups. In group therapy delivered via avatars, these affordances may lower barriers to self-disclosure, foster more candid exchanges, and strengthen therapeutic alliance among participants. Designing refugee-focused Metaverse platforms with sensitivity to these psychological mechanisms – through features that preserve anonymity while also cultivating trust – may therefore be critical for maximizing engagement and therapeutic outcomes. These features may be beneficial for refugee populations, who often face stigma and barriers to open disclosure in traditional settings. Notably in the current study, stronger therapeutic alliances in the metaverse group led to better symptom outcomes, demonstrating that relational dynamics remain central even in virtual interventions.

While reductions in general distress persisted at the 3-month follow-up, the attenuation of anxiety and depression benefits highlights the need for sustained engagement strategies to support longer-term stress and trauma recovery. It is important to note that the original study design, out of caution at this early stage, specified exclusion of participants scoring above the PTSD cutoff of 27 on the National Stressful Events Survey PTSD Scale (LeBeau, 2014). In practice, however, the vast majority of screened individuals exhibited elevated PTSD symptoms, likely reflecting the humanitarian crisis context of the sample. Excluding these participants would have substantially limited both the generalizability and ethical relevance of the findings. Consistent with best practices for trauma-informed research and following consultation with field clinicians, these individuals were retained in the study. Clinicians were trained to monitor participant distress throughout the sessions and to provide immediate support or referrals when necessary. Taken together, these findings suggest that participants with elevated PTSD symptoms may require longer-term and more consistent engagement to achieve enduring mental health benefits, particularly given the ongoing stressors they face. Future interventions may therefore benefit from incorporating booster sessions, sustained access to virtual support communities, and integration with other support systems or more intensive evidence-based treatments.

5. Limitations

Several limitations should be noted:

- High attrition rates (44% retention at post-intervention)
- Predominantly female sample, limiting generalizability
- Reliance on self-report measures
- Lack of formal fidelity monitoring
- Potential selection bias due to NGO-based recruitment

Despite these limitations, the randomized design, use of validated measures, and consistency of findings across sensitivity analyses strengthen confidence in the results.

6. Conclusion

This study demonstrates that metaverse-based support groups are both feasible and effective for improving mental health outcomes among refugee populations. The findings suggest that immersive digital environments can replicate key therapeutic processes – particularly alliance – while overcoming barriers associated with traditional care. As global displacement and mental health needs continue to rise, scalable, accessible, and culturally adaptable interventions are urgently needed. Metaverse-based group therapy represents a promising direction for extending psychosocial support to underserved populations worldwide.

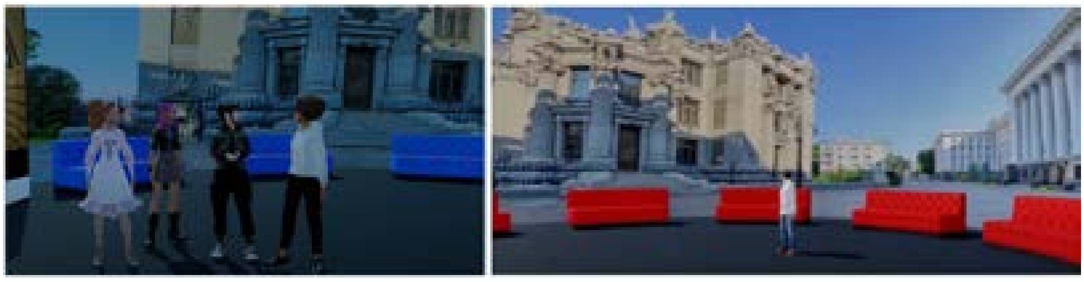

Figure 1: Spherical Metaverse Environment with Avatars.

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One format fits all? Sensory sensitivity and AI-generated cyberbullying narratives: a study protocol

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Abstract

Sensory Processing Sensitivity (SPS), a temperamental trait affecting 20–30% of adults, shapes how individuals perceive and react to environmental stimuli. As AI-generated immersive content becomes increasingly common in digital interventions, it remains unknown whether format choices interact with SPS to modulate emotional response. This paper presents the protocol of a planned experimental study comparing audio podcasts and expressive virtual humans in a cyberbullying narrative intervention. Findings will offer the empirical groundwork for sensitivity-informed design of AI-mediated interventions, a prerequisite before content can be meaningfully personalised to distinct sensory profiles.

1. Introduction

Digital interventions for cyberbullying increasingly use artificial intelligence (AI) to deliver emotionally engaging content. Virtual humans – expressive avatars with synthetic voice and facial animation – are becoming a prevalent medium for narrative-based prevention tools, on the assumption that greater social presence elicits stronger empathic responses (Gratch et al., 2007). A previous pilot study by the authors showed that AI-generated audio podcasts increased online empathy but failed to modify moral disengagement (Francisco et al., 2025), a belief system known to be resistant to change (Bandura, 1999).

A critical yet underexamined issue is whether these rich, immersive formats are equally effective across users. Sensory Processing Sensitivity (SPS) is a temperamental trait, present in an estimated 20–30% of the adult population, characterised by deeper cognitive processing of stimuli and stronger emotional reactivity (Aron & Aron, 1997; Lionetti et al., 2018). Neuroimaging evidence shows that high-SPS individuals display greater activation in brain regions associated with perception, empathy, and self–other processing (Acevedo et al., 2014), yet the same lowered perceptual threshold can lead to overstimulation and emotional exhaustion (Roxburgh, 2023).

The need to balance deep engagement with the risk of sensory overload carries direct implications for the design of AI-mediated content: a format that enhances empathic engagement for typical users may overwhelm high-SPS users, potentially triggering avoidance rather than prosocial reflection. To date, no study has directly tested how SPS interacts with audio compared to audio-visual AI-generated narratives. Before digital interventions can be responsibly personalised to distinct sensory profiles, the underlying interaction between SPS and presentational format needs validation; without it, any claim of sensitivity-informed design would be speculative.

The present protocol addresses this prerequisite. By testing whether SPS interacts with format (audio-only vs. audio-visual) and narrative perspective (third person vs. first-person victim) in shaping empathic and physiological reactivity to cyberbullying narratives, the study provides the foundational evidence on which any subsequent personalisation work must rest.

2. Proposed method

2.1. Design

The study employs a between-subjects experimental design with five groups: (i) audio podcast, third-person narration; (ii) audio podcast, first-person narration (victim); (iii) virtual human, third-person narration; (iv) virtual human, first-person narration (victim); and (v) text-only control. SPS is treated as a continuous moderator. Each participant attends two laboratory sessions approximately one week apart, allowing counterbalanced exposure to male- and female-victim narratives.

2.2. Participants

A convenience sample of approximately 230 university students aged 18–25 will be recruited on campus, targeting retention of at least 196 participants after attrition (approximately 40 per experimental group). This sample size provides 80% statistical power to detect medium-sized effects (Cohen's $f = 0.25$) in the primary ANOVA and moderation analyses ($\alpha = 0.05$), based on an a priori power analysis conducted with G*Power.

2.3. Stimuli

Stimuli are fictional but ecologically valid cyberbullying narratives developed and validated in a previous pilot study (Francisco et al., 2025). Narratives are generated as native Portuguese audio using NotebookLM. Virtual-human versions pair the audio with an expressive avatar animated with congruent facial expressions and lip-sync.

2.4. Measures

Participants' baseline profiles will be assessed at the beginning of Session 1. These include the evaluation of individual Sensory Processing Sensitivity using the *Highly Sensitive Person Scale – Revised* (Pluess et al., 2024; Portuguese adaptation under development by the authors) and the assessment of behavioral history based on the *Cyberbullying Inventory for College Students* (CICS).

To evaluate the impact of the intervention and the different presentational formats, online empathy and moral disengagement will be measured as primary outcome variables. These will be assessed using the *Empathy in Virtual Contexts Questionnaire* (EQVC; Francisco et al., 2023) and the *Process Moral Disengagement in Cyberbullying Inventory* (PMDCI). While a previous pilot study using audio podcasts showed no significant changes in this construct (Francisco et al., 2025), the current protocol introduces expressive virtual humans and first-person perspectives. These high-immersion features are expected to enhance the humanization of the victim, potentially overcoming the cognitive stability of moral disengagement mechanisms observed in simpler formats. After each exposure in both sessions, participants will complete a stimulus evaluation questionnaire. Additionally, during exposure, biometric data (electrodermal activity, heart rate, and respiration) will be recorded continuously via Bioplux sensors. Simultaneously, facial expressions and gaze will be captured with FaceReader 9.0 for the automatic extraction of action units and valence indices.

2.5. Procedure

Data collection will only begin upon ethics approval. After informed consent, in Session 1, participants complete the initial battery for baseline profiles (HSPS-R and CICS) and the pre-exposure administration of the outcome measures (EQVC and PMDCI), followed by a 60-second resting baseline. Sensors are then calibrated, and the first narrative is presented according to group allocation, with synchronous recording of physiological and facial data. At the end of the Session 1 exposure, the stimulus evaluation questionnaire is administered.

Session 2 (approximately one week later) replicates the exposure procedure with the counterbalanced victim gender. At the end of the Session 2 exposure, the stimulus evaluation questionnaire is administered. Following this, participants complete the post-exposure administration of the EQVC and PMDCI to evaluate intervention-driven changes. All video recordings are processed offline by FaceReader 9.0 and deleted immediately after numerical extraction, in line with GDPR requirements.

2.6. Analysis Plan

SPS is modelled primarily as a continuous moderator based on HSPS-R total scores. Given that no validated categorical cut-offs yet exist for the HSPS-R, exploratory latent profile analyses (LPA) will be conducted by combining HSPS-R subscales with baseline cyberbullying involvement (CICS). These profiles will then be used to identify user subgroups and predict differential responses to each format (audio-only vs. audio-visual) regarding: (a) change in self-reported empathy (pre- to post-exposure); (b) change in moral disengagement levels (PMDCI) (pre- to post-exposure); (c) facial valence indices and physiological arousal during exposure.

3. Ecpected contributions

This work is expected to yield three contributions. First, methodological: the combination of native-language AI-generated stimuli with multimodal physiological and facial measurement reduces self-report bias in a domain where social desirability is known to confound empathy and moral-disengagement research. Second, theoretical: results will clarify how SPS – a neurobiologically grounded individual difference – interacts with presentational format, extending the environmental sensitivity framework (Pluess, 2015) into human–AI interaction. Third, and most importantly, applied: findings will provide the empirical foundation required before AI-mediated interventions can be responsibly personalised to distinct sensory profiles. The study is thus positioned not as an inclusive-design intervention in itself, but as a necessary first step towards sensitivity-informed design – one that clarifies whether format choices matter for sensitive users before prescribing how content should be adapted for them.

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Ethics and study status

This protocol constitutes a methodological extension of a prior study by the authors (Francisco et al., 2025), which received full ethics approval. The current protocol – which adds virtual human stimuli, multimodal physiological and facial measurement, and SPS as a moderator – is under review by the Research Ethics Committee. Data collection will begin upon approval; depending on timing, preliminary data may or may not be available at the time of presentation.

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02

STROKE & NEUROMOTOR REHAB

Virtual Reality for Upper Limb Stroke Rehabilitation: A Quality Improvement Study Evaluating Patient Outcomes and Clinical Feasibility

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Abstract

Upper limb impairment affects most stroke survivors, yet routine rehabilitation often provides far fewer repetitions than the 300–800 movements linked to neuroplastic change. This extended abstract reports a dual-phase Quality Improvement study examining whether a commercial, controller-free virtual reality system could increase therapy dose in an acute stroke unit without unacceptable workflow burden. Four stroke patients completed matched 30-minute conventional occupational therapy and VR sessions, while 18 occupational therapists assessed feasibility through usability scales, competency checks, and interviews. VR produced 200–500% more repetitions, median 354%, with positive feedback, no adverse events, and good usability, though supervised practice remained necessary afterwards.

1. Introduction

Stroke remains a major source of long-term disability, and upper limb impairment affects around 70% of survivors Langhorne et al. (2011). Recovery is strongly linked to high-dose, task-oriented practice, yet observational work shows that conventional stroke rehabilitation often delivers only a few dozen meaningful upper limb movements per session Lang et al. (2009). More recent observational work reports somewhat higher but still sub-threshold counts, ranging from around 36–57 repetitions in a recent systematic review to a mean near 210 in a detailed video analysis Newton et al. (2023), Proulx et al. (2025); the conventional counts observed here fall within this contemporary range. Translational and clinical rehabilitation literature suggests that substantially larger numbers of repetitions, often in the range of 300–800 movements, are needed to drive the neuroplastic adaptation associated with motor recovery Birkenmeier et al. (2010).

This mismatch between evidence-based dose targets and routine clinical delivery is especially problematic in acute stroke services, where therapist time, patient fatigue, and ward pressures restrict opportunities for intensive practice. Virtual reality has been proposed as a way to narrow this dose gap by combining structured exercise with immediate feedback, performance tracking, and game-like motivation Bui et al. (2021), Hao et al. (2024). However, successful adoption depends on more than efficacy alone: systems must also be usable, safe, and workable for busy clinical teams.

This paper presents a dual-phase Quality Improvement study undertaken at the Royal Victoria Hospital Acute Stroke Unit, Belfast. The study evaluated *Resynk*, a commercial VR platform for upper limb stroke rehabilitation that runs on Meta Quest 2, 3, and Pro and uses controller-free hand tracking. Two practical questions guided the work:

1. Can VR increase upper limb repetition counts by at least 20% relative to conventional therapy without additional staffing?
2. Is the system sufficiently usable and acceptable for occupational therapy staff to incorporate into routine care?

2. Method

2.1. Design and Setting

The study used a Quality Improvement (QI) design rather than a randomised controlled trial. This approach better reflected routine ward practice and produced findings that were more applicable to implementation. The work was conducted in the 31-bed acute stroke unit at the Royal Victoria Hospital

2.2. Participants

Eight patients were recruited to the efficacy phase over six months. However, one was discharged early, one moved to another hospital and two did not achieve a 30 minute session length used for comparison, so four patients completed the study. Inclusion criteria required confirmed stroke, age over 18 years, an identifiable upper limb deficit, ability to follow simple commands, and capacity to consent. Exclusion criteria included acute medical instability, global aphasia, active delirium, uncontrolled hypertension, seizure history, significant vestibular risk, and implanted devices that would preclude headset use.

Eighteen of nineteen eligible occupational therapists from acute and community stroke teams took part in the feasibility phase. One therapist declined because of workload pressures.

2.3. Intervention and Measures

Resynk provides nine upper limb rehabilitation games targeting movements such as reaching, grasping, supination, pronation, and pinching. A companion web application allows therapists to set patient profiles, prescribe games, define daily goals, and review repetition counts. The controller-free design was a key implementation feature because many acute stroke patients cannot reliably grip handheld controllers.

For the patient phase, participants received 30-minute VR sessions two to five times per week during admission. The platform automatically logged repetition counts. For comparison, two 30-minute conventional upper limb occupational therapy sessions per patient were observed, and repetitions were manually counted by an additional therapist using tally counters.

For the staff phase, feasibility was examined using a Technology Acceptance Model framing. Measures included the System Usability Scale (SUS), post-training and one-month competency checklists, and semi-structured interviews about safety, barriers, and support needs. Quantitative patient outcomes were summarised descriptively, with paired comparisons assessed using the Wilcoxon Signed-Rank Test because of the small sample and non-normal rehabilitation data.

3. Key findings

The patient phase showed a substantial increase in upper limb practice intensity when VR was used as an adjunct to routine therapy. Across participants, VR produced 200–500% more repetitions than conventional sessions, with a median improvement of 354%. This comfortably exceeded the study's target of a 20% increase. The intervention also improved attainment of the minimum neuroplastic threshold: VR sessions reached between 33% and 232% of the 300-repetition benchmark, whereas conventional sessions achieved only 8% to 33%. Table 1 provides a condensed summary of the main patient efficacy and staff feasibility outcomes.

The detailed cases help explain the practical value behind these numerical gains. An 82-year-old participant with marked weakness engaged successfully despite needing facilitation. Another patient with fine motor coordination difficulties achieved the highest repetition counts, apparently aided by the competitive structure of the games. A third patient with motor and perceptual deficits was able to practise both domains within the same activity. These cases suggest that benefit was not confined to a narrow patient subgroup.

Subjective responses were also favourable. Most patients rated the VR sessions as a positive experience, and most agreed or strongly agreed that the system motivated them to do more rehabilitation because it was more interesting than standard exercises. Importantly, no adverse events were reported. In an acute stroke context, where concerns around dizziness, tolerance, or cognitive overload often obstruct adoption, the absence of safety issues is a notable implementation signal.

Staff feasibility results were similarly positive overall. The average SUS score was 81, which falls in the good-to-excellent range and exceeded the predefined threshold of 70. Interview data highlighted enthusiasm for the motivational quality of VR and its potential to add therapy intensity without constant one-to-one therapist delivery. At the same time, the competency checks clarified where implementation friction remained. Immediately after training, all staff could independently use the headset and web application. At one-month follow-up, however, more routine administrative tasks such as logging in, creating profiles, or editing goals sometimes required verbal prompting. This pattern indicates that the core concept was acceptable, but operational reliability depended on reinforcement.

4. Discussion

The study supports the view that clinically designed VR can narrow the rehabilitation dose gap in acute stroke care when it is used as an adjunct rather than a replacement for conventional occupational therapy. The findings align with broader evidence that VR can improve engagement and increase opportunities for upper limb practice Hao et al. (2024), and with recent meta-analytic work suggesting that VR combined with standard rehabilitation is more effective than VR alone Enríquez-Canto et al. (2025). The practical significance of the present study lies in its service-facing emphasis: it examined not only whether repetitions increased, but whether a real ward team could absorb the system into routine work.

Several design features appear central to that feasibility. First, hand tracking reduced an obvious access barrier for patients with weak or impaired grip. Second, the gamified structure supported motivation through immediate feedback, scoring, and progressive challenge, which is consistent with established accounts of VR's rehabilitation value Bui et al. (2021). Third, the therapist dashboard made it possible to prescribe tasks and monitor activity in a clinically meaningful way rather than treating the technology as a generic entertainment device Adams et al. (2015).

The work nonetheless has clear limitations. Repetition count is an intermediate, process-level outcome rather than direct evidence of functional recovery: a higher dose is a necessary condition for, but not a guarantee of, improved upper limb function Lang et al. (2016). Encouragingly, a recent systematic review suggests that dose increases of at least 200% may be required before meaningful functional gains emerge Patel et al. (2026), a range within which the present 200–500% increases fall, although confirming functional benefit would require impairment- and activity-level measures beyond the scope of this study. The study was also single-site with a small patient sample (four of eight recruited completed the matched comparison) and no randomised control group or blinding, so the gains cannot be separated from novelty or attention effects. VR and conventional repetitions were recorded by different methods (automated logging versus manual tallying). Repetition counting was performed by 2 therapists. The 18 therapists who used the VR separately with patients were to be able to give feedback but not with the same patients where the repetitions were original counted The results should therefore be read as preliminary implementation evidence that motivates rather than substitutes for a larger randomised controlled trial with blinded functional outcome assessment.

From an implementation perspective, the main lesson is that training cannot be a one-off event. The one-month competency decline suggests that successful deployment requires that practice be supported by further expert supervised training as staff need to feel comfortable and confident when using it. Access to quick-reference materials, and simplified login workflows was also considered important. For services considering adoption, VR appears most credible as a structured supplement delivered for 20–30 minutes, three to five times per week, targeted at patients who can follow simple commands and tolerate headset use. Staff newer to stroke rehabilitation demonstrated strong technological skills but required additional support with clinical reasoning for appropriate VR application. This suggests that training programmes must address both technical operation and therapeutic integration.

Domain	**Outcome**
Patient efficacy	VR increased repetitions by 200–500% versus conventional therapy; median increase 354%.
Representative repetition counts	Patient 1: 25 to 110; Patient 2: 100 to 696; Patient 3: 27 to 98; Patient 4: 54 to 171.
Dose attainment	VR reached 33–232% of the 300-repetition threshold; conventional therapy reached 8–33%.
Patient experience	Most patients reported VR was a positive experience and increased motivation for rehabilitation.
Safety	No adverse events reported by patients or staff.
Usability	Mean SUS score 81; 16 of 18 staff scored the system at 70 or above.
Competency retention	Immediate post-training competency was 100%; at one month, setup and login tasks required prompts for some staff.

Table 1: Condensed summary of patient efficacy and staff feasibility outcomes.

5. Conclusion

This Quality Improvement study indicates that controller-free VR is a credible way to increase upper limb rehabilitation intensity in acute stroke care while remaining acceptable to clinical staff. In this setting, *Resynk* generated substantially higher repetition counts than conventional occupational therapy, was positively received by patients, and was judged usable and safe by therapists. The next step is not to ask whether VR should replace hands-on therapy, but how services can combine both approaches to deliver more intensive, motivating, and scalable rehabilitation.

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Integrating Shared co-located Clinician-Patient Augmented Reality into rehabilitation tools

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Abstract

Virtual Reality holds great rehabilitation potential, however an adoption barrier for practical use is the disconnect between patients and both clinicians and their physical surroundings. Co-located Augmented-Reality can mitigate these issues by placing both in real-world environments with augmented challenges while avoiding disconnection. As a proof of concept, we implemented a tool with co-located spaces where patients and clinicians can interact with augmented content safely together. We performed a usability study (n=8), which demonstrated the tool's usability and potential. This approach can potentially boost the adoption and effectiveness of augmented rehabilitation tools helping to unlock their potential.

1. Introduction

Recent years have seen the development of a wide variety of Virtual Reality (VR) tools for rehabilitation in the realms of physical and occupational therapy. These include tools for conditions such as stroke Khan et al. (2024), Landim et al. (2024), Parkinson's Kwon et al. (2023), orthopaedic injury Tang et al. (2025) and many more (reviewed in Rutkowski et al. (2020)). These tools are thought to hold the potential to break several significant bottlenecks limiting current rehabilitation tools given their flexibility, naturalness, easier logistics etc. However, their adoption in practice for clinical use still remains limited – why?

One key reason for this is the disconnect involved with VR use, as they block patients' field of vision and present them with a virtual world. However, in doing so, they prevent them from seeing the world around them and the dangers in it. For example, hospital wards where equipment, medical staff, and other patients are found. In parallel, the clinicians are also disconnected from their patients, with whom the interaction takes place outside the virtual environment, which often they either cannot see or can view only via a computer/tablet screen. How can we break this disconnect?

Augmented Reality (AR), in which the user is presented with augmented content while still in the real world may help mitigate the disconnect from the environment and preserve empathy, in addition to causing less nausea De Cecco et al. (2023), Navas-Medrano et al. (2024). And indeed, while still less mature there are several attempts to develop rehabilitation tools using this approach Modlin & Kuo (2025). In parallel, shared collaborative sessions in virtual environments have shown success in reducing the feeling of isolation, mitigating the barrier between patient and clinical staff Marques et al. (2024), Oliveira et al. (2026), Worlikar et al. (2023). However, despite the suggested advantages De Cecco et al. (2023), Navas-Medrano et al. (2024) these two approaches have seen only very limited combinations as previous attempts were limited by expensive hardware and environment setups and the need for controlled in-lab settings that were less naturalistic De Cecco et al. (2023). In contrast, new recently available tools make this approach more practical in terms of cost and setup and can be deployed more naturalistically.

Thus, here we suggest the use of co-located Shared AR via an asymmetric interface as a step forward towards these challenges. We implement such a tool as a proof of concept, and then test its usability in terms of safety and functionality. We chose to implement two tasks that explore different aspects of this approach – a reaching task, which focuses on dynamic interactions between patient and clinician, and a road crossing which enables clinicians to safely train and test users on a dangerous task in the real world.

2. Methods

Terminology. A **Shared virtual environment** is one in which multiple users can perceive the same digital content simultaneously, in this case breaking the disconnect between patient and clinician. A **co-located augmented environment** is one in which both users are in the same physical space in the real world with the augmented targets appearing in the same physical locations. An **asymmetric interface** means that while both users perceive the same augmented content, they are also offered different affordances and options. This enables clinicians to control the task in real-time without the patient changing parameters or getting distracted by controls.

Tools. We used Meta Quest 3 Headsets which offer full-color-passthrough AR for the participants, while the experimenters used a Quest 3 or Quest Pro interchangeably. The software was developed using Unity and programmed in C#. We utilized Meta's "Shared Spatial Anchors" feature. This setup enables multiple users to share and interact with common virtual objects while simultaneously tracking the handheld controllers and headset movements of both patient, the clinician, and any required targets without external equipment. Participants used the controller's grip button to grasp objects and move them around, while the experimenters interface included a standard menu which could be controlled via controller touch or ray-cast.

Participants. 8 healthy participants (5 males, all right-handed). The experiment was approved by our university's IRB (#1149/25) and all participants signed their informed consent.

Reported Results Format. The usability survey following each task consisted of quantitative Likert scale questions (1–10, 10 high), Binary (Yes/No) compliance checks, and open-ended subjective questions to capture qualitative feedback on experience, usability, and concerns. All results are reported as mean±SE.

2.1. Scenario 1: Reaching Virtual Objects

In traditional treatment methods, the clinicians are limited in the number of objects they can place, their size, their behavior, and especially where they can place them in space so that they challenge specific movements. Here, the clinician can place virtual targets anywhere in the 3D space of the physical environment (i.e. including midair) and the participant is tasked with reaching them, grasping them by bringing their hand to the object location and using the controller's grip button, and then carrying them to target locations and releasing them there (see Fig. 1 A).

The locations of the clinician, target, and patient's head and hands are tracked continuously by the headsets without external equipment. In this scenario the participant interacts with an experimenter in a shared co-located environment.

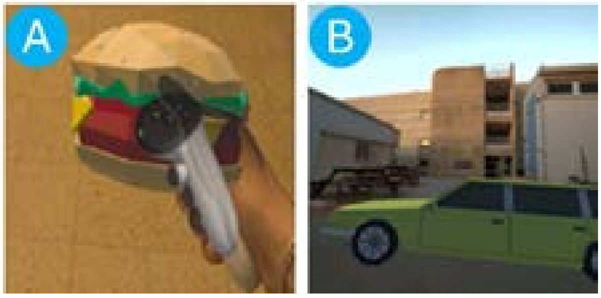

Figure 1: A: Scenario 1 – Reaching task. Patient point of view while performing the reaching task. B: Scenario 2 – Outdoor street crossing task. A patient's point of view of a car crossing the road. The patient needs to wait for the vehicles in their path to pass and when the road is safe, cross safely to the other side.

2.2. Scenario 2: Road Crossing

In traditional real world settings, this task can be dangerous to practice, and practicing in VR with natural locomotion is difficult as it requires a large space and is not naturalistic enough (e.g. stepping off sidewalks). Here, the clinician controls a virtual car placed in a street in front of the participant (Fig. 1 B), and the participant is tasked with crossing the real world street without it colliding with them, which is a safe and naturalistic way to practice it. Here as well, the participant interacts with an experimenter in a shared co-located environment.

2.3. Experimental procedure

Our usability study was aimed at testing if our tool is functional and stable as a proof of concept for this general approach. In addition, our goal was to assess the clarity and intuitiveness of the user interface, the naturalness of the motion of the virtual object, and the overall user experience. Throughout the experiment, the participant performed all tasks co-located with the experimenter. The participants first received an explanation of the experiment and gave their informed consent. Then participants performed three tasks. Each task was followed by a survey to gather feedback on the user experience. Objective overall functionality and participant performance were tracked throughout.

Task 1: Reaching Targets. This task involves a basic interaction scenario where the participant and experimenter are immersed in a shared AR environment through two headsets. First, both donned their headsets and entered into a joint augmented space, but each had different interface options via the asymmetric interface. The experimenter (in the 'clinician' role) then creates a virtual object (a hamburger) and places it in the air within the space (see Fig. 1 A). The participant (in the 'patient' role) is then expected to interact with the virtual hamburger – grab it, move it, place it in the space, and give it back to the experimenter. This task was performed indoors.

After this basic interaction the participants performed scenario 1, in both roles, focusing on interaction with multiple virtual target objects. The experimenter assumes the role of a 'clinician' and creates seven virtual targets and positions them within the space. The participant assumes the role of the 'patient' and is tasked with grabbing each virtual object, one at a time, and placing it into a real basket that is physically present in the environment. Once these steps are completed, the participant and the experimenter switch roles and repeat the process. This task was performed indoors as well.

Task 2: Road Crossing. In this task, the participants perform scenario 2. The experimenter (in the 'clinician' role) remotely controlled the virtual vehicle's movement (as described in Scenario 2). The participant must determine the right time to cross the road while the vehicle is moving and safely cross it ten times. To ensure participant safety and prevent real-world hazards, the task was conducted in a semi-isolated university zone equipped with a physical barrier to block vehicular entry. Testing was restricted to low-activity afternoon hours, and a second experimenter actively monitored the environment throughout the protocol to mitigate any real-world safety risks.

3. Results

All of the participants successfully completed the tasks, reaching all targets and safely avoiding the virtual car, with no adverse effects or nausea being noted. Data was extracted successfully from the controllers and headsets' movements throughout the experiment.

From a technical perspective, participants reported that the tool was easy to operate both in terms of hardware ("How comfortable was the physical equipment to use?"; 8.5 ± 0.6; Likert 1-10, 10 easy) and software ("How comfortable was the software interface to use?"; 9.75 ± 0.25). A strong sense of co-presence was maintained across both environments ("How much did you feel a sense of presence in a shared space with the clinician?"; 9.75 ± 0.25 10 high).

In task 1, participants reported that it was highly intuitive to initialize the collaborative space ("How clear was it to create a new room?"; 9.8 ± 0.1; Likert 1-10, 10 easy), join it ("How clear was it to join a room?"; 9.8 ± 0.1), and instantiate new virtual objects ("How clear was it to create a new virtual object?"; 10 ± 0). Spatially locating targets ("How easy was it to locate the objects in virtual space?"; 9.5 ± 0.2) and manipulating them ("How well were you able to grab and transfer the objects?"; 9.7 ± 0.2) scored consistently high. There were no reports of nausea or dizziness during the first (1.62 ± 0.37; Likert 1-10, 10 uncomfortable) or the second part of this task (2.0 ± 0.53). Open subjective remarks from this task were overall enthusiastic.

In task 2, participants found the simulation elements to be satisfactory, but indicated a deficit in environmental presence ("To what extent did the experience resemble crossing a real road?"; 6.6 ± 0.9), and noted the car design and movement as insufficiently realistic. Moreover, participants had mixed feelings regarding physical deployment ("Did you feel comfortable being outdoors with a headset on?"; 6.2 ± 0.8); some found it exciting and saw great potential, while others felt uneasy, fearing the possibility of tripping, the potential arrival of an actual vehicle, and of "looking weird" to passerbys.

4. Discussion

In this manuscript we described a proof of concept for the use of co-located augmented spaces utilizing standard commercial headsets for tasks which can be used for rehabilitation. Our results supported this approach – the tool which we implemented was intuitive and easy to use in different scenarios both when participants played the roles of clinicians and of patients. However, while this demonstrates the potential of this approach, this is far from a mature system, as evidenced by some of the user comments for scenario 2. Furthermore, the participants were able-bodied, limiting the ability to generalize to patients, and not with clinical background limiting generalizability to clinical staff – the combination of these factors limits the evaluation of the tool to basic usability only as a first step of demonstrating the potential of this approach. The next steps are to further develop this system, and others like it within this approach, and to test them in depth with both clinical staff and patients.

5. Conclusions and future work

We successfully implemented our tool, and then successfully tested its usability, demonstrating that it is both functional and user-friendly and without adverse effects. The tool was well received by participants, who reported ease of use and an overall positive experience and were enthusiastic about its potential for rehabilitation use. Most importantly, participants reported high levels of connectedness to the clinician and to their surroundings. However, the test also highlighted areas for improvement, particularly in the realism of virtual object movements, such as the car in the road crossing scenario. While some participants found the outdoor application of the tool exciting and beneficial, others expressed concerns about comfort, stigma and safety outdoors. This proof of concept demonstrates the potential of this approach for rehabilitation and we aim to now further develop such tools and test them with patients and clinical staff.

Acknowledgements

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Disclosure of Interests

The authors have no competing interests to declare.

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Designing Multiuser VR Rehabilitation Games: Balancing Semi-Structured Play and Clinical Structure for Engagement and Care Support

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Abstract

Virtual reality (VR) can increase motivation and access in stroke rehabilitation, but designers must balance engaging play with clinically meaningful activity. We present En-ACT, a multiuser VR system for Meta Quest headsets combining semi-structured social play, structured assessment-style tasks, and an AI-supported virtual physiotherapy assistant. We report an early Patient and Public Involvement (PPI) evaluation with six health professional lecturers and a consultation with two NHS occupational therapists. Feedback was strongly positive: participants highlighted the motivational benefits of playful shared activities, the clinical relevance of structured tasks such as a virtual Box and Block Test, and the potential of multiuser VR to reduce isolation and support remote care. We argue that future platforms should treat social presence, adaptable game mechanics, and measurable therapeutic tasks as complementary rather than competing goals, with the multiuser layer acting as “social glue”.

1. Introduction

Stroke is a leading cause of long-term disability, and many survivors require sustained upper-limb rehabilitation to recover functional movement [Langhorne et al., 2011]. Conventional therapy can be effective, but access is often constrained by transport, staffing, geography, and the challenge of maintaining motivation across long recovery periods. VR has been widely explored as an adjunct to rehabilitation because it can provide repetitive practice inside motivating environments and support home-based delivery [Soleimani et al., 2024]. Yet a persistent design problem remains: highly gameful systems may improve adherence while offering limited clinical structure, whereas assessment-driven systems can be clinically useful but less engaging over time.

This paper addresses that tension through EnACT (Enhanced Active Therapy), a multiuser VR platform built on three linked ideas: playful activities that make repeated movement feel social and rewarding, structured tasks that resemble established assessments and let progression be observed, and multiuser interaction that may reduce isolation while supporting encouragement, shared attention, and remote supervision [Charles et al., 2020]. It asks how health professionals view semi-structured versus structured VR tasks, what value they place on multiuser interaction, and how such a system fits within rehabilitation practice.

Multiuser and collaborative VR for rehabilitation is an active area: recent systems bring clinician-supervised therapy into stroke survivors' homes [Thielbar et al., 2020] and use collaborative serious games to raise motivation and social interaction [Oliveira et al., 2025]. EnACT's contribution is integrative rather than a single new technique. To our knowledge it is the first platform to combine genuinely multiuser sessions, controller-free hand tracking, both semi-structured play and validated clinical assessment, and a bounded conversational assistant within one standalone system.

2. Enact system

EnACT was developed in Unity (Netcode for GameObjects) for standalone Meta Quest hardware. It supports up to four users in a shared session, typically one clinician and up to three patients, allowing supervised home use or small-group activity. A core decision was to use hand tracking rather than handheld controllers, lowering barriers for users with limited grip strength while making manipulation feel closer to everyday reaching and grasping. The experience spans four spaces: a lobby for orientation and avatar customisation, a living room for social tabletop activities, a physio gym for therapeutic and assessment-style tasks, and a meditation scene for relaxation.

Activities fall into two complementary categories. Semi-structured play foregrounds engagement: in "Rob the Nest", a competitive game, players collect objects from a shared central area into personal containers, encouraging repeated reaching and transfer; other social activities include cooperative tasks, shared drawing with virtual pens, and joint video viewing. These support repetition without making the experience feel overtly clinical.

Structured clinical tasks provide a clearer therapeutic rationale: a virtual Box and Block Test based on the standardised dexterity assessment [Mathiowetz et al., 1985], plus arm range-of-movement and guided grab-and-place exercises with adjustable demands. These support progression, comparability across sessions, and future therapist-facing analytics.

The platform also includes Emma, an AI-supported virtual physiotherapist that explains activities, answers simple rehabilitation questions, and directs users to appropriate exercises. In the prototype it is a conversational guide rather than an autonomous clinical decision-maker, supporting confidence and adherence while keeping the therapist central, in line with emerging conversational agents for stroke rehabilitation that leave clinical decisions to therapists [Retevoi et al., 2024].

3. PPI study

3.1. Method

An initial PPI session was held with six health professional lecturers from Ulster University (physiotherapy, exercise physiology, radiotherapy, and therapeutic radiography). The aim was not to measure patient outcomes but to gather informed feedback on whether the concept, tasks, and interaction model appeared credible and useful from a professional perspective. The session comprised an introduction and tutorial, a demonstration of the AI assistant, a multiplayer VR experience across the environments, and a facilitated group discussion; five participants later completed an online questionnaire.

The questionnaire captured overall impressions of VR for rehabilitation, ratings of the environments, appraisals of individual activities, perceived impact on motivation and home use, and open-ended comments. Given the formative aim and small sample, closed responses were summarised descriptively as counts and percentages (the sample size precluded inferential testing), and discussion notes and open comments were examined thematically to identify recurring topics. This PPI approach was chosen because early stakeholder feedback can shape later design decisions and help identify adoption barriers before larger trials. As an involvement activity rather than a study of human participants, the work did not require formal research ethics approval, consistent with national PPI guidance. A follow-up consultation was conducted in February 2026 with two occupational therapists working in NHS stroke services, who experienced the updated platform and completed a structured feedback questionnaire.

3.2. Findings

Overall responses were strongly positive. Five of six participants rated both VR for rehabilitation and the multiuser approach very positively. The living room was the strongest performer for engagement and perceived effectiveness and the physio gym for appropriateness and therapeutic focus; no environment was rated below the scale midpoint.

Table 1 summarises the main quantitative signals, which support both sides of the design strategy. structured tasks were consistently rated beneficial and usable within rehabilitation plans, while playful, social activities also scored highly for enjoyment, adherence, and confidence.

Measure	**Result**
Overall impression of VR rehabilitation	83% very positive
View that multiuser VR could enhance rehab	83% very positive
Grab-and-place and virtual Box and Block tasks	100% positive on understanding, benefit, and plan use
Rob the Nest game	92% easy to understand, 83% beneficial, 92% usable in plan
Agreement that VR could improve motivation	80% highest agreement
Agreement that patients could benefit from home use	60% highest agreement

Table 1: Selected findings from the PPI evaluation.

The discussion data added nuance. Participants repeatedly described the multiuser element as "social glue" supporting motivation and emotional wellbeing as well as exercise, valued remote shared activity for those isolated between appointments or unable to travel, and welcomed hand tracking for lowering barriers for users who struggle with controllers.

Participants also flagged practical considerations: visual correction, headset comfort, independent donning of hardware, and the need for playful tasks to connect clearly to therapeutic purpose. The occupational therapy consultation reinforced the findings: both therapists rated all activities 5/5 for appropriateness, classified the system as a therapy tool, and called the multiuser capability a "game changer" for supporting multiple patients remotely, also identifying applications in perceptual deficits and cognitive sequencing.

4. Discussion

Across both stages, the findings suggest that semi-structured play and structured clinical tasks are complementary rather than competing design modes. Playful activities create the conditions for sustained engagement, being social, less intimidating, and more likely to make repeated movement feel worthwhile; structured tasks contribute legitimacy, measurability, and alignment with therapist expectations.

Our central proposition is that multiuser VR can act as "social glue" for rehabilitation: connective tissue that links patient to peer (belonging and reduced isolation), patient to clinician (remote supervision and continuity between appointments), and patient to programme (sustained engagement across a long recovery). This extends prior work on gamified rehabilitation and social presence in virtual environments [Sánchez-Gil et al., 2025, Oh et al., 2018]. The benefit may reach the therapy itself, not only the experience of it: multiuser stroke training has yielded longer sessions and greater arm movement than solo practice [Thielbar et al., 2020]. The social and clinical goals are thus mutually reinforcing, the social glue sustaining participation long enough for the structured, measurable tasks to do their work.

The prototype AI assistant was received positively, but its future role should remain carefully bounded: most useful as an interface aid that explains, prompts, and encourages rather than a replacement for clinical judgement.

The initial PPI is limited by its small, non-probability sample and by participants being health professional educators rather than stroke survivors; the occupational therapy consultation partly mitigates this but remains small in scale. Exposure was brief and the findings perceptual, with no behavioural or clinical outcomes measured, so they should be read as early-stage design guidance rather than evidence of efficacy. Deliberately, this is the first stage of a staged, user-centred process: next steps are co-design with stroke survivors, patient-facing feasibility studies, and longer deployments capturing the data the system already records (Box and Block Test levels, arm range of movement, session adherence) alongside therapist dashboards linking in-world activity to progress indicators.

5. Conclusion

EnACT shows how a multiuser VR platform can combine social play, structured therapeutic activity, and lightweight AI support in one coherent experience, an approach that early PPI feedback and the occupational therapy consultation suggest is promising. We argue that the multiuser dimension acts as "social glue" linking patient, peers, and clinician, and that this is what holds engagement and clinical structure together. VR rehabilitation need not force a choice between the two; instead, social, playful interaction can sustain participation while embedding tasks that therapists can interpret, adapt, and trust.

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Developing an Augmented Reality Tool for Walking and Attention Rehabilitation

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Abstract

Walking rehabilitation post-stroke requires complex motor-cognitive integration. While virtual reality shows potential, safety concerns and challenges with environment complexity and naturalness limit its clinical adoption. This study presents a tool attempting to address these barriers by the use of augmented reality, which maintains the user's view of the real world mitigating these issues. We evaluated the tool's usability and found that the system functioned as planned, without failures or discomfort while utilizing the planned advantages of safety and connection to users' surroundings. These results act as a basis for the next step of testing with a clinical population.

Keywords

Augmented Reality (AR), Rehabilitation, Post-stroke rehabilitation, Attention Rehabilitation, Walking rehabilitation, Mobility.

1. Introduction

Resuming walking after a stroke is not just a motor task, but a complex activity that requires a combination of physical control and cognitive processing Rice et al. (2022) as the real world is full of obstacles and tasks. In practice, many stroke patients have particular difficulty in realistic walking situations that combine attention, navigation, and decision making – that is, in walking under conditions that simulate everyday life. Many studies indicate that encouraging walking in real environments contributes to improved physical, functional, and cognitive outcomes Cho et al. (2015), Miller et al. (2021), but in practice many rehabilitation frameworks often emphasize improvements in controlled clinical settings, with limited transfer to real-world walking Bansal et al. (2024). Moreover, cognitive impairments, such as spatial neglect, reduce mobility, safety, and independence, highlighting the complexity of walking rehabilitation Appelros et al. (2002), Plummer et al. (2013). Therefore a key challenge is not just encouraging the movement in and of itself, but restoring the ability to combine the physical and cognitive demands of real environments.

Virtual reality (VR) has been proposed as a promising tool to address these needs, especially in the context of improving patient engagement and creating interactive-yet-controlled training environments Tunc et al. (2024), Notkin et al. (2026). Studies indicate that the use of VR may improve balance, gait, and motor function, as well as contribute to neuroplastic changes and cognitive engagement Tunc et al. (2024), Wei et al. (2025), Thakur et al. (2025), especially when combined with traditional therapy. In addition, VR allows for immediate multisensory feedback, objective performance monitoring, and personalized training, while creating complex scenarios without the need for extensive physical infrastructure Tunc et al. (2024), Hadjipanayi et al. (2024).

However, despite these advantages, VR has significant barriers that limit its clinical application. Immersive virtual environments may impair interaction with the real world Kouijzer et al. (2023), alter gait patterns De Keersmaecker et al. (2023), and limit the ecological validity of training Kouijzer et al. (2023). In addition, there are safety challenges, spatial constraints, and side effects such as cybersickness Kouijzer et al. (2023), which may affect the patient experience and the ability to apply the technology broadly. As a result, despite the potential, clinical adoption of VR remains limited.

Unlike VR, augmented reality (AR) combines the real environment with virtual stimuli Milgram & Kishino (1994), thus preserving the natural context of walking. This combination allows patients to perform real movement while being exposed to controlled cognitive challenges, without disconnecting them from their surroundings. As a result, AR may improve safety, enable continuous interaction with clinical staff thus reducing the feelings of isolation during training, preserve natural walking patterns, and improve the ecological validity of training. These benefits are also accompanied by a reduction in cybersickness symptoms De Cecco et al. (2023), Navas-Medrano et al. (2024).

To utilize this potential, we developed an AR mobility rehabilitation tool for stroke patients, designed to integrate motor and cognitive demands during real-world walking in a way which connects the patients with their environment. The system utilizes gamified virtual obstacles that encourage patients to navigate around and between them, alongside collectibles and penalties elements that guide path selection and promote goal-directed movement. Finally, we tested the system's usability on a group of healthy participants as a preparatory step for testing it with patients which is currently underway.

2. Methods

2.1. Our tool

Our tool is an AR rehabilitation system that encourages interactive patient movement and spatial attention in hospital environments. We developed it in an iterative fashion with feedback from clinical rehabilitation staff. The software was programmed using Unity (with C#) for the Meta Quest 3 headset, which offers full-color-passthrough AR and enables real-time interaction and tracking. When the user activates the tool, their environment is augmented with collectible targets (e.g. floating coins), objects they must avoid (e.g. floating viruses) and obstacles which they must circumvent (e.g. chairs, monitors). These can be flexibly configured by the therapist before each trial. The object's location and spatial distribution are controlled by the clinical staff to challenge the patients to explore their environment, move through it naturally while collecting and avoiding objects, and focus their attention on different spatial areas of it (e.g. for patients challenged by spatial neglect). The tool can be deployed in any environment, utilizing Meta's scene Mesh, and thus is not locked to a specific hospital or ward. A dedicated Head Up Display (HUD) is implemented to inform the participants of their score in real time (see Fig. 1).

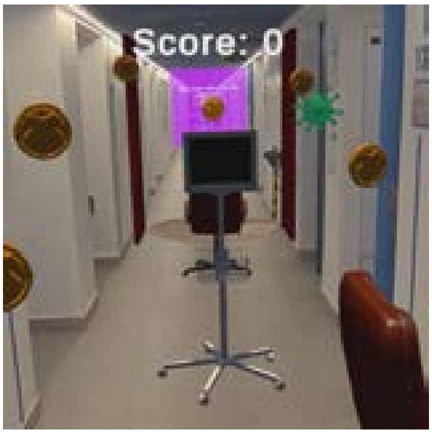

Figure 1: Patient's point of view with the AR content such as coins, viruses, medical monitor, and office chairs using the Meta Quest 3 passthrough.

2.2. Experimental procedure

To assess the technical stability, user experience, and interface clarity of our system before clinical deployment, we conducted a usability study involving 7 healthy participants. The experiment was approved by our university's IRB (Approval No. 1149/25) and all participants signed their informed consent.

The participants first received an explanation of the experiment and gave their informed consent. Each participant performed 3 trials. The experimental environment was a corridor that is 10 meters long and 1.4 meters wide, with virtual elements: 8 collectible coins, 2 penalty viruses and 4 obstacles. The participant dons the headset, and is guided to walk in the corridor back and forth. While walking, the participant is tasked with collecting coins, while avoiding obstacles (e.g., chairs, monitors) and viruses. These objects can be collected by reaching them physically with the controllers or HMD. Objective overall functionality and participant performance were tracked throughout. After completing the task, participants answered a survey consisting of 1–7 Likert scales (with 7 being high) to gather feedback on their experience. Responses were analyzed using a one-tailed Wilcoxon signed-rank test, and all statistical results are reported as mean ± SE.

3. Results

We developed an AR system for motor and cognitive rehabilitation. We activated the system successfully both in lab and clinical settings.

In our usability study, all participants successfully completed three full trials without any technical issues. All customizable features functioned as intended, including trial configuration, stage transitions, dynamic object regeneration, user location and activity logging and live scoreboard tracking. Survey feedback indicated high ease of use (6.7 ± 0.49; $p < 0.01$, effect size $r = .91$ and no symptoms of motion sickness symptoms or discomfort (1 ± 0; 100% consensus), measured on a 1–7 scale (1 = not at all, 7 = very much). Movement trajectory and interaction data indicates active user engagement with collectibles and obstacles throughout the task (see Fig. 2).

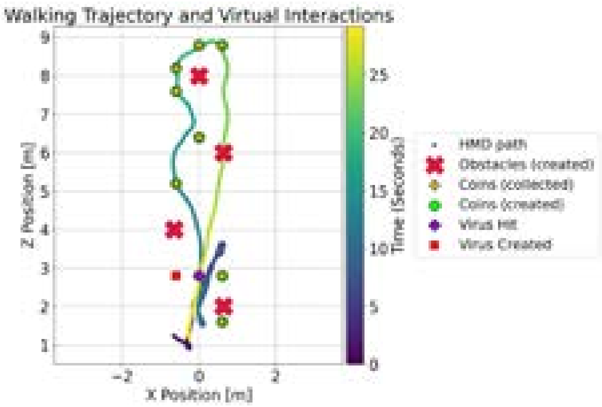

Figure 2: Walking trajectory and virtual object interactions during one trial. HMD position over time, with color indicating elapsed time. Symbols mark virtual elements: red crosses for obstacles, yellow-plusses represent coins that were collected, green circles indicate coins that were created, red squares for created viruses, and purple diamonds for virus collisions.

4. Discussion

The study findings indicate that our AR system is technically and positively received by users. The high level of usability and the absence of discomfort or motion sickness are particularly important in the context of rehabilitation applications, where patient acceptance and cooperation are a prerequisite for the success of the intervention.

The system allows for easy deployment in existing clinical environments, such as corridors of the rehabilitation wards in hospitals, without the need for physical modifications or additional dedicated equipment. This advantage with the possibility to integrate the system into daily rehabilitation routines, supports widespread clinical application.

The use of AR allows users to remain connected to the physical environment, thus potentially improving safety during walking sessions. With the combination of interactivity, real-time feedback, and game elements may increase user engagement, as also found in previous studies in the field.

The system's ability to record events such as collisions, item collection, and spatial navigation with time and location stamps opens up the potential for objective and detailed assessment of user performance, which could be used in the future to develop new digital biomarkers for assessing motor and cognitive function.

However the main limitation of our work is that it is clearly just the first step – our tool must now be tested with patients and must undergo feasibility and clinical efficacy studies, steps which we are now undertaking.

5. Conclusions

This project developed an AR rehabilitation tool for motor and cognitive rehabilitation within real-world hospital environments and evaluated its usability. The findings indicate successful usability and set the stage for the next phases of this project, with emphasis on deploying it with patients and integrating the system into routine workflow with clinicians.

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Disclosure of Interests

The authors declare that they have no competing interests.

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Virtual reality-based and conventional cognitive interventions in community-dwelling older adults: The moderating role of cognitive reserve

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Abstract

This study evaluated the efficacy of three community-based interventions for older adults: virtual reality cognitive stimulation, traditional cognitive stimulation and socioemotional competence training, while examining the moderating role of cognitive reserve (CR). The sample included 65 older adults attending a community facility who completed baseline and post-intervention neuropsychological assessments following a three-month intervention program. Linear mixed model analyses, which included baseline age as a covariate to account for group differences, revealed that individuals with lower and average CR improved across all interventions, whereas individuals with higher cognitive reserve showed greater gains in the virtual reality and traditional groups. These findings highlight the importance of personalized intervention approaches tailored to individual CR profiles.

1. Introduction

Population ageing represents a major public health challenge, particularly in Portugal, one of the oldest countries in the European Union, where more than 2.5 million individuals are aged over 65 years (Fundação Francisco Manuel dos Santos, 2024). A substantial proportion of older adults live alone, increasing vulnerability to loneliness and social isolation, factors consistently associated with cognitive decline and reduced cognitive functioning in later life. In this context, identifying effective community-based interventions to support healthy cognitive ageing has become increasingly important.

Cognitive reserve (CR), defined as the capacity to maintain cognitive functioning despite age-related or pathological brain changes, has been proposed as an important moderator of cognitive ageing and intervention responsiveness. Factors such as educational attainment, occupational complexity, and engagement in cognitively stimulating activities contribute to CR and may influence cognitive outcomes following intervention (Mondini et al., 2016). Among emerging intervention approaches, virtual reality (VR)-based cognitive stimulation has gained increasing attention due to its ability to provide immersive, engaging, and ecologically valid experiences that may enhance motivation and adherence compared with traditional interventions (Gamito et al., 2020). However, evidence regarding the effectiveness of VR interventions in community-based settings remains limited. In parallel, socioemotional interventions targeting emotional regulation and social interaction may also indirectly support cognitive functioning (Wei et al., 2024), although their comparative efficacy remains unclear.

The present study aimed to evaluate the efficacy of three community-based interventions implemented in a community facility for older adults: a VR-based cognitive stimulation program (VR-CS), a traditional paper-and-pencil cognitive stimulation program (PP-CS), and a socioemotional competence training program (SECT). Additionally, the study examined whether baseline cognitive reserve, assessed using the Cognitive Reserve Questionnaire (CRQ), was associated with differential cognitive outcomes following intervention.

2. Methods

2.1. Participants

The sample consisted of 65 participants enrolled in a community multidomain program. Most of the sample were women (57 female). The sample was predominantly Portuguese (95.5%), with a mean age of 75 years-old (SD = 5.20). Most participants (15%) had 4 years of schooling corresponding to complete 1st Cycle of studies, while 13.5% had 9 years of schooling corresponding to the 3rd Cycle of studies. Two participants were excluded because of prior neurological diagnoses. Group sizes were unequal, with the paper-and-pencil group (PP-CS; n = 33) being significantly larger than both the virtual reality (VR-CS; n = 18) and socioemotional groups (SECT; n = 14). No statistically significant differences in schooling were found across groups ($p > .05$). A statistically significant difference was found for age ($p = .021$), indicating that participants in the VR-CS group were younger than participants in the PP-CS group. Mean ages by group were as follows: VR-CS (M = 72.1, SD = 4.83), PP-CS (M = 76.6, SD = 5.01), and SECT (M = 75.4, SD = 5.32). To account for this baseline imbalance, age was entered as a covariate in the subsequent linear mixed model analyses.

2.2. Measures

- Addenbrooke's Cognitive Examination – ACE-III (Peixoto et al., 2013)
- Subjective Memory Complaints Questionnaire – SMC (Ginó et al., 2010)
- Instrumental Activities of Daily Living – IADL (Araújo et al., 2008)
- Geriatric Depression Scale – GDS-15 (Barreto et al., 2003)
- Satisfaction With Life Scale – SWLS (Diener et al., 1985)
- Cognitive Reserve Questionnaire – CRQ (Rami et al., 2011; Sobral et al., 2014)

2.3. Procedures

After approval from the institutional ethics committee and informed consent, participants completed a baseline neuropsychological assessment and were subsequently allocated to one of three intervention groups. All interventions were conducted twice weekly in about one-hour sessions over a three-month period, with equivalent frequency and duration across conditions. The VR-CS group used the Systemic Lisbon Battery (Gamito et al., 2020) in a non-immersive desktop-based setup to train cognitive functions through ecologically valid tasks, while the PP-CS group completed traditional cognitive stimulation exercises targeting domains such as attention, memory, language, and executive functioning. The SECT group participated in group-based activities focused on emotional regulation, communication, self-awareness, and problem-solving. Sessions were conducted by trained psychologists, and participants completed a post-intervention neuropsychological assessment using the same measures applied at baseline. Figure 1 describes the procedure in this study.

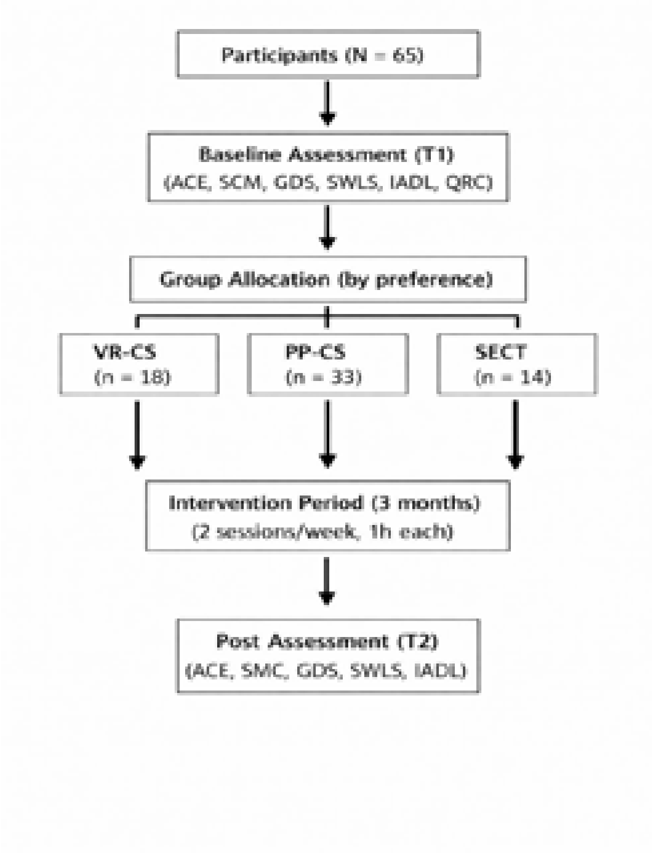

Figure 1: Procedure followed in this study.

3. Results

Linear mixed model analyses, controlling for baseline age, revealed a significant overall improvement in global cognitive functioning (ACE) from pre- to post-intervention ($F(1, 67) = 28.21$, $\eta p^2 = .30$, $p < .001$). No significant main effects of Group ($F(2, 67) = 1.39$, $\eta p^2 = .04$, $p = .256$) was observed. The main effect of cognitive reserve approached significance ($F(1, 67) = 3.87$, $\eta p^2 = .05$, $p = .053$), indicating differences better cognitive performance among participants with higher cognitive reserve. Importantly, a significant TimePoint × Group × CRQ interaction emerged ($F(2, 67) = 5.71$, $\eta p^2 = .15$, $p = .005$), showing that cognitive reserve moderated intervention outcomes. Participants with lower and average CR improved across all interventions, whereas individuals with higher CR showed attenuated gains in the socioemotional competence training group (SECT), while improvements remained significant in the VR-CS and PP-CS groups.

For subjective memory complaints, higher CR was associated with fewer complaints overall ($F(1, 67) = 4.27$, $\eta p^2 = .06$, $p = .043$). A significant TimePoint × Group interaction was also observed ($F(2, 67) = 5.14$, $\eta p^2 = .13$, $p = .008$). Post hoc analyses indicated that the SECT group showed a significant increase in subjective memory complaints following the intervention ($p = .012$), whereas no significant changes were found in the VR-CS or PP-CS groups ($p = .244$). No significant effects were observed for depressive symptoms, life satisfaction, or their interactions with cognitive reserve and intervention group (all *p*'s > .05). Inferential analyses were not conducted for IADL scores due to limited variability in the data.

4. Conclusion

This study examined the effects of three community-based interventions for older adults: VR-based cognitive stimulation (VR-CS), traditional paper-and-pencil cognitive stimulation (PP-CS), and socioemotional competence training (SECT), with a particular focus on the moderating role of cognitive reserve (CR). Overall, participants demonstrated improvements in global cognitive functioning following intervention, although the magnitude of these gains varied according to intervention type and baseline CR. Individuals with lower and average CR benefited across all intervention modalities, whereas participants with higher CR showed greater responsiveness to the cognitively demanding VR-CS and PP-CS interventions. In contrast, socioemotional competence training appeared to provide indirect cognitive benefits particularly for individuals with lower CR, potentially through mechanisms related to emotional regulation, self-efficacy, and social engagement. The increase in subjective memory complaints observed in the SECT group may reflect enhanced metacognitive awareness rather than actual cognitive decline. These findings highlight the importance of personalized and multidimensional intervention approaches tailored to individual cognitive reserve profiles. However, the results should be interpreted cautiously due to the non-randomized preference-based allocation design, the unequal group sizes, and the baseline age differences between groups, which, despite statistical adjustment, may still constrain causal interpretation, emphasizing the need for future randomized controlled studies with larger samples.

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03

PHYSICAL & ORTHOPEDIC REHAB

Embodying the Phantom: A Low-Cost, Inclusive VR Mirror Therapy Driven by 2-Point Tracking

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Abstract

This paper presents a two-point torso prediction system designed for use in virtual reality (VR) mirror therapy apps for individuals living with phantom limb pain (PLP) following an upper-limb amputation. PLP affects up to 80% of individuals with limb loss, significantly impacting their quality of life and contributing to depression and anxiety. While traditional mirror therapy can be effective in treating pain, modern VR apps offer greater flexibility and customization. However, many existing VR interventions rely on expensive external sensors and complex hardware setups, creating societal and economic barriers that limit widespread and at-home accessibility. To address this, we developed a system that estimates torso orientation using a two-point tracking system (the head and one hand), utilizing only consumer VR devices. Operating at the engine level without relying on external sensors or custom simultaneous localization and mapping (SLAM) datasets, this hardware-agnostic, six degrees of freedom solution facilitates accessible room-scale VR development. This paper outlines the technical design of the system and introduces the upcoming usability trial designed to test its viability as an accessible, inclusive, and low-cost intervention.

1. Introduction

Phantom limb pain (PLP) is the experience of pain in a part of a limb that has been amputated, frequently persisting for years and significantly reducing a person's quality of life (Polat et al., 2021). Mirror therapy is a common treatment approach, using a mirror to reflect the intact limb to generate the visual illusion that the missing limb is present, thereby alleviating pain (Campo-Prieto & Rodríguez-Fuentes, 2022). Recently, virtual reality (VR) technology has been applied to simulate this illusion, supporting advanced customization and an immersive environment.

Despite the potential of VR, current interventions often present significant accessibility, societal and financial barriers. A review of recent VR PLP treatments (Farsi et al., 2025) highlights that the vast majority rely heavily on external electromyography (EMG) or optical sensors to control the virtual limb. The complexity and high cost of these sensor-dependent interventions limit their versatility for regular, inclusive, or at-home use.

This document describes a lightweight mirror-therapy VR tool (MTVR) designed to overcome these technological and accessibility barriers. The MTVR system utilizes the built-in capabilities of modern consumer Android-based VR devices, supporting full room-scale tracking without external trackers or custom simultaneous localization and mapping (SLAM) pipelines. By relying exclusively on a novel 2-point torso prediction system, this app allows patients to navigate and interact with their virtual environment freely, maintaining accurate representation of the phantom limb.

The design of this intervention is heavily influenced by research on homuncular flexibility and virtual embodiment (de Vignemont, 2017). Visuo-motor synchronicity is a critical influence on body ownership and agency in VR (Mottelson et al., 2023). By maintaining strict temporal synchronicity (the avatar moves in sync with the user) and mechanical consistency (each motion has a consistent, proportional, and reliable outcome), the system promotes a greater level of virtual embodiment and proprioceptive drift between the affected limb and the mirrored virtual limb (Steptoe et al., 2013, Ichinose et al., 2017). Crucially, doing so within a lightweight hardware footprint democratizes access to this therapy, removing the financial and spatial barriers typical of clinical-grade motion capture systems. This system is currently being prepared for an initial usability trial, paving the way for a future clinical study.

2. System design for inclusion and accessibility

2.1. Avatar, Environment, and Customization

To promote inclusion and self-location, MTVR features a highly customizable humanoid torso and arms. The legs of a traditional humanoid avatar have intentionally been omitted due to the inability of common consumer VR devices like the Meta Quest 2, 3, 3s, or Pico 4 Ultra to track leg movements without the use of peripheral tracking devices. Acknowledging the diverse backgrounds of patients, the avatar's skin tone and limb size can be personalized via an in-app slider (*figure 1, A*) and automatic calibration process. The experience takes place in a familiar, well-lit living room environment featuring interactable objects to promote user presence and agency and includes a television (which is used as a grounded method of administering instructions to the user) (*Figure 1, B*).

Figure 1: **A)** *The skin-tone customization slider and dominant hand selection tool for MTVR.* **B)** *MTVR environment, uses warm lighting and home-like features to feel familiar and comfortable to users.*

2.2. Mirroring and the Virtual Limb

Following calibration, the user is prompted to select their dominant hand by placing it within a glowing marker in the virtual space. The amputated limb in VR then mirrors the motion of the dominant limb using the forward direction of the avatar's torso as an axis of symmetry. Relying on the hand and finger tracking native to consumer VR devices, the mirrored limb reflects all 6 degrees of movement and individual finger bone rotation, allowing users to freely interact with objects using either limb.

2.3. Two-Point Torso Prediction

2.3.1. Tracked Variables

The two-point torso prediction system relies on six factors: the position of the users' head mounted display (HMD), the orientation of the HMD, the change in orientation of the HMD over time (0.5 seconds to reduce jitter), as well as the position of the users' dominant hand relative to the HMD measured in degrees (or the orbit of the hand), the orientation of the dominant hand, and the orbit of the hand over time (also 0.5 seconds). These six values are taken from three-dimensional space and projected onto the horizontal plane (the X and Z axes), as this is the plane of translation and rotation which influences the axis of symmetry of the mirrored limb.

2.3.2. Rotation and Translation Gates

As the position of the mirrored limb depends on the axis of symmetry bound to the users' torso, it cannot be allowed to move and adjust continuously as this would result in the unintended motion of the mirrored limb, breaking the rule of visuo-motor synchronicity. Instead, a minimum threshold is applied to both the translation and rotation of the HMD as these are found to be the strongest indicators of a users' intentional body movement. After some experimentation, those thresholds are set at 15° for rotation, and 5 cm for translation relative to an anchor point whose position and rotation are updated to the new position and orientation of the HMD each time these thresholds are passed. These values have shown to be small enough to offer a sensation of continuous movement for the user (maintaining visuo-motor synchronicity) while filtering out the noise of smaller movements and preventing the need to recalculate the transform of the torso every frame.

2.3.3. Torso Translation

The position of the torso is dependent only on the position of the HMD along the horizontal plane. In the event that the distance between the torso and the HMD on the horizontal plane (d) is greater than the translation threshold, the torso is set to follow the position of the HMD at a velocity of $3d$ m/s. This creates a smooth motion where the torso accelerates and smoothly slows to a stop based on d. Once the threshold is surpassed, the tracking of the HMD's position on the horizontal plane is continuous until d is 0.

2.3.4. Torso Rotation

Torso rotation prediction relies on a series of checks to determine whether there is intentional torso rotation or simply active head motion. First, a check is made as to whether the HMD is rotating and the dominant hand is orbiting meaningfully (at a rate above 15°/second for both) in the same direction. Should both tracking points be rotating in a relatively synchronous manner, it is a strong indication of intentional rotation. Second, as the rotation of the HMD passes the threshold, it is first determined whether the static hand position is within 30° of the forward direction of the HMD. If this arm threshold is surpassed, a calculation is made to determine whether the angular gap (difference in degrees between the orbit of the dominant hand in orientation of the HMD) is growing or shrinking. If the angular gap is greater than 30° and is currently shrinking at the time that the 15° base rotational threshold is passed, intentional torso rotation is detected. There is a third and final condition in which the HMD is not meaningfully rotating. This third condition is effectively the inverse of the second condition: first, the HMD must be greater than 15° from the current anchor orientation with a 30° angular gap to the orbit of the dominant hand. If these conditions are met, and the hand is shown to be orbiting towards the current forward direction of the HMD, it is taken to imply the intentional torso rotation towards the look direction of the headset. When intentional torso rotation is detected, the torso begins rotating smoothly in the forward direction of the HMD following the same principles outlined in section 3.3.3, wherein the speed of rotation is determined by the angle gap between the torso and HMD on the horizontal plane and torso rotation is continuous once triggered until that gap reaches 0°.

3. Integration into clinical care: Upcoming usability trial

To evaluate the therapeutic impact and accessibility of this system, MTVR is currently being deployed in a usability study at Sunnybrook Health Sciences Centre's St. John's Rehab program in Toronto, Canada. The study aims to recruit individuals with upper-limb amputations. Participants will utilize a Meta Quest 3 Head-Mounted Display integrated with the *caregiVR* platform (*caregiVR Inc., 2026*) to engage in a 30-minute session of guided standardized virtual arm exercises. To ensure the system is genuinely inclusive and user-friendly, the study will capture extensive usability and physiological metrics, including:

- **System Usability Scale (SUS):** To capture subjective perceptions of the system's ease of use and accessibility.
- **Prosthesis Embodiment Scale:** To evaluate feelings of ownership, agency, and the anatomical plausibility of the virtual mirrored arm.
- **Fast Motion Sickness Scale:** To continuously monitor for VR-induced sickness, ensuring the 2-point tracking system does not introduce disorienting latency or jitter.
- **Changes in PLP and Telescoping:** Evaluated pre- and post-session using a Numerical Rating Scale and an online app (https://demo.phantomlimbs.ca/).

Feedback from users with limb loss, as well as experts in rehabilitation, will directly inform iterative design improvements. The goal of this phase is to establish proof-of-concept for an accessible, low-cost VR program that can be widely distributed for at-home PLP treatment, paving the way for a clinical trial. Although pain relief outcomes have not yet been empirically established, the system shows promise for improving engagement and accessibility in rehabilitation through immersive, gamified experiences, potentially enhancing adherence for individuals with post-amputation pain.

4. Implications & applications

Future work will focus on continuing to refine the system outlined above to handle fringe conditions and a dynamic weighting system for the tracked variables. This app is currently being developed as part of an ongoing trial which will assess the usability and therapeutic impact of the intervention to influence future design decisions.

However, beyond clinical rehabilitation, this 2-point torso prediction algorithm presents significant opportunities for addressing physical diversity in general consumer VR. Traditional room-scale VR apps inherently design for three-point tracking (a headset and two hands), creating a systemic barrier that excludes individuals with upper-limb loss from fully participating in standard VR experiences. Because this novel system is computationally light and designed for the OpenXR standard, it can be easily implemented into most VR apps. By successfully providing a dynamic axis of symmetry using only the head and one hand, this hardware-agnostic tool offers new accessibility solutions for broader VR app design. Future applications of this algorithm could allow commercial developers to create inclusive virtual environments and games where users with unilateral mobility differences can stand, walk, and interact with the same agency and visuo-motor synchronicity as two-handed users.

5. Limitations

Prioritizing accessibility through two-point tracking on standalone consumer hardware (e.g., Meta Quest series, Pico 4 Ultra) sacrifices the exact spatial accuracy of clinical-grade motion capture and omits lower-body representation. Technically, the algorithm's static translation and rotation thresholds require refinement to incorporate dynamic parameter weighting. Finally, the system requires validation with the target population. Our ongoing trial will evaluate its real-world performance, assess its therapeutic impact on phantom limb pain, and ensure the tracking method avoids inducing VR-related motion sickness.

6. Conclusion

While clinical-grade VR therapies offer high accuracy, their reliance on complex hardware creates systemic barriers to access for the average patient. MTVR demonstrates that computationally light, hardware-agnostic solutions, like the 2-point torso prediction system, can offer comparable visuo-motor synchronicity and mechanical consistency on cheap, consumer-grade devices. By prioritizing inclusivity through customizable avatars and removing the need for external sensors, this system presents a scalable model for making advanced VR rehabilitation accessible to broader populations living with disabilities. We would like to acknowledge that the project was generously funded by The War Amps, an organization serving all Canadian amputees, including children.

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Move, Enjoy, Interact: Virtual reality dancing for youth with motor limitations

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Abstract

Enjoyment, physical engagement, and social interaction are the experiences most valued by youth with motor limitations in dance contexts. Building on this framework, the present study examines whether immersive virtual reality (VR) dance can provide these core qualities. During a one-week camp, youth with motor limitations participated in immersive VR dance sessions. Through qualitative and quantitative measures, we investigated whether three dimensions central to dance practice (moving, enjoying, and interacting) were meaningfully experienced in VR. Results were broadly positive, suggesting immersive VR dance holds promise as a complement to dance practice for youth with motor limitations.

1. Introduction

Dance offers a unique combination of physical, cognitive, and psychosocial benefits for youth with motor limitations, making it valuable in rehabilitation contexts (May et al., 2021). It also integrates qualities that are especially meaningful: moving (being physically active and engaged in one's body), enjoying (having fun), and interacting (sharing meaningful experiences with others). These dimensions were identified as central to youth engagement in dance through a participatory study involving youth, families, and practitioners (Poncet et al., 2025), and can serve as a framework for what adapted dance practice should prioritize. Despite the well-recognized benefits of dance for youth with motor limitations, access to dance remains limited for many youth with motor limitations due to physical, environmental, and social barriers (McKenzie et al., 2021). As a result, opportunities to experience the full benefits of dance are often restricted.

Social immersive virtual reality (VR) has emerged as a promising tool to address some of these barriers (Phelan et al., 2023). By creating shared, embodied virtual environments, VR enables users to participate in activities that may be difficult to access physically. The feasibility of VR dance with youth with motor limitations has already been demonstrated (Houzangbe et al., submitted), yet it remains unclear whether VR dance can deliver the core experiential qualities that matter most to youth and practitioners (Poncet et al., 2025). The present study examines whether immersive VR dance can support enjoyment, movement, and meaningful social interaction during a one-week dance camp. Guided by the framework proposed by Poncet et al. (2025), we evaluate VR not as a technology in itself, but in terms of its capacity to foster what youth and practitioners identify as most important in dance. This is the first study to move beyond basic feasibility by empirically evaluating a VR intervention against these user-centered priorities to optimize engagement.

2. Methodology

2.1. Research Design

Using a convergent parallel mixed method design, this study combined quantitative and qualitative data to assess whether VR dance met the core dimensions valued in dance for youth with motor limitations: enjoyment, movement, and interaction (Poncet et al., 2025). This mixed approach allowed us to capture rich, meaningful insights from the participants' lived experiences.

2.2. Participants

To prioritize safety znd operational practicality during VR dance practice, we intentionally limited recruitment to a convenience sample of ten adolescents with motor limitations (mean age = 13.3 years, SD = 2.3; 6 females, 4 males), including four manual wheelchair users. Inclusion criteria required participants to be aged 11 to 18, have a confirmed motor limitation diagnosis and be able to follow instructions. Those with severe intellectual disability, epilepsy, stereoscopic vision disorders, severe balance disorders (except wheelchair users), or planned botulinum toxin injections during the camp week were excluded. Two female dance instructors participated to offer a professional perspective. Both had experience teaching dance to youth with disabilities, one as a school instructor and the other as a physiotherapist trained in adapted dance. One had prior VR experience; the other did not. Before the camp, both received a best practice guide and completed a two-hour VR familiarization session led by the research team. Written informed consent was obtained from all participants or their legal guardians, assent from participating youth, and the study was approved by the CHU Sainte-Justine research ethics board.

2.3. Intervention

The one-week camp included both in-person and VR dance sessions; this paper focuses exclusively on the latter. VR sessions were conducted on VRChat using Meta Quest 3 headsets, consistent with our prior study (Houzangbe et al., submitted). Participants chose their virtual environment and avatars, fostering a sense of agency and ownership. The youth were divided into two groups of five that worked together throughout the week, alternating between group activities and whole-class sessions. VR experiences occurred exclusively in these group settings. Two environments were selected (outer space and an underwater setting), with each group selecting its preferred environment. Each session lasted approximately 45 minutes and was held three times throughout the week, in a dedicated room where each participant had a 4×4 m area to move freely. One dance instructor and one researcher were fully immersed in the virtual environment alongside participants, while an additional team member remained in the physical room to ensure safety and spatial boundaries.

2.4. Quantitative Data

Primary measure. To assess whether VR dance sessions met their three intended objectives, participants completed a brief satisfaction survey after each session. Using an age-appropriate, anonymous pictorial scale with three response options (satisfied, neutral, dissatisfied) designed to minimize cognitive load and prevent choice fatigue (Mellor and Moore, 2014), a satisfaction rate was calculated for each objective per session by assigning scores of 2, 1, and 0 respectively.
Secondary measures. Given that suitability and usability could influence all three objectives, both were evaluated alongside primary outcomes. Participants rated VR appropriateness using the Suitability Evaluation Questionnaire (SEQ; Gil-Gómez et al., 2013), a 14-item tool covering enjoyment, level of immersion, and cybersickness (score out of 65), administered after the first and third VR sessions. Instructors evaluated system usability with the French version of the System

Usability Scale (SUS; Gronier & Baudet, 2021), a validated 10-item measure on a five-point Likert scale (0 to 100), completed after their first VR dance session and at the end of the camp.

2.5. Qualitative Data

All 10 participants took part in the focus groups, with six sessions held in total (three per group, approximately 15 minutes each) were led by a research team member at the end of each camp day to document perceptions, satisfaction, and perceived facilitators and barriers to VR dance participation. Data were audio-recorded, fully transcribed, and anonymized for analysis. Both dance instructors also maintained a daily logbook, completed before sessions, during lunch breaks, and at the end of each day, to document program content, adaptations, and perceived facilitators and barriers.

2.6. Data Analysis

Quantitative data were analyzed using descriptive statistics and one-sample Wilcoxon signed-rank tests to assess whether the primary measures were significantly positive, with an expected median of 50%. The threshold for statistical significance was set at $p < 0.05$. Qualitative data were thematically analyzed using LibreQDA software by three members of the research team. Following the convergent design framework (Creswell & Plano Clark, 2018), quantitative and qualitative data were analyzed separately. Finally, both datasets were integrated during interpretation using a confirm-contradict-expand framework.

3. Results

3.1 Moving

Quantitative results: Participants reported significantly satisfying levels of movement in the second and third VR sessions ($p_{2,3} = .014$), while the first session was not deemed sufficiently physically engaging ($p_1 = .102$). Overall ratings were high, with no significant differences observed between sessions (see Fig. 1). Qualitative results: VR activities supported motor engagement, though movement varied by individual ability and context. Instructors documented physical engagement in their logbooks, including spontaneous transitions to standing among some participants who had been seated during the session: "Participant 406 is in a wheelchair and then stands up" (Dance instructors). Notably, this participant was ambulatory and had chosen to sit in a wheelchair to rest, yet chose to rise and engage more fully in the VR activity. Participants also self-reported feeling active: "we moved more in there" (Participant 403). However, movement in VR was perceived as qualitatively different from in-person dance: "the way we move there... it's not the same" (Participant 406), and motor participation was at times limited by fatigue, wheelchair constraints, and familiarity barriers such as joystick handling.

3.2 Enjoying

Quantitative results: Participants reported significantly high enjoyment across all three VR sessions ($p_1 = .002$, $p_2 = .003$, $p_3 = .005$), with no significant differences between them (see Fig. 1). *Qualitative results*: Sessions were broadly perceived as enjoyable, with positive appreciation expressed consistently across focus groups: "I loved VR" (Participant 403). Immersion, visual environments, avatars, and creative opportunities were identified as key contributors, and instructors noted sustained engagement throughout. Enjoyment was nonetheless reduced for some participants by technical difficulties (low sound, uneven avatar sizing, drained batteries) and disorientation: "Participant 406 did not want to continue and mentioned that the environment was somewhat frightening" (Dance instructor).

3.3 Interacting

Quantitative results: Participants rated the level of interaction across all VR sessions as significantly positive ($p_1 = .008$, $p_2 = .008$, $p_3 = .002$), with no significant differences observed between sessions (see Fig.1). *Qualitative results*: Social interaction was a salient feature of the VR experience, taking primarily playful and spontaneous forms facilitated by avatar embodiment: "I love it when my hand goes through her head... it's really funny" (Participant 409). These exchanges elicited enjoyment and amusement, but also occasional frustration: "she won't leave me alone!" (Participant 405). Instructors independently observed similar patterns of spontaneous interaction across sessions.

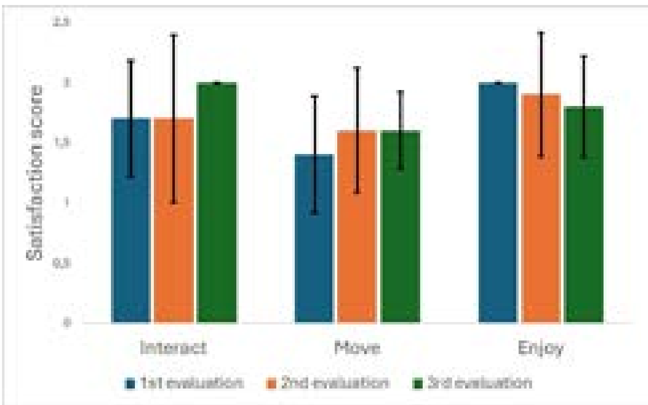

Figure 1: Satisfaction scores for the Interacting, Moving and Enjoying objectives across the three evaluation sessions. Error bars represent standard deviations.

3.4 Secondary measures

SEQ scores indicated high perceived suitability across both sessions ($M_1 = 56.3/65$, $SD_1 = 6.38$; $M_2 = 57/65$, $SD_2 = 6.02$), with a small, non-significant increase over time. Instructor-reported usability was similarly high, with both instructors showing a slight, non-significant, improvement between sessions (Instructor 1: $SUS_1 = 77.5$, $SUS_2 = 80$; Instructor 2: $SUS_1 = 62.5$, $SUS_2 = 75$).

4.Discussion and conclusion

Using a convergent parallel design, this study examined whether immersive VR dance could support the three qualities most valued in dance (moving, enjoying, and interacting) as identified by Poncet et al. (2025), among youth with motor limitations. Quantitative results were largely positive across all three dimensions, while qualitative findings expanded upon or confirmed these data by providing essential contextual information. Movement scores reached significance only from the second session onward, likely reflecting a familiarization effect. These high scores were corroborated by qualitative evidence of physical engagement. However, differences between VR and real-life movements, fatigue and technical difficulties negatively impacted the experience. This suggests that initial familiarity with the technology is necessary for participants to move as intended. Enjoyment was the most consistently positive dimension, driven by immersion, avatar embodiment, and creative engagement, though technical difficulties and occasional disorientation tempered the experience for some participants. While the quantitative data were overwhelmingly positive, qualitative insights provided nuance, revealing that the high degree of immersion was potentially overwhelming for certain participants. Consequently, careful selection of virtual environments and situations is essential to optimize experiences for youth. Quantitative results regarding interaction were also consistently positive, and were confirmed by qualitative findings, which demonstrated that avatar-mediated exchanges fostered spontaneous peer contact. As a minor caveat, some interactions caused frustration, specifically the inability to reject certain interactions or limit intrusions into one's personal space. These interaction features can be disabled within the software settings and should be tailored to participant preferences. Secondary measures further supported these findings, with high SEQ and SUS scores. Taken together, these results suggest that immersive VR dance can meaningfully deliver the experiential qualities that youth and practitioners identify as central to dance practice. Rather than positioning VR as a replacement for in-person dance, these findings support its potential as a viable complement, particularly for youth who face physical, environmental, or social barriers to participation.

Some limitations should be noted. First, the study relied on self-reported measures, an effect we sought to mitigate by using a simplified three-level response scale for our primary objectives. Second, the relatively small sample size limits the generalizability of the findings; however, this constraint was necessary to ensure participant safety and maintain intervention quality. Finally, as an exploratory study, unforeseen technical difficulties altered the experience for some participants, which will be addressed in future iterations. Future work will examine home-based immersive VR dance, inviting children to join shared virtual sessions from their own homes, to test whether enjoyment, physical engagement, and social connection can be sustained without physical co-presence, thereby broadening access for youth with motor limitations.

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Improving functional rehabilitation through virtual reality-based physiotherapy: A systematic review and meta-analysis

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Abstract

Virtual reality technologies have been integrated into physiotherapy and neurorehabilitation programs in order to improve patient engagement, motor learning, and functional recovery. The aim of this study is to evaluate the effectiveness of VR-based physiotherapy interventions in improving functional rehabilitation outcomes in persons with neurological and physical impairments. A systematic review and meta-analysis will be conducted following PRISMA guidelines. Major databases including PubMed, Scopus, and Web of Science will be searched to identify randomized controlled trials and clinical studies evaluating VR-assisted physiotherapy interventions. Outcomes related to motor performance, balance, gait, and functional independence will be analysed. The results are expected to provide evidence about the clinical effectiveness of immersive technologies in physiotherapy and their potential role in modern rehabilitation practice.

1. Introduction

Technological innovation has transformed rehabilitation practices in recent decades (Chua & Kuah, 2017). Among emerging technologies, virtual reality has gained attention as a therapeutic tool that is capable of improving motor recovery, cognitive engagement, and functional outcomes in persons with neurological and musculoskeletal disorders (Kamari et al., 2024). Virtual reality environments allow patients to interact with simulated tasks that mimic real-world activities while providing immediate feedback and adaptive difficulty levels (Naqvi et al., 2024). Conventional physiotherapy interventions rely on repetitive exercises designed to restore mobility, balance and functional independence, but patient adherence and motivation can sometimes limit therapeutic outcomes (Ley & Putz, 2024). VR rehabilitation introduces immersive and interactive elements that increase patient engagement while enabling therapists to monitor performance and adjust training parameters (Capriotti et al., 2025).

Several clinical studies have investigated the potential benefits of VR physiotherapy in neurological rehabilitation, especially among individuals with stroke, Parkinson's disease, cerebral palsy and other neurological conditions (Laver et al., 2017; Dockx et al., 2016; Chen et al., 2018; De Keersmaecker et al., 2025). Evidence suggests that VR interventions may improve balance control, gait parameters, and upper limb motor function through improved motor learning and neuroplasticity mechanisms (AlSoqih et al., 2025).

Despite increasing interest in VR rehabilitation, the general effectiveness of these interventions is a topic of ongoing investigation. Previous studies vary in methodological quality, intervention protocols, and outcome measures, making it difficult to draw definitive conclusions regarding their clinical impact (Bilika et al., 2023; Kasicki et al., 2025). Therefore, the aim of this study is to systematically review and quantitatively synthesize the available evidence about the effectiveness of VR physiotherapy interventions in improving functional rehabilitation.

2. Methods

2.1 Study design

This research will use a systematic review and meta-analysis design in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The methodology will focus on evaluating the effectiveness of VR physiotherapy in improving functional rehabilitation outcomes.

2.2 Search strategy

A comprehensive literature search will be conducted in the following electronic databases: PubMed, Scopus, Web of Science, Cochrane Library. Search terms will include combinations of keywords such as "virtual reality", "physiotherapy", "rehabilitation", "motor recovery", "neurorehabilitation". The search will include studies published between 2021 and 2026 (published until March, 2026).

2.3 Inclusion criteria

Studies will be included if they are randomized controlled trials or controlled clinical studies, if they used VR physiotherapy interventions, participants with neurological or physical impairments and evaluation of functional rehabilitation outcomes such as balance, mobility, motor function. Studies not published in English, conference abstracts without full data, and studies lacking relevant outcome measures will be excluded.

2.4 Data extraction and analysis

Data will be extracted by the reviewer with a standardized data extraction form. Extracted variables will include study design, participant characteristics, intervention protocols, outcome measures and duration of intervention. Meta-analysis will be conducted using standardized mean differences with 95% confidence intervals to evaluate the pooled effect of VR physiotherapy interventions on functional outcomes.

3. Expected results

Based on previous literature, it is expected that VR physiotherapy interventions will show moderate to significant improvements in several functional rehabilitation outcomes, including balance performance, gait parameters, motor coordination and functional independence. VR training may also improve patient adherence and motivation compared to conventional physiotherapy interventions. Also, immersive environments may facilitate task-specific motor training and stimulate neuroplasticity, contributing to improved functional recovery among individuals undergoing rehabilitation.

4. Discussion

The integration of immersive technologies into physiotherapy is a promising direction for modern rehabilitation. VR systems provide interactive environments that encourage active participation, real-time feedback, and personalized therapeutic protocols. These characteristics may improve traditional rehabilitation approaches by improving patient motivation and promoting more intensive and engaging therapeutic exercises. Moreover, VR technologies allow clinicians to design personalized rehabilitation scenarios that simulate real-life activities, thereby improving the transfer of motor skills to everyday functional tasks. Nevertheless, several challenges remain. These include variability in intervention protocols, differences in VR hardware systems, and limited long-term follow-up data. Future research should focus on standardized treatment protocols, multicentre clinical trials, and cost-effectiveness analyses to better understand the role of VR technologies in rehabilitation practice. VR physiotherapy has the potential to improve functional rehabilitation outcomes and may become an integral component of contemporary rehabilitation programs.

5. Conclusion

Virtual reality technologies are innovative and promising approach to improving functional rehabilitation outcomes in physiotherapy. Through immersive and interactive environments, VR interventions may improve motor recovery, balance, and functional independence among persons with neurological and physical impairments. The findings of this systematic review and meta-analysis aim to provide evidence-based information into the clinical effectiveness of VR physiotherapy and support its integration into rehabilitation practice.

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Saudi End-User Perception and Expectations Toward Using Virtual Reality-based Physiotherapy Systems as an Exercise Tool for People with Knee Osteoarthritis: qualitative study

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Abstract

Knee osteoarthritis (OA) is highly prevalent in Saudi Arabia and associated with poor exercise adherence. Virtual reality (VR)-based physiotherapy may enhance engagement; however, its acceptability remains underexplored. This qualitative study explored the expectations, needs, and concerns of Saudi end-users (individuals with knee OA and physiotherapists) regarding VR-based physiotherapy. Fourteen semi-structured interviews were analysed using inductive thematic analysis. Four themes were developed: (1) knowledge and impact of knee OA; (2) perceptions of exercise for knee OA; (3) digital health in Saudi Arabia; and (4) perceptions of VR-based physiotherapy. Participants expressed generally positive attitudes, particularly regarding motivation and accessibility; however, concerns related to safety, cultural appropriateness, and digital literacy were evident. VR-based physiotherapy is perceived as promising, but implementation requires culturally appropriate design and system integration. The findings highlight context-specific determinants of digital rehabilitation adaptation.

1. Introduction

Osteoarthritis (OA) affects over 250 million people globally, with knee OA prevalence in Saudi Arabia reported to be higher than in Europe, Asia, and the United States (Alrowaili 2019). Major clinical guidelines recommend exercise as a core treatment strategy (National Institute for Health and Care Excellence (NICE) 2022); however, low adherence rates remain a major challenge. Repetitive exercise routines often reduce motivation, and a recent study found 36% of individuals with knee OA in Saudi Arabia rarely performed their prescribed exercises, with potential consequences for functional outcomes (Mashrai et al. 2022).

Virtual reality (VR)-based physiotherapy has emerged as a promising digital intervention to enhance exercise engagement. Evidence suggests that VR-based approaches are associated with higher motivation, improved adherence, reduced pain, and better balance outcomes compared to conventional exercise therapy (Blasco et al. 2021). Despite growing evidence supporting VR-based physiotherapy, translation into clinical practice remains limited (Proffitt et al. 2019). Prior research has focused on outcomes rather than behavioural and sociocultural determinants of adoption, particularly in non-Western contexts. (Glegg and Levac 2018; Wei et al. 2024). The Unified Theory of Acceptance and Use of Technology (UTAUT) offers a useful framework, emphasising perceived usefulness, ease of use, and contextual influences (Venkatesh et al. 2003). However, its application to VR-based physiotherapy in Saudi Arabia remains limited. This study, therefore, explored the expectations, needs, concerns, and willingness of Saudi end-users (people with knee OA and physiotherapists) to engage with VR-based physiotherapy systems as an exercise intervention for individuals with knee OA.

2. Methodology

This qualitative descriptive study used semi-structured interviews with individuals with knee OA and musculoskeletal physiotherapists in Saudi Arabia. Participants were purposively sampled to capture variation in experience and digital health engagement. Prior to interviews, participants were provided with a brief standardised description of the VR-based physiotherapy (SPIN-VR) system developed at Cardiff University, including a practical example of different exercise scenarios via video demonstration (Figure 1). The SPIN-VR system is described in detail in Al-Amri et al. (2025).

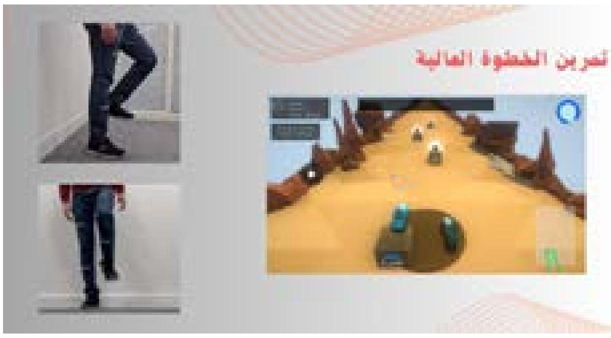

Figure 1: example from the demonstration video.

Interviews were audio-recorded, transcribed verbatim, and analysed using an inductive thematic analysis following Braun and Clarke's framework (2006). Coding was led by the first author, with a subset independently coded to enhance credibility. Themes were refined collaboratively. The interpretation was subsequently informed by the UTAUT constructs. Trustworthiness was supported through member checking, peer debriefing, and an audit trail. Detailed descriptions of each analytical phase are presented in Table 1.

Phases	Process
1. Familiarising with the data	Self-transcription, self-translation, and review of the notes by DS facilitated a comprehensive understanding of the data content and context
2. Generating initial codes	The main researcher (DS) independently coded all the transcripts, approaching each with fresh eyes to ensure comprehensive coding. Three randomly selected transcripts (representing 10% of the dataset) were independently coded by an external coder experienced in qualitative approaches (MA). DS and MA subsequently met to discuss and compare their coding, resolving any differences through discussion until consensus was reached on codes and their meanings. The final codebook was reviewed and discussed with the senior researchers (MAA and KB).
3. Searching for themes	DS developed candidate themes and a thematic map to examine cross-connections between concepts.
4. Reviewing themes	All authors (DS, MAA, KB) verified that the subthemes and themes accurately represented the coded extracts and the overall dataset.
5. Defining and naming themes	All authors (DS, MAA, KB) discussed and refined the definitions and names of each subtheme and theme.
6. Producing the report	DS developed the initial draft. MAA and KB contributed to the development of the report and provided critical input.

Table 1: Detailed descriptions of analytical phases.

This study received ethical approval from the School of Healthcare Sciences Research Ethics Committee at Cardiff University in December 2023 (reference number REC1148).

3. Results

A total of eight musculoskeletal physiotherapists (five females and three males; mean age: 35.5 ± 4.92 years) and six individuals with knee OA (three females and three males; mean age: 53.67 ± 6.49 years) were interviewed. Four themes were developed from the iterative analysis, and pseudonyms were assigned to ensure participant anonymity.

3.1 Knowledge and impact of knee OA

All Saudi participants with knee OA experienced difficulties across multiple life aspects, including restrictions in religious practice, leisure activities, household tasks, and social engagement. Nevertheless, both end user groups demonstrated limited knowledge of the condition, describing it as "pain" or "friction", reflecting limited awareness of its underlying complexity "*I do not really know what osteoarthritis means, but I feel pain in my right knee..." (Participant with knee OA, SAMYA). "Knee OA means friction between the thigh bone and the leg bone." (Physiotherapist, NAIF)*. Consequently, most participants with knee OA relied on over-the-counter analgesia, while some reported temporary relief from corticosteroid injections or had trialled alternative approaches such as topical creams and kinesiology tape. Self-management strategies, including activity modification and spiritual practices, were also reported by the majority of participants with knee OA.

3.2 Perceptions of exercise for knee OA

The therapeutic value of exercise was acknowledged by both end-users. Physiotherapists recommend exercise to reduce knee loading, maintain joint function, slow disease progression, and potentially delay surgical intervention*"…I always tell my patients, think of these exercises as buying time for your knee. If you do it [exercises] regularly, you can delay the need for surgery for several years". (Physiotherapist, RAYAN)* Participants with knee OA reported pain reduction during the supervised exercise program. However, adherence was limited due to a range of multifaceted barriers. Commonly cited obstacles included fear of increased pain and joint damage *"……every time I tried to do my exercises, I thought, What if this makes the pain worse? What if I damage my knee even more? And then I stopped doing my exercise". (Participant with knee OA, SAMYA).* Additionally, the absence of immediate results, the repetitive nature of prescribed exercises, and time constraints were mentioned as challenges, while severe pain episodes prevented some participants from attending sessions entirely. Physiotherapists identified low patient motivation as the key challenge to long-term adherence, compounded by systemic issues including limited clinic space, staff shortages, and restricted appointment availability. In response, the majority of physiotherapists had adopted hybrid delivery models incorporating video or web-based exercise platforms alongside paper-based materials, adapted according to patient age and digital access. Despite these approaches, physiotherapists consistently reported a low participation rate among individuals with knee OA.

3.3 Digital health in Saudi Arabia

All participants from both end user groups were actively engaged with government-developed digital health platforms, including "*Tawakkalna*" and "*Sehaty*", with many also utilising virtual appointments and telephone consultation services. Most participants with knee OA identified digital convenience, time efficiency, and enhanced safety as benefits, particularly during the COVID-19 pandemic *"The app [Tawakkalna] is fantastic; it saves me time and money." (Participant with knee OA, SAMYA).* Virtual appointments were especially valued by participants in rural areas or with mobility limitations. Nevertheless, notable barriers were also reported, including technical difficulties and limited digital literacy. Privacy concerns were also raised, with some participants with knee OA expressing discomfort regarding data sharing through the Sehaty app. Additionally, gender-related discomfort during virtual consultations deterred some participants from using these services.

3.4 Perceptions of VR-based exercise for Knee OA in Saudi Arabia.

The majority of participants expressed positive views toward the concept of VR-based physiotherapy, describing it as "*amazing*", "*innovative*" and "*outstanding*". Physiotherapists were particularly enthusiastic about non-immersive VR systems, expressing the belief that these could improve motivation and offer a home-based solution that reduces burden for both patients and clinicians *"This [VR system] will help to make home exercise more effective as patients can easily operate it from their home and reduce loads on face-to-face appointments" (Physiotherapist, RAYAN).* Participants with knee OA acknowledged that the system could help them to overcome exercise barriers, most notably pain, by redirecting attention toward in-game performance rather than joint movement *"Just while watching the short example in the video, I forgot my knee pain, and I was focused on how the person played that game, and I tried to mimic his movement; I think it will make the exercise less painful". (Participant with knee OA, RAMI).* Physiotherapists further emphasised the importance of customisable features that enable personalised treatment plans and objective performance monitoring *"This exercise can be chosen … that is very helpful* *as each patient needs specific exercise, so this will allow me to develop an exercise program and actually allows patients as well to choose and modify with me"(Physiotherapist, DALAL).* However, concerns were raised regarding the risks of dizziness and loss of balance, particularly among older individuals with knee OA, as well as supervision requirements, funding constraints, and potential resistance to novel technology. The majority of participants stressed the importance of aligning the system with Saudi culture and norms by integrating Arabic, enhancing privacy and avoiding camera use, offering support and group-play options, and excluding culturally sensitive or religiously prohibited content from game scenarios to enhance the system's acceptability and usability in the Saudi context.

4. Discussion and conclusion

Participants among both groups expressed motivation and willingness to engage with the VR-based physiotherapy system, describing it as innovative and entertaining. These findings are consistent with previous literature suggesting that VR can offer a motivating and accessible alternative to conventional physiotherapy (Lo et al. 2024). Participants in both end-user groups expected the system to be enjoyable and convenient, potentially addressing the well-documented barriers to exercise adherence among individuals with knee OA (Dobson et al. 2016; Matallaoui et al. 2017). This is consistent with the UTAUT framework (Venkatesh et al. 2003), in which participants' perceived benefits of the VR-based physiotherapy system, including pain distraction and improved motivation, reflect performance expectancy. This study extends the existing literature by identifying context-specific barriers and needs among both people with knee OA and physiotherapists pertinent to the Saudi population, including camera avoidance, the need for Arabic-language support, and the need to ensure culturally appropriate content. In addition, the resource constraints, therapist shortages, and concerns regarding technical reliability identified by physiotherapists align with broader systemic challenges described in the physiotherapy technology adoption literature (Glegg and Levac 2018). Additionally, limited knowledge of knee OA has been observed among both end-users, which may negatively affect perceptions of the utility of VR-based physiotherapy. For example, the misconception that exercise leads to further joint damage can contribute to fear of movement and poor engagement in physiotherapy (Dobson et al. 2016). While a VR-based physiotherapy system may partially address this fear by providing distraction and real-time feedback, it does not fundamentally provide education on knee OA. Therefore, VR-based physiotherapy systems may need to incorporate educational components to improve health literacy among both end-user groups alongside exercise delivery. Addressing these factors is essential for the successful integration of the VR-based physiotherapy system into practice in the Saudi context.

In conclusion, Saudi end-users demonstrated a positive attitude toward VR-based physiotherapy for knee OA, recognising its potential to improve motivation, enable personalised care, and mitigate individual and systemic barriers to exercise adherence. While culturally specific adaptations, including Arabic-language support and culturally appropriate content, are essential for implementation in Saudi Arabia, the barriers and enablers identified here resonate broadly across diverse healthcare systems facing similar challenges, including limited resources, digital literacy gaps, and low physiotherapy adherence. These findings therefore contribute a critically needed cross-cultural perspective to the global evidence base, informing the equitable and inclusive design of VR-based physiotherapy technology internationally.

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04

AUTISM SPECTRUM DISORDERS

A Game-Based Multimodal Data Capture Pipeline for Research on Emotional Regulation in Autistic Adults

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Abstract

Research on emotional regulation in autistic adults requires methods that effectively capture physiological responses and behavioural context. This paper introduces a game-based multimodal data capture pipeline that integrates a controlled environment with synchronised physiological sensing to facilitate future studies. The pipeline records key gameplay events as candidate regulation-relevant anchors and aligns them with multimodal recordings for event-centred analysis. Session outputs are stored with structured metadata and event logs to ensure quality control and reuse. The focus is on technical implementation and feasibility, establishing a foundational pipeline for future ethically approved research on emotional regulation in autistic adults.

1. Introduction

Emotional regulation is an important and under-explored area of research in autistic adults, particularly in interactive contexts where behavioural and physiological responses unfold over time rather than appearing as isolated events. Studying such processes requires instrumentation that can capture both what the person is doing and what is occurring across multiple physiological channels concurrently. Game-based environments provide a useful foundation for this instrumentation, offering environments in which repeatable tasks can be modelled, along with structured event sequences and controllable interaction conditions. In this work, SuperTux is used as an interchangeable gameplay environment within a multimodal capture pipeline designed to support future research on emotional regulation in autistic adults. The aim is to complete each level as quickly as possible while collecting as many coins as possible, avoiding enemies that cause the player to respawn and lose some of their collected coins and any power-up abilities.

SuperTux was selected because it is open source, lightweight, modifiable, and provides a repeatable game structure in which events such as coin collection, enemy contact, power-up loss, and respawning can be logged consistently and autonomously. The first level provides familiarisation, while later increases in task demand create candidate regulation-relevant event anchors without assuming a fixed emotional response.

The contribution of this paper is therefore technical and infrastructural: it presents the implementation of a synchronised data-capture pipeline that links gameplay events with multimodal physiological signals in a structured, reusable form. This work lays the foundation for later HCI studies by establishing the acquisition and synchronisation layer needed for later ethically approved studies. This paper builds on previous work by extending the broader multimodal gameplay framework from Buxton et al. (2026), implementing a focused pipeline for future research on emotional regulation in autistic adults.

Modality	**Location**	**Sample Rate**	**Channels**	**Parameters and Notes**
EEG	Scalp	250 Hz	10	Dry active electrodes, F1, F2, C3, Cz, C4, P3, Pz, P4, O1, O2
ExG	Forehead	250 Hz	0-2	Passive EEG Fp1, Fp2
EMG	Facial	250 Hz	4-6	Contains ExG
EOG	Facial	250 Hz	2	4 EMG electrodes
PPG	Ear clip	250 Hz	n/a	Red & IR light A2 clip placement
IMU	Forehead	250 Hz	6-axis	Accelerometer with +/- 4g range Gyroscope with +/- 500 deg/s
IMU (MAG)	Forehead	25 Hz	3-axis	Magentometer with +/- 1300 uT

Table 1: Available Galea Beta headset modalities (Buxton et al. 2026, Table 1).

2. Background

Emotional regulation is increasingly recognised as an essential area of autism research. However, it is methodologically challenging to investigate this among autistic adults due to the subjective nature of the required judgment (Fok et al. 2025). Existing research suggests that individuals with autism spectrum condition (ASC) may experience variations in emotional reactivity and recovery. However, the evidence on study design in autistic adults is heterogeneous (Mazefsky 2015). This creates a need for longitudinal research to capture events in real time. For autistic adults, this is increasingly important as their experiences are under-represented and differ when compared to their child counterparts (Fok et al. 2025).

Previous multimodal systems have demonstrated richer analyses than unimodal applications (D'mello & Kory 2015). Physiological sensing, modalities, such as EEG and PPG, are widely explored for the recognition of emotional states due to changes in attention and arousal that may not be visible from studying behaviour alone (Ahmad & Khan 2022). However, these modalities are only useful when they are observed in relation to specific events, which makes synchronising context and physiology a core requirement for any pipeline.

Game-based environments offer an engaging setting for this work as they provide repeatable tasks, controllable events, and a structured environment in which behavioural and physiological responses can be observed in tandem. Although previous autism-gaming research has focused on educational intervention rather than adult emotional regulation, it supports the idea that game-based environments can provide accessible, observable data-collection opportunities for co-produced autism research López-Bouzas & Del Moral-Pérez (2023). Building on this, there is a clear need for concrete technical pipelines that use gameplay events with synchronised sensing capabilities to support research on emotional regulation in autistic adults.

Existing work has established the broader rationale for synchronised multimodal games and the multimodal infrastructure for future research applications (Buxton et al. 2026). However, there remains a need for a concrete implementation tailored to the requirements of future adult autism research, particularly where repeated sessions, structured event annotation, and downstream explainable analysis are anticipated.

3. Methodology

Due to the lack of research on emotional regulation in adults with ASC, the foundation presented by Buxton et al. (2026) is extended using the Galea headset. The available modalities for the headset are shown in Table 1. With the focus of this implementation on emotional regulation among autistic adults, the locations of interest are the Frontal, Parietal, and Occipital regions of the brain (Gkintoni et al. 2025). The Galea electrode placement is shown in Figure 1, excluding the frontal-pole 1 and 2 (Fp1/2) passive ExG electrodes.

These regions were selected for their relevance to game-based tasks: Frontal electrodes for cognitive control, Central for movement planning, Parietal for attention and sensory integration, and Occipital for visual processing. This mapping aids in channel selection, rather than providing precise neural source localisation.

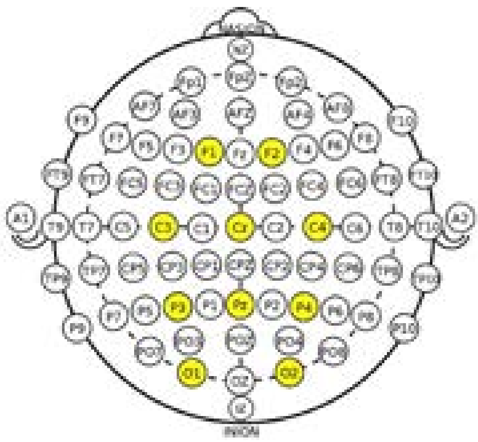
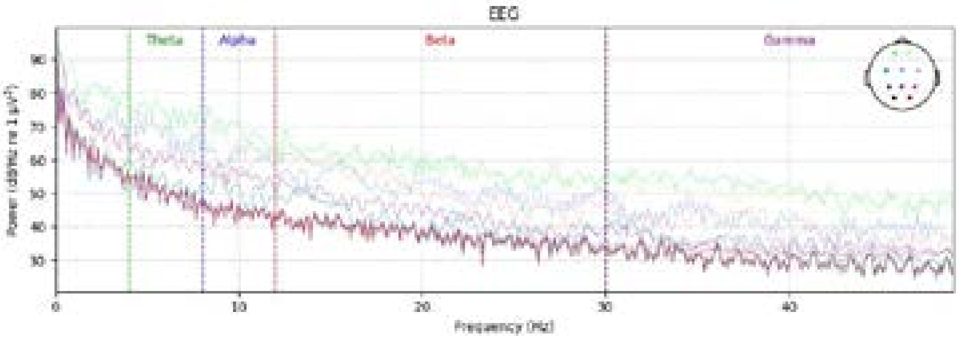
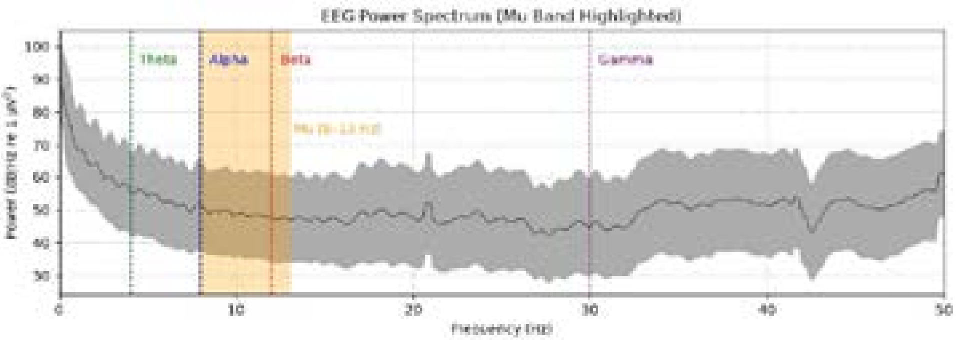


Figure 1: International 10-20 EEG electrode placement of the Galea headset (OpenBCI 2023).

Data recorded from the Galea was converted from CSV to BDF format using a custom script, combining both raw ExG and PPG/EDA based on the recorded time. This time-synchronised BDF file was then imported into MNE-Python for analysis and preprocessing. As the Galea system applies a hardware bandpass filter, a 50 Hz notch filter was applied to reduce mains electrical interference. Example PSD outputs are shown in Figures 2a and 2b.



(a) *EEG PSD with individual electrodes colour-coded.*



(b) *PSD with Mu highlighted in orange.*

Figure 2: EEG Power Spectral Density (PSD; up to 50 Hz) sectioned into relevant bands Theta (θ; 4-7 Hz), Alpha (α; 8-12 Hz), Beta (β; 13-30 Hz) and Gamma (γ; > 30 Hz).

In addition to broad EEG band inspection, the same PSD output enables calculation of the Mu rhythm, typically examined in the 8–13 Hz range over central sensorimotor electrodes. Although this frequency range overlaps primarily with the alpha range, Mu activity is interpreted as sensorimotor processing rather than general posterior alpha activity. The current pipeline supports future Mu power calculation by averaging or integrating spectral power within the central channels. In future participant studies, event-related changes in Mu power could be examined around gameplay events such as enemy collisions or respawns. This would allow the pipeline to explore motor engagement and response preparation during game interaction, while avoiding claims that Mu activity alone indicates emotional state.

4. Discussion

The principal contribution of this paper is the implementation of a reusable capture pipeline motivated by the methodological needs of future adult autism research on emotional regulation. The work establishes the technical foundation needed for future HCI studies by integrating repeatable gameplay, structured event annotation, OpenBCI Galea multimodal physiological capture, and synchronised export. In practice, gameplay events such as coin collection, enemy collision, power-up loss, and respawning can be recorded as timestamped markers during acquisition and aligned with the Galea recording timeline during conversion to BDF. This creates an event alignment layer in which physiological and inertial data can be segmented around specific gameplay anchors for later event-centred analysis and explainable modelling.

The use of a game-based setting offers practical advantages in terms of repeatability, observability, and controllable task structure, but also introduces important limitations. In-game events should be understood only as candidate proxies for regulatory relevance, not as direct indicators of internal affective state, while the current implementation does not establish biomarkers, validated labels, or autism-specific findings.

5. Conclusion

This paper has presented a game-based multimodal data capture pipeline for future research on emotional regulation in autistic adults. The present contribution is technical rather than inferential, demonstrating implementation readiness and data capture feasibility rather than validated participant-level conclusions. As a result, the paper serves as a foundational component by establishing the acquisition, synchronisation, and event-annotation infrastructure required for subsequent ethically approved studies involving autistic adults.

Future work will combine this infrastructure with participant recruitment, headset comfort and adherence checks, suitable ground truth measures, and camera recordings reviewed by a neuropsychologist to support behavioural annotation of observable emotional regulation states. These annotations can then be compared with self-report, gameplay markers, and physiological change to validate event-to-signal alignment.

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Protocol for a Randomised Controlled Trial and Feasibility Evaluation of a Large Language Model-Based Digital Social Interaction Programme to Improve the Social Communication Skills of Autistic Children in China

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Abstract

In China, 0.7% of school-aged children have autism. Access to long-term social communication intervention remains limited. We evaluate a large-language-model-based digital social interaction programme designed for autistic children in China aged between 3-8 years old. The intervention integrates social story videos with real-time LLM-driven conversational practice to enhance social communication skills. Randomized controlled trial will compare the digital intervention plus standard care, with standard care alone over 12-weeks. Primary outcomes: Vineland-3 Socialization score. Secondary measure: Social Responsiveness Scale (SRS) and Autism Behavior Checklist (ABC). We aim to provide evidence for AI-supported home-based social communication interventions for young children with autism

1. Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental condition characterised by persistent deficits in social communication and social interaction, alongside restricted and repetitive behaviours (American Psychiatric Association, 2013). In China, large-scale epidemiological data remain limited, but multi-site studies suggest a prevalence of approximately 0.7% among school-aged children (Zhou et al., 2020).

Social communication impairment is one of the core characteristics of ASD, affecting social initiation, understanding of emotional cues, conversational reciprocity, and non-verbal communication (Wetherby, 2006; Wetherby et al., 2007). These characteristics influence peer relationships, academic engagement, and community participation, and are associated with increased risk of anxiety, depression, and reduced quality of life (Silveira-Zaldivar et al., 2021; Wang et al., 2025). Early effective social skills intervention is therefore essential.

Digital health technologies, such as computer-assisted tools, mobile applications, and virtual reality environments can provide structured, engaging, and repeatable learning experiences

(Battocchi et al., 2009; Ploog et al., 2013; Voss et al., 2019). Yet most existing digital tools rely on pre-programmed content and lack the dynamic, reciprocal qualities of real social interaction.

Large language models (LLMs) introduce a new paradigm. LLM-driven systems can simulate naturalistic dialogue, adapt to a child's responses, and provide consistent, patient, and personalised feedback. Early studies suggest that LLM-mediated interaction may support communication and social learning in ASD (Mishra et al., 2024). Building on this potential, the present study evaluates a digital intervention combining social story videos with LLM-based interactive dialogue to create a structured "watch-practice-reinforce" training cycle.

2. Methods

2.1. Study design

This paper presents the protocol for an ongoing randomized controlled trial with trial registration number ChiCTR2400093278, which adopts a single-centre, randomized, positive-control design. Children in the intervention group will receive the digital social interaction training in addition to standard in-person rehabilitation, while the control group will receive standard rehabilitation only. The intervention period is 12 weeks. Assessments will be conducted at baseline (T0) and post-intervention (T1). Parents in both groups will complete standardised questionnaires.

2.2. Participants

Based on prior ASD social skills and digital intervention studies, an expected effect size of $d = 0.5$ was used for power analysis ($\alpha = 0.05$, power = 0.80). A minimum of 64 participants per group is required.

Accounting for 15–20% attrition, 75 participants per group will be enrolled. Thus, a total of 150 children aged 3–8 years diagnosed with ASD will be recruited from a paediatric outpatient clinic in Beijing, China, and randomly assigned in a 1:1 ratio to either the intervention or control group. Eligible participants must have a DSM-5 diagnosis of ASD confirmed independently by two child psychiatrists, and a Childhood Autism Rating Scale (CARS) score of 30 or above. Families must use Mandarin as their primary home language, and children must be able to participate in assessments and training and have no medication use during the study period.

Children will be excluded if they present with significant sensory or motor impairments, neurological conditions such as epilepsy, severe psychiatric disorders or medical issues that could interfere with participation, or severe behavioural problems. Additional exclusion criteria include colour blindness, prior exposure to similar digital interventions, and having a sibling concurrently enrolled in the study.

As of May 2026, 42 families have been enrolled, with a 95% completion rate for baseline assessments and a median daily training adherence of 87% during the first two weeks of pilot deployment.

2.3. Intervention

Children in the intervention group will receive a large-language-model-based digital social communication training programme in addition to their ongoing in-person therapies. The system operates on an Android tablet and integrates mobile internet connectivity, speech recognition, and

LLM-driven natural language processing to create a structured and continuous social interaction training environment.

Grounded in principles of early social-cognitive development and neuroplasticity, the intervention follows a “social story video learning-LLM interactive dialogue practice” model targeting foundational social communication skills. Each day, the system delivers 8–10 short animated social story videos of approximately two minutes each. These videos depict common social scenarios relevant to young children, such as greeting others, requesting help, sharing toys, taking turns, expressing gratitude, or comforting peers, and present characters’ behaviours and emotional expressions in a clear, visually accessible format. The aim is to support children’s understanding of social rules and emotional cues across familiar contexts.

Figure 1: Social scenarios including dealing with fears of lightening, crossing busy streets and queuing to play.

Immediately after viewing the videos, children transition to an interactive dialogue module featuring a child-friendly virtual character *Maya* powered by a large language model. *Maya* engages the child in real-time conversation, interpreting spoken or typed responses and generating adaptive prompts that probe comprehension, emotion recognition, and scenario-based reasoning. Interactions may involve identifying characters’ emotions, discussing appropriate behavioural responses, or relating the scenario to the child’s own experiences.

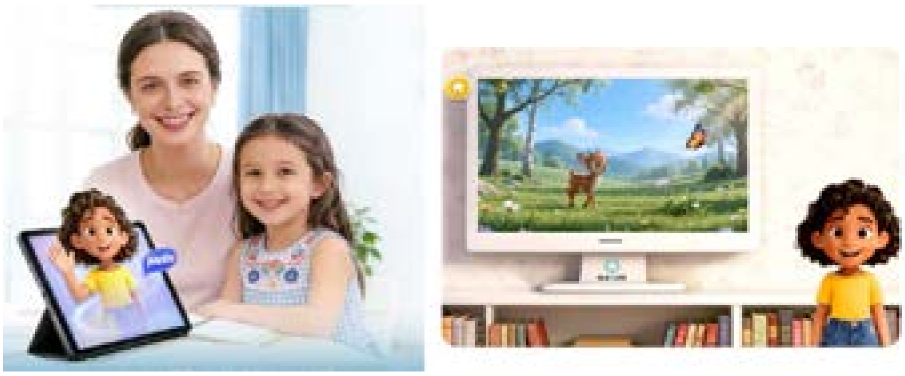

Figure 2: Maya engaging with the child in real-time conversation.

The system dynamically adjusts the difficulty of questions and conversational scaffolding based on the child’s responses, and provides encouraging feedback to reinforce appropriate social communication. Training is delivered in a one-to-one digital format, with each child using an individual tablet while a parent or therapist offers minimal assistance to support device use and maintain engagement. Sessions last approximately 10–15 minutes, occur once daily, and continue for 12 weeks. The system automatically records training duration, number of interaction turns, and response content for subsequent adherence and outcome analyses. Throughout the intervention period, research staff conduct regular follow-ups to monitor progress and address technical issues.

2.4. Safety and ethical considerations

The involvement of young autistic children requires a robust safety and ethical framework. The system therefore incorporates multiple layers of protection that were developed through a co-design process involving autistic consultants, clinicians, parents, and engineers. The LLM operates within a tightly constrained domain limited to pre-approved social-communication topics and scenario-based prompts, ensuring that all dialogue remains aligned with therapeutic goals. A multi-layered filtering system combines rule-based and classifier-based detection to identify and block inappropriate, confusing, or emotionally intense outputs, and any response that falls outside the approved domain is automatically replaced with a safe, deterministic alternative.

For conversational branches involving safety, conflict, emotional distress, or uncertainty, the system uses structured and predictable templates. This reduces ambiguity, prevents hallucination-driven variability, and maintains a stable interaction pattern that is developmentally appropriate for young children. All interactions are logged, and any flagged responses are reviewed by research staff. A caregiver remains present during every session to provide additional oversight and to support engagement.

The safety architecture and interaction design were shaped by autistic consultants who participated in early prototyping and scenario review. Their insights emphasised the importance of predictable phrasing, stable conversational rhythms, and low-arousal visual design to reduce cognitive load and support emotional safety. They also highlighted the need to avoid ambiguous or metaphorical language, which can introduce unnecessary uncertainty; as a result, all dialogue is written in clear, concrete, literal terms. Consultants further noted that cultural and linguistic localisation is essential for comprehension, prompting revisions to phrasing, scenario selection, and character behaviour to ensure alignment with children's real-world environments. They also recommended the inclusion of emotionally safe pathways, including gentle redirection and the option to step away from topics that may cause discomfort.

Together, these safeguards aim to ensure that LLM-mediated interactions remain predictable, emotionally safe, culturally relevant, and developmentally appropriate for young autistic children, while maintaining the flexibility and responsiveness that make conversational AI a promising tool for social communication support.

2.5. Outcome measures

The primary outcome will be the Vineland Adaptive Behavior Scales, Third Edition (Vineland-3), a widely used caregiver-reported measure of adaptive functioning. The Vineland-3 assesses Communication, Daily Living Skills, and Socialization, with an optional Motor Skills domain for younger children. The measure yields both domain-specific standard scores and an Adaptive Behavior Composite, and is extensively used internationally and increasingly in China for evaluating functional profiles and intervention outcomes in children with ASD. Secondary outcomes will include the Autism Behavior Checklist (ABC) and the Social Responsiveness Scale (SRS). The ABC is a 57-item caregiver- or practitioner-completed checklist assessing autism-related behaviours across sensory responses, social relating, body and object use, language, and self-help skills, with higher scores reflecting greater symptom severity. The SRS is a 65-item measure of social communication difficulties and autism-related traits across five domains: social awareness, cognition, communication, motivation, and restricted behaviours. Both instruments have strong psychometric properties and are widely used in clinical and research settings to assess behavioural characteristics and social functioning in ASD.

3. Data analysis

All primary analyses will follow an intention-to-treat (ITT) framework, including all randomized participants regardless of adherence to the digital intervention. Linear mixed models (LMMs) will be used to examine change over time in primary and secondary outcomes, specifying participant as a random intercept to account for within-subject correlation and including fixed effects for group (intervention vs control), time (baseline vs post-intervention), and the group × time interaction. Baseline score, age, sex and socioeconomics status will be entered as covariates. The primary test of efficacy will be the group × time interaction for the Vineland-3 Socialization standard score. Secondary models will be fitted for SRS and ABC scores. Effect sizes (e.g., Cohen's d) and 95% confidence intervals will be reported for between-group differences at endpoint, mirroring the approach used in our previous digital intervention trial, where a medium-to-large effect was observed on the primary adaptive outcome. Missing data will be handled under the missing-at-random assumption using maximum likelihood estimation within the LMM framework; prespecified sensitivity analyses will include multiple imputation and per-protocol analyses restricted to participants who complete a predefined minimum proportion of digital sessions. For feasibility, adherence will be summarised descriptively (e.g., proportion of planned sessions completed, mean training minutes, distribution of interaction turns), and exploratory dose–response analyses will examine whether higher engagement with the LLM system predicts greater gains in social outcomes, using additional LMMs or regression models with adherence indices as predictors.

4. Ecpected outcoms and proposed mechanisms

Based on effect sizes observed in our prior cognitive-motor digital trial and on existing social skills interventions in ASD, we anticipate a small-to-medium to medium effect (approximately Cohen's d ≈ 0.4–0.6) on Vineland-3 Socialization scores in favour of the LLM intervention, with converging but potentially smaller effects on SRS and ABC scores. We expect the intervention group to show a steeper improvement trajectory over 12 weeks than the control group, particularly among children with higher adherence to daily sessions.

Mechanistically, we hypothesise that repeated exposure to structured social stories, combined with high-frequency, low-pressure conversational practice with the LLM, will enhance social understanding, emotion recognition, and conversational reciprocity, which in turn will translate into improved everyday social functioning as captured by caregiver-reported measures. We also anticipate that the home-based, parent-supported format will strengthen generalisation of skills across settings and that exploratory analyses may reveal a dose–response pattern in which greater engagement with the digital system is associated with larger gains in social communication and adaptive behaviour.

5. Conclusion

This study addresses a critical gap in ASD intervention: the need for accessible, scalable, and interactive social communication training. Traditional in-person therapies are resource-intensive and often insufficient in frequency. Digital tools can extend learning opportunities, but most lack the dynamic reciprocity of real social interaction.

LLMs offer a novel solution by enabling naturalistic, adaptive dialogue. When combined with social story videos, the system provides both structured modelling and interactive practice. This aligns with developmental and neuroplasticity principles emphasising repeated, context-embedded learning.

If effective, the intervention could serve as a complementary home-based therapy, reducing reliance on scarce professional resources and supporting continuous practice beyond clinical settings.

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Game-based collaborative interactions among moderately functioning autistic adults

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Abstract

This study focused on examining the motivation of moderate-low functioning autistic adults to establish interaction, cooperation, and interpersonal communication through group activities with the BlazePod platform. The study was based on a pre-intervention, intervention, and post-intervention paradigm. The pre- and post- setup included building a model by using Lego bricks. The results of this study show a significant increase in verbal and nonverbal initiative and cooperation during the intervention with BlazePod platform. The study concludes that a reaction-based game platform is an effective motivation tool for social connections and cooperation, but human mediation is required to transfer these skills to natural environments.

1. Introduction

Adolescents diagnosed on the moderate-to-low functioning autism spectrum require substantial support. They face complex and significant challenges in social communication with restricted and repetitive behaviours. These difficulties are manifested in a limited ability in verbal and nonverbal social communication skills, and in the absence of spontaneous cooperation with their peers. This phenomenon is especially pronounced even when students study together in the same educational setting for years. Although the school provides a stable, safe, and supportive educational environment, including lessons aimed at encouraging interpersonal relationships, natural communication between students remains very poor and is often practically non-existent. This situation raises the need to search for innovative intervention channels that will encourage communication. To try to break through this communication barrier, this study examines the use of the BlazePod system as a game-based collaborative interaction tool. The system provides a structured and clear environment that reduces the social and sensory overload that characterizes face-to-face interactions. The research goal is to examine if the BlazePod system is able to support game-based collaborative interactions between research participants such as waiting in line working together to complete a task without requiring high language and expressive abilities.

Autism spectrum disorder (ASD) is a complex developmental disorder that affects behaviour, social interaction, communication, and academic skills. Its exact causes are unknown, although it is thought to involve genetic, psychological, neurological, fragile health, and environmental factors. Baird et al. (2006) and Brugha et al. (2011) have described deficits in social communication and interaction across multiple contexts. Children with ASD have repetitive patterns of behaviour, interests, and/or activities and can have a wide range of symptoms, skills, and levels of impairment. Some are mildly impaired by their symptoms, while others are severely disabled. The Diagnostic and Statistical Manual of Mental Disorders (DSM-5) defines three severity levels for ASD: Level 1–requiring support; Level 2–requiring substantial support; Level 3–requiring very substantial support. These three levels differ in social communication and restricted, repetitive behaviours. Among people with moderate-to-low functioning autism, social interaction, both verbal communication and nonverbal cues such as eye contact and body gestures, is often limited. Social impairments are apparent even with supports in place, including limited initiation of social interactions and reduced or abnormal responses to social overtures from others. additionally, inflexibility of behavior, difficulty coping with change, and other repetitive behaviours appear frequently.

The study by Shattuck et al. (2011) revealed that adolescents with autism participate less in organized or informal social activities, especially when there is a decrease in the level of independent functioning and communication ability. The difficulty is not only manifested in a lack of initiative, but also in a lack of response to requests from the environment. Rosenberg et al. (2017) also emphasized that there is a clear link between the level of communication skills and participation in daily activities. Shattuck et al. (2011), argue that social connection does not develop naturally among students with autism, even when they are in a group setting over time. However, Rosenberg et al. (2017) found that when group activity includes tasks that require physical or cognitive coordination, such as collaborative solution or mutual response, the emergence of communication can be identified. Therefore, the structure of the activity and mediation are critical for transforming the group into an active social space for this population. These difficulties emphasise the importance of structured group activity as a tool to encourage interactions. Weiss and her colleagues (Weiss et al. 2011) presented in their research the multi-user touch tables that "forced collaboration" – the technology requires two users to work together to complete a task. Their research showed that cooperation in children with autism can be improved by defining game rules that require joint actions, interactions, and cooperation between the participants. Likewise, research on cooperative puzzle games using touch technology succeeded in encouraging social initiatives and coordination between participants (Battocchi et al. 2009). These environments allow for the creation of "joint attention" around an external object, thereby reducing the direct social barrier.

The above introduction indicates that people with moderate-to-low functioning autism face significant difficulty with initiative and social functioning, even in a familiar group setting. On the other hand, it appears that structured "forced collaboration" activity may stimulate basic communication. The current study aims to examine the power of game-based collaborative interactions with a reaction-based training platform (BlazePod) and its effect on interpersonal communication among participants with moderate-to-low functioning autism. The BlazePod is an interactive, reaction-based training platform. This system provides cognitive and physical challenges in an engaging environment. While the motor benefit of BlazePod is clear, we aim to examine whether the collaborative game activity may encourage initiative or social cooperation.

The main focus of this study is to examine the social ability of participants with moderate-to-low functioning autism to enhance their verbal communication and nonverbal cues such as eye contact and body gestures through their group activity with the BlazePod platform, and whether they able to transfer and apply social skills in other domain activities (e.g., building with Lego bricks). The two research questions were:

1. What social interaction characteristics (verbal and nonverbal initiative, cooperation, level of mediation) and interaction patterns (post-response, attentional bias), do participants initiate during the Lego task? (pre- and post-BlazePod intervention)
2. What social interaction characteristics (verbal and nonverbal initiative, collaboration, level of mediation) and interaction patterns (reaction after, attentional bias), do participants initiate during BlazePod activity?

2. Methods

2.1. Participants

Four participants aged 19–20 years old participated in this study. All the participants are diagnosed as having moderate-low functioning autism. All participants study in an inclusive school for students with moderate-low functioning autism. All are verbal but with significant difficulties in the area of social communication, and without motor problems.

2.2. Research Instruments

Lego set – The participants were asked to perform a free building task using the Lego bricks.

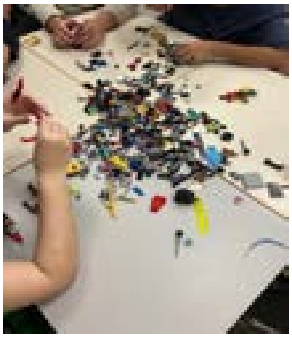

Figure 1: Building with Lego bricks.

BlazePod – The BlazePod is an interactive, reaction-based training platform. This system provides cognitive and physical challenges in an engaging environment. The BlazePod consists of light 'Pods' (See Fig. 2) that illuminate and can be placed on any surface. The Pods are connected to an app which stimulates light-activated reaction training. The BlazePod's app includes over 200 pre-designed drills and allows the development of custom training sessions by adjusting the number of Pods, the time-out constraints, and the specific goals of the target workout: improved reaction time, mental agility, or endurance. Moreover, the BlazePod's app provides real-time feedback which includes performance logs.

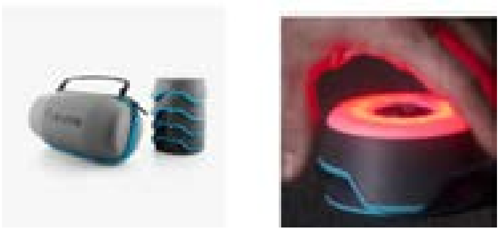

Figure 2: BlazePod system (from https://blazepod.co.il).

2.3. Data Collection Instruments

Lego task – A free activity was given; no detailed guidance was given on whether to build individually/in pairs/as a group, and without instructions for constructing the model. The free and unstructured activity allows the researcher to observe the group's natural social interaction.

BlazePod intervention – This intervention included two phases: the first phase focused on training the participants to play independently with the BlazePod platform – random mode (1st and 2nd session). In the second phase the participants played with BlazePod as a group or in pairs, on tasks ranging from basic tasks – All at once mode (3rd and 4th session) medium – Focus mode (5th and 6th session) to more complicated tasks that require collaboration between the players – sequence mode (7th and 8th session).

Observations – Participant's Lego and BlazePod activities were videorecorded during all sessions.

Coding scheme – A coding scheme was developed to analyze the participants' activities throughout the research intervention.

2.4. Data Analysis

Data analysis involved qualitative analyses; these data focused on pre-and post-test Lego tasks and BlazePod activity. The analysis focused on identifying patterns of social interaction, such as verbal and non-verbal communication initiatives, collaboration, and coordination between participants.

2.5. Procedure

This study was conducted within the school setting. The intervention with the participants occurred once a week for ten weeks, at a fixed time during the week. The study process included ten sessions in five stages: (i) Stage one included parents' introduction and explanation, following which parents signed a consent form; (ii) Stage two focused on the pre-test Lego bricks task observation (approx. 30 minutes); (iii) Stage three included the main intervention: first, two sessions of introduction to the BlazePod platform and then six sessions playing with the BlazePod, each session lasting 30 minutes; (iv) Stage four, repeating the Lego bricks task and observation (post-test approx. 30 minutes); and (v) Stage five included analyzing the research data.

3. Results

The results were based on qualitative analyses of the Lego tasks (pre- and post- tasks) and BlazePod intervention. The following research questions were asked:

What were the social interaction characteristics (verbal and nonverbal initiative, cooperation, level of mediation) and interaction patterns (post-response, attentional bias), which the participants initiated during Lego task? (pre- and post- BlazePod intervention)

This question examined the change in participants' ability to initiate verbal and nonverbal interaction as a result of experiencing the game-based reaction-based interactions. In the pre-test the participants received no interaction initiative, and the data indicate a thorough social interactions disconnect. The results show that throughout the entire session (30 minutes), the level of verbal and nonverbal initiative was 0% for all four participants. No verbal initiative such as inquiries, requests, or comments were recorded between the participants. Similar results were found on nonverbal initiatives such as eye contact, gestures, reaching out. Each participant was immersed in his or her own world, with no attempt to make eye contact or attract the other's attention. After the intervention (post-task), the data reveals nascent, very small, social interactions. Few participant verbal initiative events were recorded: Participant M. initiated almost 30 seconds of verbal initiative whenever required, and Participant P. also initiated about 16 seconds of initiative. No nonverbal communication and cooperation were recorded.

What were the social interaction characteristics (verbal and nonverbal initiative, collaboration, level of mediation) and interaction patterns (reaction after, attentional bias), which the participants initiated during BlazePod activity?

These results reflect the process that participants went through over eight sessions within the BlazePod intervention. These data examined the gradual change in the frequency and quality of initiative as the tasks became more complex (from introductory training tasks to more complicated tasks that required collaborative action between the players). A consistent upward trend in frequency and quality of verbal interactions initiative were observed, with findings indicating a clear positive correlation: as the number of sessions increased and the tasks became more complex (requiring interdependence), the frequency of verbal initiative interactions increased and their quality improved. These developments were demonstrated by progression from using single words to complete sentences, nonverbal interaction, and collaborations. For example, Participant M in the 2nd session presented verbal initiative at 10% without cooperation; at the 3rd session he initiated verbal and nonverbal communication 25% of the time, cooperated 5% of the time, and started guiding fellow participant 25% of the time; in the 6th session he was at 31% cooperation; and in the 7th session he increased to 50% cooperation when required. In the last session (8th) he reached a peak of 44% verbal and nonverbal initiative when required and a peak of 84% cooperation time.

In general, for all participants, basic communication such as "basic response": single words like *"here," "red," "blue,"* or short enthusiastic exclamations appeared simultaneously around the 5th session. Full verbal initiative was relatively rare (about 4–7%). In the peak sessions, (7th and 8th sessions) participants received a sequential task – they were first required to self-regulate (wait their turn) and then to engage in joint attention (look at a friend's Pod/listen to a friend's instructions/instruct themselves). As interdependence increased, participants upgraded communication. The group average of verbal initiative jumped to 21.77%, such as: *"M. go to the Blue" or "A. wait a second."*

The unique finding is the gap between joint attention and eye contact. The participants demonstrated high joint attention to the task and coordinated hand gestures through their group players, as well as long gaze, but a lack of direct eye contact between the participants was notable. This finding is consistent with the characteristics of the disability and shows that technology enables extensive social interaction even without the need for direct eye contact.

Figure 3 Participants playing with BlazePod (6th session).

4. Discussion

The discussion will focus on three central claims that emerge from the data results and correspond with the literature reviewed.

Game interaction supports social interaction – The BlazePod focuses on reaction-based game motoric interactions that present to the participants as a structured environment which reduces load and requires cooperation between the players to succeed in the game. This hidden requirement forced the participants to generate social interactions. This finding clearly reinforces the claim of Weiss et al. (2011), who showed in their research how collaborative technologies (the Diamond touch table) can force cooperation by defining game rules that require joint action. Moreover, the increase in initiative interactions supports the model of Crowell et al. (2019), who argued that technology provides a predictable and consistent environment that reduces sensory and social load. Unlike the Lego game, where the rules are vague and social interaction is not necessary and can even be threatening, the BlazePod provided clear feedback (via lights and sounds). This certainty allowed participants, as Kientz et al. (2014) predicted, to direct cognitive resources toward social interaction rather than anxiety, thereby creating a safe space for communication.

Executive functions and technology and it impact on social interactions – Past research on BlazePod by Bryan & Haynes (2024), found that the BlazePod improves coordination, selective attention, and working memory. The current research results confirm this claim. In the Sequence task (7th–8th sessions) the participants were first required to self-regulate (wait their turn) and to engage in joint attention (look at a friend's Pod/listen to a friend's instructions/instruct themselves). This finding also corresponds with Battocchi et al. (2009), who showed how cooperative games create 'joint attention' around an external object. In the current study, the external objects were the illuminated Pods, which served as an anchor for attention, allowing participants to interact without direct eye contact (one of the major difficulties in autism). People with autism often have difficulty with flashing lights, but in the BlazePod platform the flashing lights acted as strong and focused visual stimulus that helped them focus on the task, and through it, on their friend. As Bryan & Haynes (2024) noted, improving attention is critical: when the participant manages to ignore background noise and focus on the light, he is free to absorb the social activities.

What impact is there on collaboration in game interaction by moderate-low functioning autistic adolescents? – Current results demonstrate that being together in the room (Lego task) does not create interaction between the participants. On the other hand, the participants were able to have social interaction even without direct eye contact. We may assume that the collaborative activities between the participants were influenced by the BlazePod special game platform, which has a hidden demand for collaboration between the players to succeed in the game. Similarly, Rosenberg et al. (2017), claim that interaction depends largely on the structure of the activity.

Maybe moderate-low functioning autistic adolescents identify and understand this hidden collaboration demand in the game and as the BlazePod is a reaction-based game they meet the challenge of these social interactions differently from the Lego construction challenge that requires no collaboration to succeed.

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We thank the four participants for their time and effort.

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A Mixed Methods Study: Culturally Responsive Tangible Near Field Communication Brick Play for Facilitating Communication and Language Development in Autistic Young Children of West African Descent

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Abstract

Despite advances in assistive and digital health technologies and research, there is a paucity of technology-mediated, child-led interventions that remain culturally neutral, with relevance for autistic young children of West African descent. This paper assesses the effectiveness of culturally-tailored Near Field Communication (NFC) brick play in promoting communication and language development (CLD) of autistic young children of West African descent living in England. Findings from a pilot explanatory sequential mixed methods intervention across multiple cases in home environments indicated increased joint attention and improved CLD. This study proffers a renewed conceptualisation of CLD, as emerging through culturally situated interaction.

1. Introduction

Autistic characteristics in young children aged three (3) to five (5) years of West African descent living in England often involve challenges in communication and language development (CLD), important for socio-cultural participation and early learning. Early interventions for autistic young children often discount cultural contexts of autism, especially within Human-Computer Interaction (HCI) technologies (Lorusso et al., 2018), compounding cultural and contextual factors and limiting access to culturally responsive interventions. A mismatch between autistic children's lived and living experiences.

Despite significant advances in HCI, accessibility appears to be inconsistently addressed, often excluding users, especially within systems and environments, whose cultures do not conform to standard known interaction assumptions. This can reduce accessibility and effectiveness for this particular demographic. Play-based interventions which reduce barriers for persons with diverse cognitive, sensory, or tactile needs demonstrate significant potential in promoting engagement, communication, and behaviour change. Similarly, child-led tangible play can reduce barriers for autistic young children, enabling CLD to emerge through dialogic (Wegerif, 2011) interaction rather than instruction.

This paper introduces NFC brick play, a tangible, accessible, adaptive, child-led, play-based intervention for autistic young children of West African descent, designed to support CLD through culturally responsive, embodied interaction. The study adopts an explanatory sequential mixed methods design (Cresswell & Plano Clark, 2018) to evaluate the intervention's effectiveness, over six weeks of dyadic interactions, in enhancing engagement and CLD. The study contributes empirical evidence to demonstrate how culturally relevant interventions promote dialogic interaction, reframe users' engagement, and impact communication and language development (CLD) of autistic young children of West African descent.

2. Background and related word

2.1. Background

Evidence is of a widening gap in the support of autistic young children aged three (3) to five (5) years, whose differing cultural backgrounds compound their CLD issues in educational and home environments. Of note are opportunities to create meaningful engagement and dialogic interaction with the combination of NFC-augmented tangible construction objects, such as specifically selected Lego® Duplo® bricks. During child-led play, physical interaction with NFC-enabled bricks and preset toys affords flexible ways of interaction, triggers digital responses to games with cultural underpinnings when activated, extending the flexibility of play and offering opportunities for engagement, joint attention and interaction, and CLD.

2.2. Tangible Interaction in Early Autism Interventions

Tangible user interfaces (Ishii and Ullmer, 1997) and embodied interaction (Dourish, 2001) inform HCI, yet remain limited in child-led play-based health and education sectors for autistic young children of West African descent. Autism interventions show potential support in joint attention, affordances of flexible multimodal interactions (Farr et al., 2012), and reduction of cognitive load. Although game-based, interactive systems support participation and motivation, most systems remain screen-centric or lack adaptability to diverse cultural contexts.

2.3. Cultural Responsiveness in Assistive Technologies

Development of assistive technologies is often within culturally dominant frameworks. These may often mismatch with the lived experiences of diverse users. Utilising traditional (passive), and culturally responsive (CR) NFC bricks (i.e., activated) to create affordances for combining tangible interaction, accessibility-first design, and adaptive child-led play (Frauenberger et al., 2016) positions NFC brick play in the reframing of interactional design priorities.

In early childhood development, socio-cultural differences influence play, dyadic interaction, and CLD styles. Emerging research highlights a need for culturally responsive and inclusive design approaches that prioritise accessible, adaptive, and contextual relevance. However, there is a scarcity of work which explores culturally grounded, tangible interventions for autism support.

3. Methodology

3.1. Research Design

The six-week pilot study adopts an explanatory sequential mixed methods design, combining quantitative methods with qualitative insights.

3.2. Participants

Participants were six autistic or suspected to be autistic young children of West African descent living in England, aged three to five years, and their parents or carers. Dyads in each case study participated in the child-led NFC brick play weekly intervention for 20 minutes, over six weeks.

3.3. Data Collection

Data were collected in two main phases through the lens of neurodiversity and a new conceptual framework for CLD in interventions for autistic young children of West African descent in their home environments.

Data collection prioritised depth, combining pragmatic ethical approaches to HCI and inclusive design by initially employing survey questionnaires, pre-intervention semi-structured interviews, and documentary evidence from professionals. Then it employed video-recorded observations during the intervention, post-intervention semi-structured interviews, and documentary evidence for post-intervention activities.

Out of the six participants, three carried out cross-over research to ensure rigour.

3.4. NFC Brick Play Intervention

The NFC brick play toolkit comprised a set of 80 specifically chosen modular construction toys (i.e., Lego® Duplo® bricks and pre-set toys. Nine (9) of the bricks were augmented with NFC sticker tags, pre-programmed with purposefully developed age and culturally appropriate online activities and games. The NFC bricks complied with the six principles of tangible user interfaces developed by the main researcher. When manipulated during play, the NFC-tagged bricks and preset toys triggered purposively developed digital cultural responses, including interactive feedback, game-based scenarios and audio prompts (i.e., CR NFC bricks).

Traditional (passive) NFC bricks were construction bricks, preset toys, and inactive NFC-augmented bricks. CR NFC bricks were activated NFC bricks using a smartphone or tablet, and the combination of ttraditional NFC bricks and visual cue cards (some of which depicted cultural content). Other resources in the NFC toolkit included the intervention protocol and intervention schedules to enable parents and carers to facilitate the intervention. The active and passive NFC bricks were designed to be accessible, cognisant of cognitive and sensory needs, and adaptable to cultural contexts. It supported dyadic interaction, verbal and nonspeaking communication, and joint attention.

Figure 1: Photograph of a selection of passive NFC-tagged bricks and preset toys, and an activated NFC brick read by a smartphone depicting purposively designed online content.

3.5. Data Analysis

Four cases produced data for the study to answer the research questions. Francis et al.'s (2019) adapted version of Parten's play stages, Mundy and Newell's theory, and CLD domains were used in analysing the pre-intervention data. Quantitative analysis (e.g., Bayesian analysis) was employed for the video-recorded and transcribed multimodal data during the intervention. Post-intervention, Francis et al.'s (2019) adapted version of Parten's play stages, Mundy and Newell's theory, and CLD domains were used in analysing the data.

Pre- and post-intervention semi-structured interviews captured parents' perspectives on the intervention's effectiveness, usability, accessibility, and cultural relevance. Video-recorded observations of dyadic child-led NFC brick play provided additional data, were triangulated with professionals' documentary evidence.

4. Results

4.1. Key Outcomes

Some findings suggested that the NFC brick play intervention increased cooperative and associative play and reduced prolonged disengagement episodes over the intervention period. Similarly, receptive language and pragmatic communication showed improvements (see Bayesian analysis below).

Culturally Responsive NFC (Active) Traditional NFC (Passive)

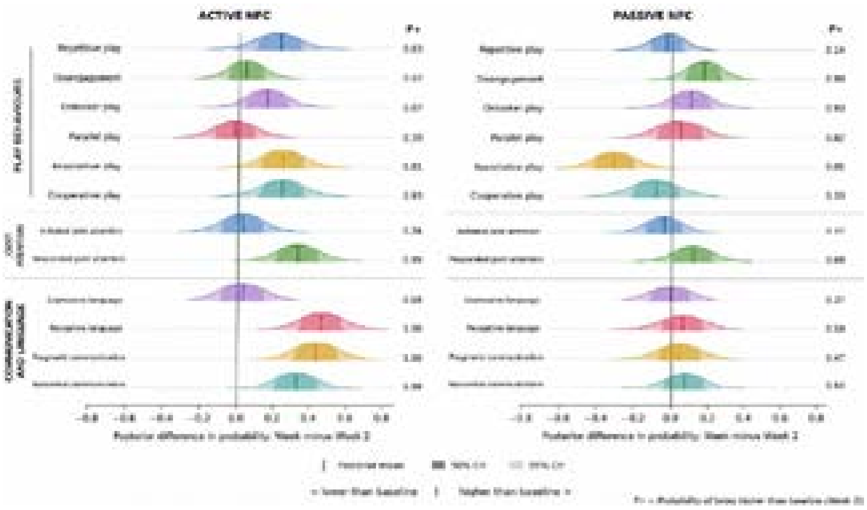

Figure 2: Bayesian posterior distributions derived from Beta-binomial estimates for play, joint attention, communication, and language behaviours.

Bayesian analysis, Forest plot of play, Joint attention, Communication and language variables, as well as Significant Spearman correlations among play, joint attention, communication and language variables, showed overall evidence of improvement in the CR NFC domains compared to the traditional domains.

5. Discussion

5.1. Results

The findings suggested that CLD should be culturally situated, bringing to the fore the role of family and culture through cultural responsiveness. Culturally responsive tangible systems can offer environments that reduce barriers to engagement, enhance dyadic dialogic interactions, change behaviours, and enhance CLD in early autism interventions. Supporting embodied, child-led interaction, the system enables CLD to emerge through meaningful engagements rather than through an individual's set of skills or structured tasks.

CLD emerged as a mediated process through interaction among the autistic child, parent or carer, NFC bricks, the visual cue cards, and the home environment, validating the reconceptualisation of CLD in interventions for autistic young children of West African descent in home environments.

6. Conclusion and future work

The study presents a culturally responsive NFC-enabled tangible intervention that supports CLD in autistic young children of West African descent and challenges normative, linear perspectives of CLD. It contributes to emerging understandings of CLD as a multimodal, relational, and culturally situated process, demonstrating how tangible technologies and symbolic supports facilitate communicative participation.

6.1. Scalability and Future Work

Future research will investigate the sustainability of effects, whether changes persist beyond novelty, scalability across diverse cultural contexts, and the intervention's integration into wider healthcare and wellbeing frameworks. Further investigation will be made on embodied communication, multimodal interaction, and culturally situated communicative practices

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Bridging the Support Gap with Generative AI Enabled Learner Profiles for Adolescents with Autism

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Abstracts

Current autism profiling frameworks are grounded in the medical model, persistently failing to translate diagnosis into effective classroom support. While the neurodiversity movement advocates for learner-led, integrated profiling, existing approaches remain clinician-driven and adult-authored. This paper reports Phase 1 findings from a two-phase study currently underway in Southern California. Across 111 responses in five stakeholder datasets, adolescents with autism and their caregivers are not merely open to generative AI-assisted profiling but actively requesting it, most emphatically among communities currently most poorly served. Phase 2 pilots a chatbot-based profiling system comparing large and small language model performance in generating learner-led, multi-domain profiles.

1. Introduction

Educational planning for learners with autism is traditionally based in clinics, linear, and led by professionals and educators (Adako et al., 2024; Papadopoulos, 2024; Pierres et al., 2024). Following initial screening, clinical profiling is used to observe a child's behaviour and communication in the classroom and consult the child's caregivers on strengths and needs (Chen et al., 2023). Findings are used to create an official educational document listing the child's strengths, needs, and goals for remediation, called an IEP (individualised educational program/plan) in the US and an EHCP (educational, health, and care plan) in the UK (Koßmann, 2022; Wright et al., 2021). This is a medical-model aligned framework, where autism is a disability to be compensated for by trying to reduce students' supposed "autistic traits" (Hannant, 2024). The traditional model has struggled to translate accurate diagnoses to effective teaching practices, described by researchers as a "support gap" (Ducarre, 2024; Hannant, 2024; Van Den Plas et al., 2024; Anderson-Chavarria, 2022). Critics of the current model desire radical change because neurodivergent students receive less or worse support than their neurotypical peers (Sidjaja, 2024; Jonkman et al., 2023; Kelly et al., 2019).

The neurodiversity movement alternatively posits that autism is one facet of a far larger spectrum of cognitive functioning (Hunt & Procyshyn, 2024; Megari et al., 2024), advocating for holistic, learner-led, self-determined, and inclusive support (Ducarre, 2024; Van Den Plas et al., 2024; Anderson-Chavarria, 2022). Their highlighting of the support gap has led to increased interest in learner profiles (Jones et al., 2023; Astle et al., 2022; Fletcher-Watson, 2022), unofficial educational documents containing key background information about the child that inform IEPs and EHCPs, enable classroom support, and provide learning targets and interventions (Tlili et al., 2022; Zajic et al., 2019; Vizard, 2009). These documents operate alongside, and aren't alternatives to, formal diagnoses/plans, offering educators organised, learner-specific analysis, understanding, and context (Herrero-Martin et al., 2024; Petersson-Bloom & Holmqvist, 2022).

Despite this promise, even "neurodiversity-aligned" learner profiles retain key aspects of the medical model, generally being driven by clinicians/institutions and authored by adults, with insufficient emphasis on self-determination (McLennan et al., 2025; Cook, 2024; Ducarre, 2024; Hasson et al., 2024; Herrero-Martin et al., 2024; Van Den Plas et al., 2024; Anderson-Chavarria, 2022; Dwyer, 2022; Green et al., 2022). Both models' approach remains outside-in, not learner-led.

A corresponding research gap reflects a lack of certainty on how the shift toward implementing integrated learner profiling will happen in practice (Cook, 2024; Schuck et al., 2021). One promising direction is generative AI (GAI), which several researchers have identified as a possible tool for streamlining profiling work (Adako et al., 2024; Pierres et al., 2024; Bahroun et al., 2023; Holmes & Porayska-Pomsta, 2023; Niemi et al., 2023).

However, the current literature remains limited to partial solutions and clinician-driven diagnostic automation (Adako et al., 2024a; Herrero-Martin et al., 2024; Li et al., 2024). Most relevant research takes a clinician-driven, not learner-led approach (Herrero-Martin et al., 2024; Horgan et al., 2022; Stack et al., 2021; Dole et al., 2016), few studies have surveyed key stakeholder groups to study GAI chatbot usage or used current technology (Atturu et al., 2025; Giannakos et al., 2024; Herrero-Martin et al., 2024; Li et al., 2024; Erden et al., 2020), and when learner inputs have been democratised, authority might have only transitioned from clinician to caregiver, not necessarily the learner (Herrero-Martin et al., 2024; Papadopoulos, 2024; Schuck et al., 2021). The two-phase methodology below directly addresses this gap, testing whether GAI can support genuinely learner-led, integrated profiling for adolescents with autism at scale. It does this by having AI become the medium of engagement for stakeholders, rather than another analyst of learner behaviour.

2. Methodology

My methodology has two phases. Phase 1 collected survey data examining stakeholder attitudes toward the current system of autism support, AI tools, and key cultural context dynamics. Phase 2 develops and pilot-tests a proof-of-concept natural language chatbot that conducts profiling interviews with learners and caregivers through a messaging platform of their choice, following a structured script like a practitioner without clinical gatekeeping. Phase 1 comprised a six-month online survey study with 111 responses in five stakeholder groups (English-speaking professionals and both English and Spanish-speaking caregivers and adolescents). Learners had either a formally documented/self-reported autism diagnosis without intellectual disability (IQ > 70), completing an online survey independently/with minimal assistance. Educators/professionals had at least three years of experience working with learners with autism and were familiar with educational profiles. Separate surveys for each group were developed and deployed, with primarily Likert scale questions (examining views on current autism support methods, learner autonomy, GAI technology, technological comfort, openness to AI-generated educational profiles, and contextual acceptability) and two open-ended questions per survey. A summary table of key results from Phase 1, derived from a full integrated analysis of survey responses, is provided (see Table 1 below). 80–90% of adolescents from Black/African/Caribbean backgrounds were dissatisfied with their support compared to their White peers, but this does not mean that they think AI could be less helpful. In terms of professional contact, the autism diagnosis & care systems are not sensitive enough to cultural and linguistic variation. Having surveyed adolescents and caregivers, they say that firstly, there needs to be a human-in-the-loop (professional review), and secondly, that stakeholders need to have dynamic consent.

Key Findings:
Black/African/Caribbean adolescents had a 1.07 point current satisfaction gap compared to White peers (M = 3.29 v. M = 4.36), but near identical motivation for AI adoption (gaps of 0.05–0.18 across all items).
Cultural and linguistic responsiveness was the only below-neutral item in the whole professional dataset (M = 2.93).
Near-ceiling privacy and governance findings (professional review before sharing (M = 4.43) and learner consent/data privacy (M = 4.22–4.50 across stakeholder groups) constitute Phase 2's design specifications.

Table 1: Summary of Key Phase 1 Results.

Phase 2 will also happen over six months, with 5–10 new learner-caregiver pairs and the same inclusion criteria. Phase 2 will be designed in response to the governance requirements and cultural responsiveness gap seen in Phase 1, while the recruitment strategy responds to cultural and linguistic barriers (clinical monolingualism advice & *familismo/confianza* gatekeeping) identified in Phase 1. Phase 2's first month focused on developing an initial 100-question chatbot script and selecting/configuring an SLM and LLM for parallel testing across different third-party platforms. Following ethical review and secure, HIPAA and GDPR-compliant deployment, the chatbots undergo pilot usability testing with learner-caregiver pairs over three months. Half the pairs will use the SLM chatbot and half the LLM, each completing one to three sessions of 30–60 minutes in which learners independently answer the script's questions on their device, observed by their caregiver. Data points are analysed iteratively post-session to refine the script/adjust the UI, with a final usability evaluation determining platform and model selection based on mean usability scores, bandwidth feasibility, and qualitative learner autonomy feedback. These two phases collectively assess the feasibility, technical viability, and stakeholder acceptability of GAI-driven, learner-led profiling, generating contextually-relevant preliminary comparative evidence on LLM vs. SLM performance.

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From Generic Guardrails to Pillars in the Structure of AI: Specificity in Paediatric Neurodisability & Neurodivergence

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Abstract

When so much of AI technological development is targeting strong and underlying elements of the human condition, mandatory markers in the sand are required. Market self-regulation does not work, as shown by the attention economy. What is needed are codified pillars, not just *guardrails*, to protect those with neurodisability and those who are neurodiverse. There are two required pillars: protection from social murder, where systemic inequity leads to preventable deaths, and protection from psychological attachment abuse arising from the emerging attachment economy. Existing AI regulatory frameworks raise questions about how vulnerabilities, disability, and dehumanised pattern recognition are recognised or obscured. This project maps AI regulations from this perspective.

Introduction

There is a gap between what regulatory approvals for Artificial Intelligence (EU Parliament and Council, 2024) should do and what they achieve. Regulation protects the public, especially the most vulnerable, such as children, from exploitation by AI tools. The EU act was the widest ranging in its limitations on the extent of AI applications, yet these regulations mention *vulnerable children* only inferentially, i.e., generic references to a wider and protected characteristic such as disability. Children with Neurodisability and Neurodivergence are unaccounted for. Other major adopters of regulations, (i.e., the United States and the United Kingdom) do even less. We explore artificial intelligence regulation through that lens, arguing that current AI regulatory efforts are cursory, only recognise "vulnerable populations" in generic terms, and are therefore not well prepared to address subtle, dehumanising, and pattern-based forms of harm (Woersdoerfer, 2025).

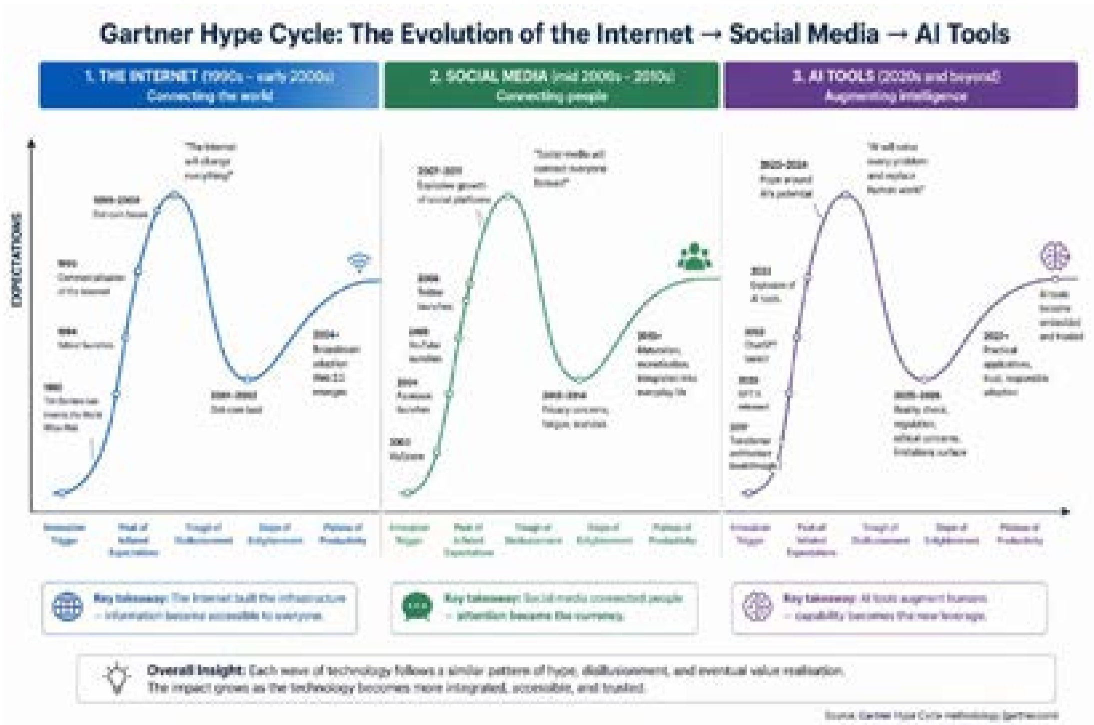

Figure 1: Gartner Hype Cycle across Internet, Social Media, and AI tools.

The current evolution of AI tools follows the Gartner hype curve model (see figure 1 above), following the evolution of the internet and social media. In that space, over 80 different versions of AI regulation are currently in circulation, with none driving wholesale international action. Successful adoption appears limited primarily because of funding-related conflicts of interest. AI regulation adoption roughly doubles every two years. In 2017, only 1 country had active AI regulation, but as of 2025, 38 countries have such regulations, and half of all UN member states (70+) have an AI plan/equivalent policy trajectory. The 2021 UNESCO recommendation on AI ethics was aimed at its 190+ member states, becoming highly influential in establishing ethical principles and human rights safeguards. Yet the only binding agreement, akin to nuclear treaties (Harding, 2024) (revealing AI's level of importance) has been the Council of Europe AI Convention (EU Parliament and Council, 2024) which attempted to establish clear guard rails *first*, assuming that protections are needed. However, they do not go deep enough, as this project explores.

1. Race to the bottom of the brain stem

With artificial intelligence and related digital technologies, our traditional legal understandings are being tested. Over the last three decades, we have engaged in what has been called a "race to the bottom of the brainstem" (Harding, 2024; Shroff, 2025). This began with emails, then the growth of the internet, then the so-called Web 2.0 with platforms like Facebook and Yahoo!, then into social media, and finally, into artificial intelligence. This is a completely new kind of race, which has revealed some of humanity's worst parts. Collectively, digitally, and at scale, our legal and regulatory instincts have not kept pace. This has happened within roughly a generation. The pace of change is so fast that traditional boundary-creating modes are circumnavigated. While pattern recognition makes us human, it can also work against us. As humans, we look for similarities in other people, things, and ways of interacting (Baron-Cohen, 2020), but this same pattern recognition can drive prejudice, bias, and, in its worst forms, a complete lack of empathy for groups we do not understand, or those we "other". These tendencies will always be encoded into large-scale AI systems, magnifying and automating structural harms, rather than merely encouraging isolated individual acts.

1.1. Mandatory Pillars and Guardrails

When so much of our technological development is targeting, whether consciously or not, fundamental and underlying elements of the human condition, then placing mandatory markers in the sand is a necessity. There is no point suggesting the market will regulate itself for humanity's betterment; it will not, as shown by the attention economy. Instead, we need a codified set of guardrails protecting those individuals who have i) neurodisabilities, that collection of neurological impairments from Cerebral Palsy, through to Profound (severe) Autism, and ii) those who are neurodiverse, like individuals with autism, dyslexia, dyspraxia, and ADHD. Mostly, neurodiverse individuals have needs, which can be sensory, but generally, communicate and use language effectively. Unlike them, individuals with neurodisabilities face lifelong and often congenital problems, often coupled with intellectual and/or physical impairment. In this light, required pillars should perform (at least) two functions: protecting those with neurodisability/disability itself from social murder, and protecting those with neurodiversity from psychological attachment abuse.

1.2. Neurodisability and Social Murder

Social murder (Ryan, 2026) encapsulates the notion that society acts through prejudice, e.g., policy that actively "others" disabled people, which makes them be seen as less than other people. As a result, the treatment of those with disabilities creates systemic inequity, which is known and can be ameliorated. Yet, nothing is done, particularly addressing preventable deaths of those with neurodisability, which is known as social murder. For example, it is well known (Mouridsen *et al*., 2008; Ryan, 2026) that one complication of profound autism is epilepsy, which is a leading cause of mortality through drowning. Yet, health, education, and social care policy and practice have not reflected this knowledge until recently (Xie et al., 2025). This system-level failure possibly excludes change, when instead, this knowledge should lead to proactive co-production, and therefore, a reduction in mortality rates (Ryan, 2026). Systemic patterns should be emphasised by AI and not overlooked.

1.3. Neurodiversity and Psychological Attachment Abuse

No less concerning is the worrying emergence in the technological move from the attention economy toward the emerging attachment economy. The former is well documented (Shu, Lai, and He, 2026), but the attachment economy is newly developing in terms of its breadth and individual impact. People are reportedly already in relationships with AI characters, and in some cases have "married" them, leading to negative effects on their well-being (Papadopoulos, 2025). Further, the slow creep of AI into pre-schoolers' toys places AI in a newly vulnerable space, and engaging with AI could potentially supersede and overshadow critical emergent and social skills like theory of mind (ToM) and self-regulation. If ToM is outsourced to a non-biological entity, the resulting developmental processes would no longer be shaped by human feedback loops (Center for Humane Technology, 2026). We aim to draw on existing AI regulatory frameworks (i.e., the EU AI Act and international principles from organisations like the OECD and UNESCO), as well as equality concepts, such as protected characteristics (sex, gender, ethnicity, disability), to ask: to what extent are disabled and neurodiverse children explicitly coded into AI regulation, and where are they simply assumed to be covered by generic references to "vulnerability" or non-discrimination?

2. Methodology

2.1. Research design, sources, & strategy

This study employs Systematic Literature Review (SLR) combined with a scoping review approach to identify, analyse, and compare international artificial intelligence (AI) regulatory frameworks for children who have either a disability, neurodisability, or are neurodivergent. This hybrid design is due to the rapidly evolving and heterogeneous nature of AI governance, and both structured evidence synthesis (SLR) and broad exploratory mapping (scoping review) are required to capture academic, policy, and legal developments and reflect AI governance research (Batool, Zowghi and Bano, 2025). Data is going to be collected from three source categories: 1) Peer-reviewed academic literature (journals and conference proceedings), 2) Policy and regulatory documents (e.g., national AI strategies, supranational frameworks, and regulatory acts such as EU AI policy instruments), and 3) Institutional and international organisation reports (e.g., OECD, UNESCO, and regulatory agencies). A structured keyword search strategy will be applied around Boolean search terms on neurodisability, neurodivergence, and disability, using terms such as “AI regulation,” “AI governance frameworks,” “algorithm accountability,” and “risk-based AI regulation.” This multi-source approach reflects established practice in AI governance research, where policy and legal documents are treated as primary analytical material alongside academic literature due to the field’s policy-driven nature (Morley *et al.*, 2022).

2.2. Initial Search

An initial search and review of peer-reviewed academic literature was conducted on June 11, 2026, using Cambridge University’s online iDiscover service. The initial search was conducted using this search string and looking for articles containing these items, in any field: ("AI regulation" OR "AI governance" OR "algorithm* accountability" OR "risk-based AI" OR "artificial intelligence governance") AND (neurodisabilit* OR neurodiverg* OR disabilit* OR "neurodevelopmental disorder*" OR autis* OR ADHD). Search results were limited by date (from 2011 to 2026) and language (only English results were considered). In total, 39 articles were identified through this initial search. After 2 duplicates and 2 foreign-language articles were removed, 33 articles were screened based on title and abstract. Of that universe of screened literature, 15 articles were sought for retrieval and assessed for eligibility (18 being excluded). Of those articles that were sought for retrieval, 9 articles were removed because they did not address the topics being examined (AI regulation/governance/ through the lens of neurodisability/neurodivergence, etc. – 8 articles) or because they were unavailable (1 article). After the completion of this initial search (and article selection and appraisal process), 6 articles have been identified as the starting point that the remainder of the review will build upon.

3. Initial results

Each of the included initial articles help to underline the importance of the two pillars and validate the foci of the broader project. First, Curtis et al. (2026) help demonstrate that merely automated models of AI governance cause systemic inequities, restricting the provision of key resources and, at least implicitly, risks social murder. Marland & Arantes (2026) offer a useful conceptual balance to the Curtis et al. (2026) article by positing that the social model of disability should mean that educators, administrators, and policymakers change their focus from attempting to “fix” whatever vulnerabilities the individual has to instead restructuring the environment (in this case, the AI architecture) around the individual, through legal means, and in doing so, obviating institutional barriers that previously existed. In addition, the analysis of Sousa et al. (2024) regarding affective computing demonstrates how it, arguably as part of the attachment economy, can read, manipulate, and exploit human emotions, which poses particularly acute risks to paediatric populations with neurodivergence. Block (2026)'s analysis of Article 50(1) of the EU AI Act provides a significant critique of existing legislative guardrails, which, for example, only have simplistic disclosure requirements, which helps to show why standard transparency laws are not effective or strong enough to protect children, particularly children with neurodivergence, from deep psychological attachment manipulation. More broadly, Bolarín-Miró et al. (2026) explicitly identify specificity as being a key requirement for global AI policies if they are to move beyond the generic category of "vulnerability" and therefore, helpfully and clearly promoting the flourishing of neurodivergent individuals. Finally, Kemigisha (2025) shows that truly inclusive governance of AI should not just be another regulatory requirement, but rather necessary in moving toward a macro-sustainable future. These articles will be used as a baseline for the broader analytical approach, the results of which will be presented in full at the conference.

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05

VR FOR ANXIETY, PTSD & OCD

Creation of a virtual reality application for remote exposure therapy in social anxiety disorder

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Abstract

This paper describes the design and development of a self-guided VR application for remote exposure therapy targeting social anxiety disorder (SAD), referred to as FaceTheCrowd VR. It focuses on the design of interactive virtual environments and non-player characters enabling gradual exposure to socially challenging situations. The application is structured as a level-based experience in which users progress through scenarios of increasing social complexity within a simulated environment. The design of the exposure scenarios was based on previous studies identifying common anxiety-provoking social situations in individuals with SAD. The paper discusses the design considerations behind the virtual environments, character interactions, and technical implementation of the system, and outlines how these elements support the therapeutic goals of exposure therapy.

1. Introduction

Social anxiety disorder (SAD), also referred to as social phobia, is characterized by an intense fear of negative evaluation during social interactions and often leads to avoidance of everyday social situations (Schneier et al., 2015). SAD can be highly distressing, fundamentally affecting all areas of everyday life. The gold standard treatment for SAD includes pharmacotherapy and cognitive-behavioral therapy (CBT), with exposure therapy as a core component typically delivered in vivo (Canton et al., 2012).

Virtual reality exposure therapy (VRET) provides an alternative approach that has shown promise in replicating real-world scenarios while maintaining a safe and controlled environment (Horigome et al., 2020). Importantly, VR technologies enable the development of self-guided interventions that may improve accessibility of treatment for individuals with social anxiety. On the one hand, many individuals avoid face-to-face therapy due to personal barriers such as fear of social interaction, time constraints, or financial limitations. On the other hand, traditional exposure therapy is also limited by practical constraints, including the difficulty of recreating specific social situations, spatial limitations, a lack of available care providers, and long waiting times.

This paper presents the design and implementation of a self-guided VR application aimed at supporting remote exposure therapy for individuals with social anxiety.

2. Methods

This section describes the technical implementation and design of the proposed VR application. It outlines the hardware and software used to develop the system, the design of the exposure scenarios, sounds and non-player characters (NPCs), as well as the methods used for data collection.

1.1. Hardware and Software

The proposed solution is targeted at Meta Quest 2 and Meta Quest 3 headsets, as they are widely available and among the most used standalone VR headsets. The application is controlled using VR controllers, enabling the users to navigate the environments (via teleportation) and interact with objects.

The application is made in Unity game engine and uses XR Interaction Toolkit, which provides a high-level interaction framework for VR applications. Firebase online database is used to store user behavioural data outside the VR headset. The NPCs that appear inside the application are created in Character Creator 4.

1.2. Design of the Scenarios

The design of the virtual exposure scenarios was based on data from an online survey (N = 149) identifying common anxiety-provoking social situations experienced by individuals with social anxiety. The situations reported as most anxiety-provoking included public speaking in front of strangers, job interviews or debates, and situations involving public embarrassment. This was in parallel supported by the systematic review performed in our lab (Jakeš et al., under review). The scenarios (see Figure 1) are structured to allow gradual exposure, progressing from lower-intensity interactions to more socially demanding situations. Each scenario includes an introductory level that allows the user to explore the environment without other characters present and to practice the interactions used in the subsequent levels.

In the *Cafeteria* scenario, the user completes tasks such as entering and leaving the building, waiting for the server, ordering food, consuming it, and paying for the meal. The higher levels introduce more demanding situations, such as receiving an incomplete order or having to sit with another customer.

The *Interview* scenario consists of interactions with a receptionist, using an elevator, waiting in a waiting room, and subsequently answering interview questions for a specified duration of time. As the difficulty increases, additional characters appear in the building, interview room, and elevator. The user may encounter situations such as being told they arrived on an incorrect date, overhearing interviewers being rude to another applicant, or having to apologize for their phone ringing.

In the *Public Speaking* scenario, the user waits until they are invited to give a speech, approaches the podium, looks around the conference room, introduces themselves, and delivers a speech on a given (randomized) topic. In later levels, the user also answers questions from the audience. The difficulty primarily depends on the speech topics and the audience's reactions. In the second level, the user describes an image instead of being given a written topic, while in the third level the topics focus on the user's personal opinions and the audience members behave in a distracting or disengaged manner.

Figure 1 Screenshots of the scenarios. From left to right: Cafeteria, Interview, and Public Speaking.

1.3. Non-player Characters

The characters used in the application are created in Character Creator 4 (CC4) by Reallusion. As the application is intended to run on standalone VR headsets with limited computational resources, the characters have been converted to the Game Base format prior to export, which provides a more optimized representation suitable for real-time applications. Running the application with five non-optimized characters creates a significant reduction in frame rate, making the application difficult to use. Low frame rates in VR are known to increase the risk of simulator sickness, making performance optimization essential.

Each character is imported into the Unity game engine using the Unity Auto Setup plugin provided by Reallusion. After import, an Animator Controller component is assigned to the character to manage its animations. Most animations used in the application are sourced from ActorCore by Reallusion, as they are designed to be compatible with CC4 characters. Some animations were further modified directly in Unity to better fit the requirements of the application.

Based on the feedback from the validation study, the characters now also have facial animations (e.g. mouth movement, blinking, and facial expressions). These play an important role in social interaction and may influence the perceived realism of NPCs. This is particularly relevant for social anxiety, where some individuals are sensitive mainly to the presence of other people, while others respond more strongly to direct social evaluation and reciprocal interaction.

To improve scene loading performance, characters are instantiated after the scene is loaded using Unity's Addressables system. This approach also enables randomization of the characters present in the scenario. Randomizing the characters increases replayability, as users may encounter different characters during repeated sessions (e.g., sitting at a table with different NPCs in the Cafeteria scenario), which may be perceived differently by the user.

Characters with more complex behaviours are assigned a *BehaviorTreeRunner* component, which executes a behaviour tree (BT) stored in a Scriptable Object. Behaviour trees are commonly used for creating modular and reactive control systems for agents, enabling flexible switching between different tasks (Colledanchise et al., 2018).

The behaviour trees used in the application contain action nodes such as *ChangeAnimationBool, InvokeEvent, WaitForEvent, Wait, Speak,* and *WalkToPosition*, each with configurable parameters. For example, the Speak node specifies the audio clip that should be played while the node is active.

Character locomotion is controlled using Unity's *NavMeshAgent* component. Each scene therefore contains an object with a *NavMeshSurface* component with pre-baked navigation data.

1.4. Data Logging

During each scenario, two types of data are collected periodically (several times per second): data logging the user's behavior in the virtual environment, and events occurring within the application. This data is stored in a *.csv* file, which enables later automated data analysis.

The positions and rotations of the user's head and hands are tracked, together with the locations to which the user teleports within the environment, allowing reconstruction of the user's behavior during the scenario. To provide additional contextual information, the first object located in front of the user's head is also logged. As Meta Quest 2 and Meta Quest 3 headsets do not necessarily provide eye-tracking functionality, this serves as an approximation of what or whom the user is looking at. The volume of sound captured by the headset's microphone is also recorded, allowing approximate detection of whether the user is speaking.

As the scenarios contain quests for the user to complete, each quest completion event is logged, making it possible to connect user behavior with the current task objective. Another logged element is the name of the audio clip played at a given time interval, to see that an NPC is talking, some distracting sound is playing, etc.

Additional scenario-related information that is not bound to specific time intervals is stored in a *.json* file. This includes the participant ID (used to distinguish anonymous participants in studies), level name (indicating the scenario and its difficulty level), application build version, and NPC data (such as the names and/or genders of the generated NPCs). The file also contains psychological measures, including STAI-6 scores (State–Trait Anxiety Inventory values recorded before starting the scenario) and quest-related anxiety ratings measured using the Subjective Units of Distress Scale (SUDS) after completing the scenario.

All data is stored locally on the VR headset and, if a network connection is available, also uploaded to a Firebase server to reduce the risk of data loss (e.g., if the application is removed from the device).

1.5. Sounds

Sound plays an important role in increasing the sense of immersion within the application (Srithammee et al., 2025). Each scenario contains ambient environmental sounds appropriate to the given setting. For example, in the Cafeteria scenario the user can hear background sounds such as utensils clinking and people chatting. Higher difficulty levels incorporate additional distracting or potentially unsettling sounds, such as laughter, phones ringing, or people coughing, which are intended to increase the social pressure experienced by the user. The sound effects used in the application are obtained from online repositories providing audio under the Creative Commons Zero (CC0) license, such as Freesound.

Character dialogue is currently generated using the Narakeet text-to-speech (TTS) system as they provide Czech language TTS.

3. Results

Preliminary results from a validation study indicate that the VRET environment successfully induces anxiety in individuals with SAD compared to a non-phobic control group, supporting the ecological validity of virtual scenarios. In the validation of the Cafeteria scenario (experimental group: $n = 26$, control group: $n = 20$), differences in overall anxiety ratings (SUDS) between groups are statistically significant across all exposure levels (analyzed via non-parametric Mann-Whitney U test: level 0 – $U = 116$, $p = 0.001$, $rrb = 0.552$; level 1 – $U = 33$, $p < 0.001$, $rrb = 0.873$; level 2 – $U = 31$, $p < 0.001$, $rrb = 0.881$; level 3 – $U = 17.5$, $p < 0.001$, $rrb = 0.933$). Similarly, in the validation of the Interview scenario (experimental group: $n = 20$, control group: $n = 20$) statistically significant differences in SUDS ratings were observed at all exposure levels (Mann-Whitney U test: level 0 – $U = 118$, $p = 0.020$, $rrb = 0.410$; level 1 – $U = 33.5$, $p < 0.001$, $rrb = 0.848$; level 2 – $U = 43.5$, $p < 0.001$, $rrb = 0.782$; level 3 – $U = 38$, $p < 0.001$, $rrb = 0.800$). Both scenarios were rated by participants as easy to understand, providing an appropriately graded level of difficulty. A similar validation study of the Public speaking scenario is currently in progress. More detailed description of the VR application and validation results will be presented at the conference.

4. Conclusion

This paper presents the design and implementation of FaceTheCrowd VR, a self-guided VR application for exposure therapy targeting social anxiety disorder. The system provides a structured, level-based experience across three socially challenging scenarios of increasing complexity, designed to support the core therapeutic principles of gradual exposure. Preliminary results from a pilot validation study demonstrate that the application successfully differentiates anxiety responses between individuals with SAD and non-anxious controls, supporting the ecological validity of the designed virtual environments. These findings suggest that self-guided VRET represents a promising and accessible complement to traditional exposure-based interventions, particularly for individuals facing various barriers to in-person therapy.

The main contribution of this work is the design and implementation of a self-guided VR system for exposure therapy, together with a set of structured social scenarios and a data logging framework enabling behavioural analysis. Future work will focus on feasibility study for remote use, and evaluation of the effectiveness of repeated exposure sessions in social anxiety symptom reduction.

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Virtual Environments for Patients with Obsessive Compulsive Disorder in Outpatient Care

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Abstract

This paper describes an RCT study examining VR-based exposure and response prevention (VR-ERP) therapy as an addition to standard care for outpatients with obsessive-compulsive disorder (OCD). A within-subject waitlist-controlled design is used; a 5-week waitlist followed by five weekly VR-ERP sessions. Symptom severity was measured using the Subjective Yale-Brown Obsessive-Compulsive Scale (YBOCS-SR) at study intake, after the waitlist period, after the VR-ERP period, and at a 2-month follow-up. Results show a significant reduction in OCD symptoms following VR-ERP ($p < .001$), maintained at follow-up ($p = .001$). Participants reported engagement in between-session exposures and rated the VR-ERP as useful.

1. Introduction

Obsessive-compulsive disorder (OCD) is a severe psychiatric condition characterized by obsessions (unwanted intrusive thoughts, urges, or images) and compulsions (repetitive, ritualized behaviors or mental acts) (American Psychiatric Association, 2022). Cognitive-behavioral therapy (CBT) with exposure and response prevention (ERP) is the gold-standard treatment for OCD; however, access remains limited, and dropout rates are high, partly because in-session exposure to feared stimuli can be difficult to arrange and emotionally demanding for both patient and therapist (Ong et al., 2016). Virtual reality (VR) offers a controllable, gradable, and ecologically valid alternative for delivering exposure, enabling patients to confront personally relevant triggers in a safe, repeatable environment (Fajnerová et al., 2023). VR-based exposure therapy has demonstrated promise in anxiety-related disorders, including specific phobias, social anxiety, and PTSD (Freeman et al., 2017). Evidence specific to OCD is emerging but limited, with early studies suggesting that VR environments can provoke clinically relevant anxiety and facilitate habituation (Bouchard et al., 2019; Fajnerová et al., 2023). The present study reports pilot data from an ongoing outpatient trial investigating the feasibility, acceptability, and preliminary efficacy of weekly therapeutic sessions with VR-based exposure and response prevention (VR-ERP) technique in adults with OCD.

2. Methods

2.1. Study Design and Participants

The study employed a within-subject waitlist-controlled design. Following screening and baseline assessment, participants were placed on a 5-week waitlist (no changes to ongoing treatment) before beginning VR-ERP. Assessments were administered at four time points: study intake (Intake), after the waitlist period (5W WL), immediately after the final VR-ERP session (5W VR-ERP), and at a 2-month follow-up (2M FU).

Eligible participants were adults aged 18–55 with a primary diagnosis of OCD (ICD-10: F42) and no severe psychiatric or neurological comorbidity. Participants were permitted to continue their pre-existing pharmacotherapy or psychotherapy without changes 2 months before study intake and throughout the study. Exclusion criteria included substance use disorders; psychotropic medications other than antidepressants, antipsychotics, or hypnotics, and medical contraindications to VR use (e.g., epilepsy, severe vestibular or neurological disorders).

2.2. Procedure

At intake, participants signed an Informed consent and completed a clinical interview, questionnaire battery, and a brief psychoeducation session covering the cognitive-behavioral model of OCD and the explanation of exposure with response prevention technique. The VR-ERP program comprises five individual sessions delivered once per week. It takes place in an immersive VR environment ("OCD house") with stimuli tailored to each participant's symptom profile, as described in Fajnerová et al. (2023) (see Figure 1 and project website https://ocddum.cz/en for more details).

2.3. Measures

Primary outcome: OCD symptom severity was assessed using the self-report version of the Yale-Brown Obsessive-Compulsive Scale (YBOCS-SR). Secondary measures included the Beck Anxiety Inventory (BAI), the Beck Depression Inventory (BDI), and the Trait subscale of the State-Trait Anxiety Inventory (STAI-T). Participants also completed a personalised fear hierarchy and, at each VR-ERP session, rated (a) the number of between-session self-directed real-life exposures completed in the preceding week, (b) the proportion of exposures in which they successfully resisted compulsions, and (c) the perceived usefulness of the VR session for managing exposure-related anxiety in daily life.

Figure 1: Illustration of the VR-based "OCD house" stimuli for exposure and response prevention therapy.

3. Results

3.1. Sample

Forty-two participants were enrolled (23 men, 19 women, mean age: 34.69 ± 10.471). To date, 22 participants (52%) have completed all four assessment time points and are included in the primary analyses. 19 participants discontinued the study for the following reasons: overall deterioration of mental health (N = 2), did not show up/the distance to care was too long (N = 2), high-risk pregnancy (N = 2), change of treatment in the waiting list period (N = 3), financial reasons (N = 1), did not profit from the treatment (N=1). The remaining participants are either still in the study (N = 1) or the reasons for not completing it are unknown (N = 7).

3.2. OCD Symptom Severity

A Friedman test revealed a significant change in YBOCS-SR scores across the four time points ($\chi^2(3) = 11.17$, $p < .001$). Post hoc pairwise comparisons showed no significant change during the waitlist period. Following VR-ERP, symptom severity was significantly lower than at intake ($p < .001$) and lower than at the end of the waitlist period ($p = .048$). At 2-month follow-up, scores remained significantly below both the intake level ($p = .001$) and the pre-VR-ERP level ($p = .017$), indicating maintenance of therapeutic gains. Figure 2 illustrates YBOCS-SR trajectories across all four time points.

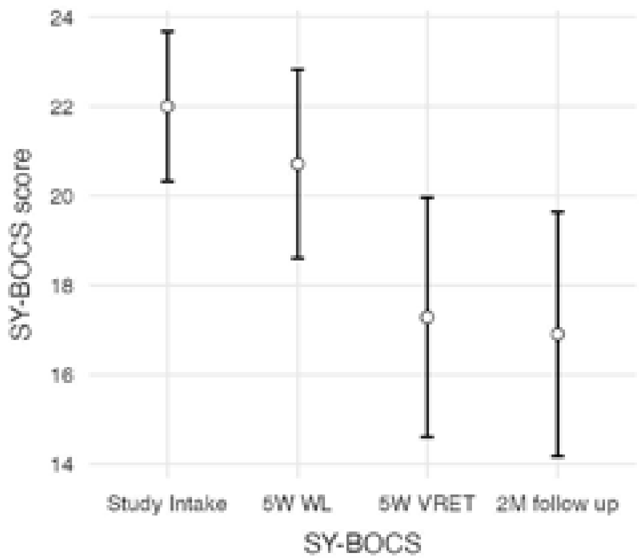

Figure 2 Changes in YBOCS-SR scores (Subjective Yale-Brown Obsessive-Compulsive Scale) across four time points: study intake (Intake), after the 5-week waitlist (5W WL), after 5 weeks of VR exposure and response prevention therapy (5W VR-ERP), and at the 2-month follow-up (2M FU).

3.3. Adherence and Perceived Usefulness

Participants assessed their adherence to exposure sessions and the usefulness of VR-ERP for managing exposure and more challenging situations in everyday life. The assessment revealed that they actively engaged in exposure sessions outside virtual reality, most frequently performing **2–5** per week. They were able to prevent compulsions in at least **one-third of cases** and considered the virtual reality exposures **useful** for managing further exposures throughout the week (see Figure 3).

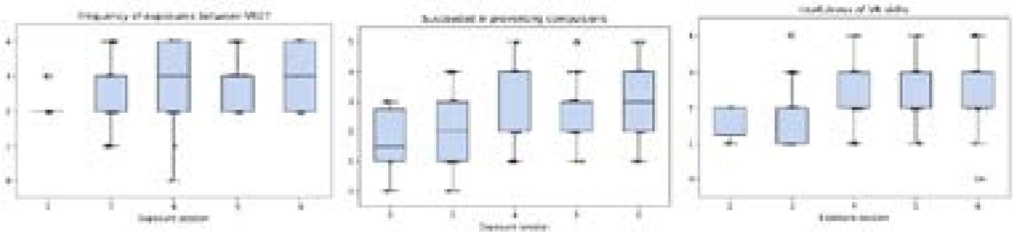

*Figure 3 Self-reported adherence where: 4 = more than 10 exposures, 3 = 6–10 exposures, **2 = 2–5 exposures**, 1 = less than 2 exposures, 0 = no exposure (on the left), succession in preventing compulsions where: 5 = always, 4 = most of the times, 3 = in half of the cases, **2 = in third of the cases,** 1 = rarely, 0 = never (in the middle) and perceived usefulness of VR-ERP, where: 4 = extremely useful, 3 = very useful, **2 = quite useful,** 1 = a little useful, 0 = not at all useful (on the right) across sessions. Values in bold indicate the mean rating across all sessions.*

4. Discussion

The present data suggest that VR-ERP is an effective and well-tolerated intervention for outpatients with OCD. Participants showed a statistically significant reduction in Y-BOCS scores following five weekly VR sessions, and this effect persisted for 2 months after treatment ended. These findings are consistent with the broader literature demonstrating VR's capacity to elicit clinically meaningful anxiety responses and support habituation in exposure-based protocols (Fajnerová et al., 2023; Freeman et al., 2017).

A notable feature of the results is the transfer of skills from the VR environment to real-life settings: participants engaged in frequent between-session exposures and rated the VR training as useful for managing anxiety-provoking situations in daily life. As this is an ongoing study, we present the data as a preliminary report and hope to see more participants complete all four stages of the protocol. Taken together, the pilot results provide promising preliminary support for the feasibility and efficacy of weekly VR-ERP as an adjunct outpatient intervention for OCD.

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Detection and Prevention of Post-Traumatic Stress Disorder Risk in First Responders by Means of a Virtual Reality Protocol

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Abstract

This presentation reports two VR-based studies examining PTSD-related vulnerability in first responders. Study 1 assessed physiological responses in 84 firefighters, showing that probable PTSD was associated with lower baseline heart rate variability, suggesting reduced autonomic flexibility at rest. Study 2 examined decision-making in 368 first responders and found that probable PTSD predicted poorer performance in emergency scenarios. Across studies, VR distinguished physiological and behavioral markers of vulnerability in ecologically relevant contexts. The findings support VR as a promising tool for PTSD detection and prevention.

1. Introduction

First responders are routinely confronted with potentially traumatic events, including sudden death, severe injuries, threats to personal safety, and repeated exposure to human suffering. This occupational exposure places firefighters, ambulance personnel, paramedics, and other emergency professionals at increased risk for post-traumatic stress disorder (PTSD), with prevalence estimates generally exceeding those reported for the general population (António et al., 2025; Berger et al., 2012; Petrie et al., 2018). Beyond symptom burden, PTSD may also affect capacities that are central to emergency work, including autonomic regulation, attention, processing speed, and emergency decision-making.

Virtual reality (VR) offers a methodologically and ethically useful way to assess these processes. It allows researchers to recreate high-pressure emergency contexts in a standardized, repeatable, and controlled environment, without exposing first responders or victims to real-world danger. For this reason, VR has been increasingly used in training and stress induction research (Dammen et al., 2022; Heldring et al., 2024).

However, its potential as a combined detection and prevention tool for PTSD-related vulnerability in first responders remains underdeveloped. The present extended abstract integrates two complementary VR-based studies to examine whether immersive emergency simulations can identify physiological and decision-making markers of PTSD-related vulnerability in first responders, with implications for early detection and prevention.

2. Virtual reality protocol and study overview

Both studies used immersive medical emergency scenarios designed to approximate operationally relevant situations for first responders. The VR protocol included avatar-based emergency scenes with audiovisual cues, time pressure, and decision points based on professional emergency-response procedures. Scenarios included, for example, a road-traffic accident involving injured victims and a pediatric cardiorespiratory arrest. The scenarios were developed from previous qualitative work with first responders and refined with professional input to increase ecological validity and procedural relevance.

Study 1 (António et al., 2025a) focused on physiological vulnerability. Eighty-four firefighters completed the PTSD Checklist for DSM-5 (PCL-5) and took part in a VR exposure while physiological data were recorded.

Heart rate variability (HRV), indexed by the standard deviation of NN intervals (SDNN), was used as a marker of autonomic flexibility, whereas skin conductance level (SCL) was used as an indicator of sympathetic arousal. Physiological data were collected during a one-minute baseline and during VR exposure.

Study 2 (Pinto et al., 2024) focused on behavioral performance during emergency decision-making. The sample included 368 Portuguese first responders. Participants completed measures of traumatic exposure and PTSD symptoms and were then exposed to two VR emergency scenarios. The task recorded the number of incorrect decisions and the time required to select the correct response. A composite emergency decision-making score was used, combining decision accuracy and reaction time, so that poorer performance reflected slower and/or less accurate decision-making.

Study	Sample	Primary markers	Main contribution
1	84 firefighters	Baseline/task HRV and SCL	Lower baseline HRV in probable PTSD, suggesting reduced autonomic flexibility at rest.
2	368 first responders	VR errors and reaction time	Probable PTSD predicted poorer emergency decision-making in immersive scenarios.

Table 1: Integrated overview of the two virtual reality studies.

3. Findings

In Study 1, first responders with probable PTSD showed significantly lower HRV at baseline. Using the PCL-5 cutoff score of 31, participants without probable PTSD had higher baseline SDNN than those with probable PTSD (M = 72.39 vs. 40.63 ms), with a medium effect size. The same pattern was obtained when probable PTSD was classified according to DSM-5 cluster criteria (M = 70.37 vs. 35.62 ms), with a large effect size. These findings suggest lower parasympathetic modulation and reduced autonomic flexibility at rest among first responders with probable PTSD, consistent with evidence linking PTSD to autonomic dysregulation and lower HRV (Schneider and Schwerdtfeger, 2020; Shaffer and Ginsberg, 2017).

However, HRV did not significantly differentiate probable PTSD groups during the VR task, and SCL did not significantly differentiate groups at baseline or during VR exposure. This pattern suggests that resting autonomic regulation may be more sensitive to PTSD-related vulnerability than task-phase HRV in this specific protocol. It also indicates that SCL measurement in active VR settings may be vulnerable to artifacts associated with movement, electrode displacement, or contextual factors such as temperature. Therefore, the physiological findings support HRV as a promising marker, while also indicating the need for longer baselines, recovery phases, larger samples, and improved SCL acquisition procedures.

In Study 2, 85 first responders (23.10%) met DSM-5 criteria for probable PTSD. Those with probable PTSD showed poorer emergency decision-making than those without probable PTSD, even after adjusting for age, years of education, and years of job experience. Specifically, they had higher composite decision-making scores, indicating slower and/or less accurate performance in the VR scenarios ($M = 19.60$ vs. 17.87; $F(1, 360) = 5.32$, $p = .02$, partial eta squared = .015). Structural equation modelling further showed that traumatic events had a direct negative association with decision-making scores, suggesting that greater professional exposure was associated with faster and more accurate decisions. However, traumatic exposure also had an indirect positive effect through PTSD symptoms, indicating that when exposure is accompanied by PTSD symptoms, performance becomes slower and less accurate.

Taken together, the two studies suggest that VR can reveal complementary markers of PTSD-related vulnerability. Study 1 identified a physiological marker at rest, whereas Study 2 identified a behavioral marker during simulated emergency response. Importantly, the behavioral data distinguish between exposure as professional experience, which may improve emergency performance, and PTSD symptoms as a vulnerability pathway, which may undermine decision-making under pressure.

4. Implications for detection and prevention

These findings have practical implications for the use of VR in trauma-informed occupational health for first responders. First, VR protocols may complement traditional self-report screening by providing performance-based and physiological information in controlled, ecologically relevant contexts. A screening model that integrates PCL-5 scores, resting HRV, and VR decision-making could help identify first responders who show early signs of vulnerability before difficulties become evident during real emergencies. Such use should not be interpreted as a clinical diagnosis, but as a risk-detection and referral-support tool.

Second, the protocol has prevention potential. Repeated VR assessments could be used to monitor change over time, evaluate readiness to return to duty after high-impact events, and identify professionals who may benefit from targeted psychological support, resilience training, or trauma-focused intervention. Because the protocol uses standardized emergency scenarios, it could also support stress-inoculation and decision-making training while allowing objective monitoring of errors, response times, and physiological regulation.

Third, the findings support organizational prevention strategies. First responder organizations should move beyond purely individual models of PTSD risk and adopt trauma-informed systems that combine routine screening, confidential referral pathways, supervisor education, and training designed to preserve operational performance under stress. VR is particularly aligned with this goal because it allows realistic but safe exposure to high-pressure scenarios, while generating data that can inform both individual support and organizational policy.

5. Conclusions

Across two studies, immersive VR differentiated markers of PTSD-related vulnerability in first responders. Probable PTSD was associated with lower baseline HRV, suggesting reduced autonomic flexibility at rest, and with poorer decision-making in emergency scenarios, suggesting potential operational consequences. These findings position VR not only as a training technology, but also as a promising platform for risk detection, prevention, and trauma-informed support in first responder populations. Future work should include longitudinal designs, clinical interviews, recovery-phase physiological data, and validation of integrated physiological-behavioral risk profiles.

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Virtual Reality Pre-Scan Simulation to Reduce MRI-Related Anxiety and Improve Scanning Efficiency

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Abstract

Claustrophobia and anxiety are leading causes of failed or interrupted MRI procedures, representing a significant cost burden on imaging services. This study investigated the effectiveness of a custom Virtual Reality (VR) pre-scan simulation in reducing MRI-related anxiety compared to a video-and-guided-meditation intervention and a standard control condition. Eighteen participants were allocated to three groups ($n = 6$ each). Anxiety was measured using the Claustrophobia Likert Questionnaire (CLQ) and the MRI Anxiety Questionnaire (MRI-AQ) before and after the procedure. The VR group demonstrated the greatest anxiety reduction, with a mean post-intervention score of 1.322 (SD = 0.281) versus 1.778 (SD = 0.202) in the control group. Paired t-tests confirmed statistical significance: Pre-MRI vs. Post-VR ($p = 0.0077$) and Control vs. Post-VR ($p = 0.0107$). These findings indicate that immersive VR simulation is significantly more effective than both standard preparation and video-based methods in reducing MRI anxiety, with implications for reducing sedation rates and improving scanner throughput.

1. Introduction

Magnetic Resonance Imaging (MRI) is a critically important diagnostic tool for a wide range of medical disciplines. Yet its clinical utility is undermined by a significant proportion of patients who experience great difficulty in tolerating the psychological challenge of the procedure. Up to 15% of patients experience claustrophobia severe enough to cause scan failure, premature termination, or the need for pharmacological sedation (Nguyen et al, 2020, Dewey et al., 2007). Worldwide there are estimated to be in excess of 100 million MRI scans per year, with one study quantifying the cost of claustrophobia-related failures at an estimated €1 billion in Europe alone (Enders et al, 2011).

The MRI environment is inherently challenging for anxious patients. The narrow bore (typically 60 cm diameter), loud gradient coil noise (up to 103 dB for certain sequences), prolonged scan durations, and physical immobilisation combine to create a highly stressful sensory environment (Sarji et al., 1998, Iwan et al.,2021). Traditional management strategies focused upon patient education or sedation carry significant limitations. Sedation introduces clinical risk, additional cost, and the requirement for anaesthetic staff while education alone can be ineffective (Lawal et al., 2023, Iwan et al., 2021).

Virtual Reality (VR) has emerged as a promising behavioural intervention for anxiety disorders, offering controlled, immersive exposure to feared stimuli. Prior work suggests VR can trigger authentic fear responses and support meaningful anxiety reduction with high patient acceptability (Anderson et al 2023). However, most existing VR applications in MRI have focused on in-scanner distraction rather than pre-scan preparation and familiarisation. This study addresses that gap by developing and evaluating a purpose-built VR simulation of the full MRI experience, deployed before the scan, as a behavioural desensitisation tool..

2. Methods

2.1. Study Design

This study Bridges the VR1/ VR2 development stages of the model proposed by Birckhead et al (2019). Namely it covers the design/ development and initial efficacy stages of the process. This was a prospective, controlled study with 18 adult participants (aged 18–65) recruited via word of mouth and email. Ethical approval was obtained from the Nottingham Trent University School of Social Sciences Research Ethics Committee (S3REC). Participants with no prior MRI experience were randomly allocated to either the VR intervention (Group B, n = 6) or a video-and-meditation intervention (Group C, n = 6). Those with prior MRI experience formed the control group (Group A, n = 6). All participants subsequently underwent a 20-minute brain MRI scan on a Siemens MAGNETOM Avanto 1.5T scanner.

2.2. VR Simulation

The simulation was engineered to elicit authentic physiological and psychological responses by replicating the perceptual experience of an MRI scan. The design encompassed detailed 3D modelling and texturing, full environmental reconstruction, integrated scanner audio, animated clinical hardware, and interactive control systems, all delivered via the Meta Quest 2 headset.

2.2.1. Scanner Modelling and Texturing

A high-fidelity digital replica of the Siemens MAGNETOM Avanto 1.5T scanner was constructed in Autodesk 3ds Max, drawing on technical specifications and reference photographs of the physical unit. The scanner model and patient table were both texture-mapped to achieve close visual correspondence with their real-world counterparts.

2.2.2. Room and Environmental Design

Beyond the scanner itself, the surrounding MRI room was reconstructed within the virtual environment. Situating the equipment within a convincing clinical space was considered essential for reinforcing the sense of presence; a scanner rendered in isolation would have undermined the ecological validity of the simulation. The complete room context contributed to the immersive quality of the experience.

2.2.3. Auditory Simulation

Scanner acoustics were captured using a Zoom H4n Pro recorder positioned in the safe vicinity of the live scanner during active imaging. Seven clinically representative pulse sequences were recorded, A T1-weighted spin echo, a T1-weighted Magnetization-Prepared Rapid Gradient Echo, T2 weighted Half-Fourier Acquisition Single-shot Turbo spin-Echo, a gradient echo field map sequence, a 2D echo-planner diffusion sequence and a T1 weighted gradient echo FLASH sequence. These were selected on the basis of literature evidence identifying them as among the noisiest, or most clinically relevant, sequences encountered in routine brain MRI (Shellock et al., 1994). The recordings were edited into a continuous 20-minute audio track, programmed to begin 10 seconds after simulated bore entry, matching the temporal structure of a real scan. A virtual buzzer tone was also embedded to replicate the patient alarm function.

2.2.4. Head Coil and Bore Movement

The head coil, a known contributor to the sense of confinement in MRI, was modelled and animated to simulate its lowering and locking sequence, heightening the participant experience of physical constraint. To simulate the transition into the bore, the bore itself was animated to move over a stationary participant. This was a more reliable and consistently replicable method of creating the experience of entering the bore than physically moving the stretcher into a static virtual bore.

2.2.5. Controls and Operator Communication

A two-controller interface managed the simulation. The participant held the left controller, the trigger of which activated a virtual call buzzer mirroring the physical emergency button used in clinical MRI. The operator used the right controller to initiate bore movement and scanner audio; a second press ended the scanning sequence and moved the participant out of the virtual bore. Real-time voice communication was enabled via a WhatsApp audio call running concurrently on the headset. This was a prototyping workaround for the complications of replicating the intercom system standard in clinical MRI suites within the VR software. When the participant pressed the buzzer, the call was automatically unmuted, allowing the operator to respond immediately.

2.2.6. Participant Protocol

Participants reclined on a medical stretcher, donned the Meta Quest 2 headset, and held the left controller as a surrogate call bell. The operator monitored the session in real time via the Meta Quest companion app screen-cast to a mobile device. The complete simulation ran for 20 minutes, matched to the duration of the subsequent MRI scan, providing participants with a temporally representative experience of the full procedure.

2.3. Video and Meditation Intervention

Group C watched an iPhone-produced MRI guidance video covering patient preparation, positioning, head coil placement, calling bell function, and a preview of scanner noise. This was followed by a 5-minute guided breathing exercise (4–7–8 technique) sourced from YouTube. Participants were encouraged to use the breathing technique during the scan.

2.4. Outcome Measures

Two validated instruments were used. The Claustrophobia Likert Questionnaire (CLQ) established baseline claustrophobic tendency across 26 items on a 0–4 scale (total 0–96, categories: Not Anxious 0–24, Little Anxious 25–48, Moderately Anxious 49–72, Highly Anxious 73–96) (Radomski et al., 2001). The MRI Anxiety Questionnaire (MRI-AQ), a 15-item, 4-point Likert instrument, was administered pre-intervention and post-scan (Ahlander et al., 2016). Selected items were reverse-scored to ensure directional consistency. Statistical analysis employed independent-samples t-tests (Welch correction for unequal variances) using MATLAB, with significance set at $p < 0.05$.

3. Results

3.1. Demographic Characteristics

Group A (Control) had a mean age of 26.0 ± 2.40 years (1M, 5F). Group B (VR) had a mean age of 25.5 ± 1.97 years (3M, 3F). Group C (Video) had a mean age of 27.0 ± 3.46 years (4M, 2F). All control participants had prior MRI experience; no VR or video participants did.

Group	Mean CLQ Score	Anxiety Level	SD
Control (A)	35.00	Little Anxious	±18.24
VR (B)	23.67	Not Anxious	±18.47
Video (C)	22.83	Not Anxious	±17.71

Table 1: CLQ Baseline Scores by Group.

3.2. MRI-AQ Anxiety Score (pre and post)

Mean MRI-AQ scores decreased following the intervention in both the Video and VR groups, while the Control group showed a small increase. The VR group demonstrated the largest reduction, with mean scores decreasing from 1.88 (SD = 0.38) pre-intervention to 1.32 (SD = 0.28) post-intervention, representing a change of −0.56. The Video group showed a smaller reduction of −0.20, while the Control group showed a slight increase of +0.08. These results indicate that the VR intervention produced the greatest reduction in MRI-related anxiety.

Group	Pre-MRI Mean (SD)	Post-Intervention Mean (SD)	Change
Control (A)	1.70 (0.38)	1.78 (0.20)	+0.08
Video (C)	1.76 (0.33)	1.56 (0.43)	−0.20
VR (B)	1.88 (0.38)	1.32 (0.28)	−0.56 ✓

Table 2: Pre- and Post-Intervention MRI-AQ Scores.

3.3. Post Intervention Anxiety and Statistical Analysis

The VR group achieved the largest reduction in anxiety (mean post-scan score 1.322, SD = 0.281). The video group showed a moderate reduction (1.566, SD = 0.438), while the control group showed a slight increase (1.778, SD = 0.202), consistent with the natural anxiety-elevating effect of the scan itself. T-test results are summarised in Table 3.

Comparison	t-statistic	Df	p-value	Significant?
Pre-MRI vs. Post-MRI (Control)	0.087	15.14	0.9315	0.9315
Pre-MRI vs. Post-Video	1.140	7.21	0.2907	No
Pre-MRI vs. Post-VR	3.295	10.38	0.0077	Yes ✓
Post-MRI vs. Post-Video	1.085	7.07	0.3137	No
Post-MRI vs. Post-VR	3.203	9.05	0.0107	Yes ✓

Table 3: Paired T-Test Results.

The VR intervention was the only condition to produce a statistically significant reduction in anxiety relative to both the pre-scan baseline ($p = 0.0077$) and the post-scan control group ($p = 0.0107$).

Neither the video intervention nor the standard MRI experience alone produced significant anxiety changes.

4. Discussion

The results confirm that immersive VR pre-scan simulation is significantly more effective than both standard MRI preparation and a combined video-and-breathing-exercise intervention in reducing procedure-related anxiety. This finding is consistent with the broader literature on VR for anxiety disorders (Anderson et al., 2023), and extends it specifically to the pre-scan preparation context, which has received comparatively less attention than in-scanner distraction approaches (Hudson et al., 2022).

The mechanism is likely twofold. First, VR delivers a form of controlled behavioural exposure: by navigating the simulated environment, lying on the patient table, hearing authentic sequence noise, experiencing the bore closing around them, participants are exposed to the stimuli in a psychologically safe setting. This mirrors established exposure-based treatments for specific phobias (Boeldt et al., 2019) . Second, the immersive and interactive nature of VR (place illusion and plausibility illusion (Slater et al., 2009) [40]) provides a qualitatively different level of engagement than passive video viewing, which helps contextualise them the video intervention's non-significant effect despite providing informational content of similar scope.

The slight increase in anxiety observed in the control group from pre- to post-scan (1.70 to 1.78) is noteworthy, suggesting that the MRI experience itself can be anxiety-provoking even for participants without pre-existing anxiety disorder, a finding that underscores the clinical case for pre-scan preparation for a broader patient population, not just those with known claustrophobia.

The simulation's design features, authentic auditory environment, animated head coil, WhatsApp-mediated operator communication, and buzzer functionality, appear to have contributed to ecological validity. Participants who had experienced the VR simulation likely entered the real scan with greater cognitive predictability of the environment, reducing the 'fear of the unknown' component that prior literature identifies as a key driver of MRI anxiety (Törnqvist, et al., 2006).

From a service delivery perspective, the implications are meaningful. Sedation for claustrophobic patients carries direct costs (anaesthetist time, recovery space, medication) and indirect costs (longer slot times, scheduling complexity). A VR pre-scan simulation, once developed, is a low-marginal-cost, repeatable, non-pharmacological intervention that could be implemented as a standard pathway for first-time or anxious patients. This would directly address the estimated €1 billion annual productivity loss from claustrophobia-related scan failures across Europe (Nguyen et al., 2020).

5. Limitations and future work

Several limitations must be acknowledged. The sample (n = 18, primarily university students aged 22–32) was small and demographically narrow, limiting generalisability to older or more clinically anxious populations. The relatively low baseline CLQ scores suggest participants were generally not highly claustrophobic, which may have attenuated the observed effect sizes; a larger effect could be expected in a clinical population with diagnosed MRI phobia. Allocation was not fully randomised (prior MRI experience determined control group membership), introducing a potential confound. The audio recording equipment was positioned too far from the scanner, resulting in some sound attenuation relative to validated reference levels (Shellock et al., 1994). There is also a need to calibrate audio volume and frequency to the specifics of the headset being used. Future work should include: (i) a larger randomised controlled trial in a clinical MRI setting with patients referred for diagnostic scanning; (ii) objective physiological measures (heart rate, cortisol) alongside self-report instruments; (iii) inclusion of patients with formally diagnosed claustrophobia or anxiety disorders; and (iv) investigation of whether VR preparation reduces measurable rates of scan interruption, sedation use, and image quality degradation.

6. Conclusion

This study provides evidence that a purpose-built VR pre-scan simulation can significantly reduce MRI-related anxiety, outperforming both standard preparation and a video-and-meditation intervention. The VR group demonstrated a statistically significant reduction in anxiety scores ($p = 0.0077$), while no significant effect was observed for the video or control conditions. These findings support the clinical adoption of VR pre-scan preparation as a patient-centred, non-pharmacological strategy to improve the MRI experience, reduce failed scans, and decrease reliance on sedation. Further research with clinical populations and larger samples is warranted to confirm and extend these findings.

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Virtual Reality Art Therapy and Trauma: A Pilot Study

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Abstract

This pilot study examined a novel, non-exposure-based intervention combining art therapy with a virtual reality (VR) immersive environment among Ukrainian adults displaced by war (N = 13). Using a within-subject design, participants completed both VR and paper-based tasks. Results indicated that VR reduced PTSD symptoms similarly to the traditional paper-based art therapy condition. Although slightly greater reductions in PTSD and disturbances in self-organization (DSO) were observed in the VR condition, these differences were not statistically significant. Findings may reflect high baseline symptom severity and the brief intervention. Nevertheless, results support the feasibility and potential of immersive art-based approaches for trauma intervention.

1. Introduction

The global burden of trauma-related mental health conditions remains high, underscoring the urgent need for scalable and accessible interventions. Exposure to potentially traumatic events – such as war, natural disasters, accidents, and violence – is widespread, affecting approximately 70% of individuals worldwide (1). Although many people recover naturally, a substantial proportion develop persistent psychological conditions, including post-traumatic stress disorder (PTSD). It is estimated that 5.6% of trauma-exposed individuals develop PTSD, with a lifetime prevalence of 3.9%, rising to over 15% among those exposed to war and violent conflict. Importantly, beyond formal diagnoses, many individuals experience subclinical yet significant psychological distress that can impair daily functioning and well-being (2, 3). Despite growing awareness, access to mental health care remains limited, particularly among vulnerable and displaced populations, highlighting the need for innovative and culturally sensitive treatment approaches.

Virtual reality (VR) has emerged as a promising tool in trauma-focused psychological interventions. Early applications, particularly in military contexts, have primarily relied on exposure-based approaches, using immersive simulations to facilitate controlled re-experiencing of traumatic events and support emotional processing (4,5). More recently, research has expanded beyond exposure paradigms to include integrative approaches such as VR-assisted art therapy, which leverages the immersive, interactive, and expressive capacities of VR environments (6). These environments offer unique affordances – including enhanced presence, creative flexibility, and user engagement – that may support therapeutic processes.

Emerging evidence suggests that VR-based art therapy can reduce anxiety, improve emotional regulation, and enhance engagement, particularly among younger populations (7, 8). Pilot studies further indicate its potential for stress reduction and creative expression, while also highlighting challenges related to usability and technological accessibility (9). Despite these promising findings, most existing VR interventions remain grounded in exposure-based frameworks, and comparatively little research has examined non-exposure, art-based VR interventions for trauma.

The present study addresses this gap by integrating a traditional art therapy framework with a VR-based immersive environment. Specifically, we developed a novel intervention that combines 3D virtual art-making with a non-exposure-based, "inner child" therapeutic task commonly used in clinical and art therapy settings. This approach shifts the focus from direct trauma re-exposure to symbolic expression, emotional regulation, and the creation of a safe, supportive internal environment.

The aim of this study is to evaluate the effectiveness of this art therapy–based intervention delivered in both traditional paper-based and VR formats among Ukrainian adults displaced by war and currently residing in Hungary. The study examines the impact of these interventions on trauma-related symptoms and compares the relative effectiveness of VR-based versus paper-based delivery. It is hypothesized that both modalities will lead to symptom reduction, with VR offering additional benefits due to its immersive and interactive properties.

2. Methods

2.1. Participants

Participants (N = 13; mean age = 28.6, 12 female) were recruited from Ukrainian communities in Budapest. Using a within-subject design, each participant completed two sessions – one paper-based and one VR-based – one week apart in randomized order. Reported stressors included war-related trauma, interpersonal conflict, and chronic psychosocial stress. The study was approved by the ELTE Faculty of Education and Psychology Ethics Committee. Participation was voluntary, with informed consent obtained and data handled in accordance with data protection regulations.

2.2. Measures

Questionnaire: The Ukrainian version of the International Trauma Questionnaire (ITQ; 10) used in this study. The ITQ assesses trauma-related symptoms and their severity across 18 items, divided into two subscales: posttraumatic stress disorder (PTSD) and disturbances in self-organization (DSO), a core component of complex PTSD (CPTSD). Items are rated on a 5-point Likert scale ranging from 0 (not at all) to 4 (extremely).

Task: For the paper-based task, participants were provided with an A4 white sheet featuring a centrally printed black-and-white outline of either a boy or a girl. They were given a set of drawing materials and an eraser, and were instructed to complete the background and surrounding environment of the figure in line with the art therapy task. The VR condition was delivered using the custom-developed VRDrawing3D.exe application, created through collaboration between psychologists and art therapists from ELTE and engineers and programmers from the University of Pannonia. The simulation was run on a Meta Oculus Quest 2 standalone VR headset connected to a ROG Strix G15 (2022) G513 laptop operating on Windows. In both conditions, participants received identical instructions.

2.3. Procedure

At the first session, participants provided written informed consent and completed a Google Forms battery including demographics and the ITQ. Participants then completed a randomized crossover art therapy intervention in either paper-based or VR format, with the alternate condition administered one week later. Time reminders were given during both conditions, and brief post-task questions were recorded by the researcher.

3. Results

3.1. Analysis Post Paper vs Post VR

In the VR condition, 8 participants (62%) demonstrated a reduction in PTSD severity category, compared to 6 participants (46%) in the paper-based condition. No participants showed worsening PTSD severity following VR, whereas one participant (8%) worsened in the paper condition. For DSO symptoms, both conditions showed an identical pattern: 6 participants (46%) improved, 5 (38%) showed no change, and 2 (15%) exhibited increased severity (see Table 1).

	Paper condition			VR condition		
	Improved n (%)	**No change n (%)**	**Worsened n (%)**	**Improved n (%)**	**No change n (%)**	**Worsened n (%)**
PTSD	6 (46%)	6 (46%)	1 (8%)	8 (62%)	5 (38%)	0 (0%)
DSO	6 (46%)	5 (38%)	2 (15%)	6 (46%)	5 (38%)	2 (15%)

Table 1: Changes after VR and Paper conditions in %Note. Improvement/worsening defined as movement of at least one severity category from baseline.

Figure 1 indicates that both the paper-based and VR interventions were associated with significant reductions in PTSD and DSO scores compared to baseline. A significant main effect of Time was observed, $F(2, 24) = 8.100$, $p = 0.002$, confirming that ITQ scores decreased across the three time points. However, neither the main effect of Subscale, $F(1, 12) = 0.228$, $p = 0.642$, nor the Time × Subscale interaction, $F(2, 24) = 0.536$, $p = 0.592$, reached significance. These findings suggest that both PTSD and DSO symptoms improved similarly over time. Although the reduction appeared more pronounced following the VR condition, the difference between VR and paper-based interventions was not statistically significant.

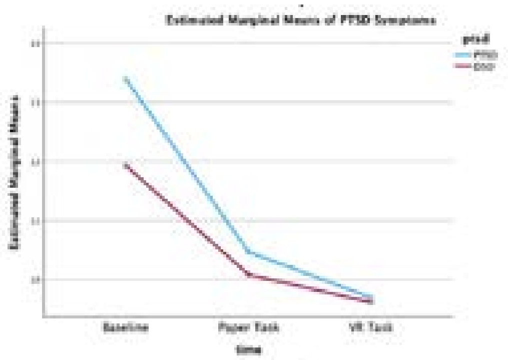

Figure 1. Changes in PTSD and DSO level by tasks.

4. Discussion

The results of this pilot study, based on a limited sample, did not support the hypothesis that VR would produce greater symptom reduction than the paper-based condition. Although the VR condition was associated with slightly greater reductions in PTSD and DSO scores, these effects were small and not statistically significant. Improvements in PTSD were consistent across conditions, suggesting that participants who benefited from one modality also tended to benefit from the other. This pattern may be explained by the high baseline severity of trauma-related symptoms (84% severe or extremely severe PTSD; 61% severe or extremely severe DSO), as well as the brief nature of the intervention, which included only two sessions.

Participant feedback provides important context for these findings, particularly given that most individuals were first-time VR users. The majority (10 out of 13) reported a reduced sense of control in the VR condition, while eight described the task as more difficult and seven as more stressful or anxiety-provoking. Difficulties in operating VR controllers and managing the cognitive demands of the environment appeared to interfere with engagement in the therapeutic process. Only three participants described the VR experience as equally or more calming than the paper-based task, highlighting its immersive and, at times, meditative qualities despite reduced perceived control.

Notably, despite these challenges and initial discomfort with the technology, reductions in PTSD severity were still observed in the VR condition. This suggests that immersive 3D environments may offer added value in trauma processing, even when usability barriers are present.

Although limited by the small sample size (N = 13), this study highlights several key considerations. Initial unfamiliarity with VR and usability challenges may reduce its short-term effectiveness; however, its immersive properties appear to hold therapeutic potential. Additionally, the findings reinforce the value of art-making itself – even through simple tasks – as an effective means of reducing psychological distress.

Future research with larger samples and repeated sessions is needed to better understand the role of immersion in therapeutic outcomes and to improve the usability of VR-based tools. With further development, VR interventions may serve as a valuable complement to traditional therapy or as an accessible alternative in contexts where mental health services are limited.

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06

BIOSENSING, AI & NEUROADAPTIVE SYSTEMS

Integrated VR & EEG – The Best Practices for Real-Time Data Collection in Research

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Abstract

This paper presents a combined real-time monitoring workflow, headset-application procedure and offline inspection pipeline specifically for the OpenBCI Galea integrated dry-EEG VR system, addressing a methodological gap in current research. Existing literature recognises that dry electrodes achieve signal quality comparable to wet systems. However, guidance for obtaining quality data remains limited. We provide a step-by-step protocol for preparing and applying the Galea headset to optimise data quality, supported by author self-testing studies that evaluate the effectiveness of our real-time monitoring approach. Finally, we identify current limitations in packet stability and latency and recommend that future work prioritise these areas.

1. Introduction

With recent advances in integrated VR-EEG systems, there is a growing interest in the collection of physiological data within immersive experiences, especially in relation to cognitive workload, affective state or as a neuroadaptive interface. The majority of existing VR-EEG studies use offline analysis of recorded EEG data, providing little insight into real-time EEG monitoring or headset-specific procedures for using the integrated headsets for data collection while VR is in use. Regarding dry-electrode systems, electrode-skin impedance and signal quality vary considerably with the user's natural movements, indicating the need for continuous inspection to maintain signal quality (Chi et al. 2010, Lopez-Gordo et al. 2014, Harris et al. 2024). Rahman et al. (2023) used separate VR headsets and EEG-based BCI systems, leading to ergonomic limitations and reduced user comfort due to the need to simultaneously wear multiple head-mounted devices while maintaining reliable EEG signal acquisition. As integrated headsets, such as the Galea, become more widely adopted within research settings, establishing practical methods for real-time inspection and data collection becomes essential.

Currently, there is no procedural framework establishing the practical methods for both real-time signal inspection and the requirements for collecting high-standard EEG data from an integrated dry EEG headset. This paper addresses these gaps by presenting a novel approach to monitoring real-time data from the Galea headset and provides a detailed, validated procedure for applying the headset to a participant for successful data collection based on extensive testing conducted by the research team.

2. Background

Technological innovations in recent years have enabled the creation of biosensing-integrated VR systems. These systems utilise multiple different electrode types, each having their own benefits and limitations. Whilst wet electrodes have been considered the gold standard for this kind of research for quite some time, there are several issues with their use, including the time-consuming nature of their application. A recent survey found that experienced practitioners spent an average of 50 minutes on a full, methodical EEG application (Hoffman et al. 2024). This very heavily restricts participant flow.

Furthermore, as they rely on a wet electrolyte (e.g., saline) for conduction, the collected signal gradually degrades. This can be problematic for longer studies, but even in shorter studies, when comparing multiple smaller tasks, a slight degradation can mask the main effects of an experiment.

Due to the extended setup times for wet electrodes, the use of dry electrodes has gained attention due to the ease of setup and removal compared to gel electrodes. When comparing wet and dry electrodes, Lopez-Gordo et al. (2014) found that dry signals are closely correlated with those of wet electrodes at 90% or more. There are various differing dry electrode designs, including nanotube (Song et al. 2017) and pillar (Aghazadeh et al. 2021) electrodes, which have been explored over the past 9 years. These electrodes have the ability to surpass hair and enables direct contact with the scalp to provide acceptable EEG data recordings. The pillar electrodes having the most similarity to the conductive polymer active electrodes used by the Galea.

3. Methodology

This paper focuses on the best practices and methods for data collection with the Galea headset, using a Varjo Aero VR attachment with eye-tracking. This was chosen as a novel, standardised headset, commercially available to research institutions, though the methodologies for other comparable headsets may be similar. The modalities for this headset include ExG (EEG, EMG and EOG), PPG, and inertial sensors (Buxton et al. 2026, Table 1).

3.1. Real-time Monitoring and Signal Inspection

Real-time monitoring of physiological signals was implemented using a custom Python application that receives Galea's filtered time-series data via UDP stream. Each packet contains a JSON-encoded array of pre-processed EEG samples. In the current configuration, approximately 108 filtered packets are received every 10 seconds, giving an effective packet rate of 10.8Hz and an inter-packet interval of 92.6ms. This rate reflects the packet arrival behaviour post-network transmission, thus representing the practical end-to-end latency of the monitoring pipeline.

The Python script runs a dedicated listener thread that handles packets without blocking the Tkinter (GUI Display) event loop. The script parses the packets from JSON and adds each packet to a per-channel dequeue buffer. The buffer length is fixed (200 samples), corresponding to approximately 18–19 seconds of visible history, with a display update rate of 80ms (12.5fps). As the visualisation is updated more frequently than the receipt of packets, new data received results only in a gradual change in the channel trace over time.

This setup provides an oscilloscope-style display (Figure 1) allowing up to ten channels of data to be displayed, each of which scales independently to its own amplitude range, allowing quick visualisation of electrode contact and confirmation of signal stability during preparation and experiment procedures.

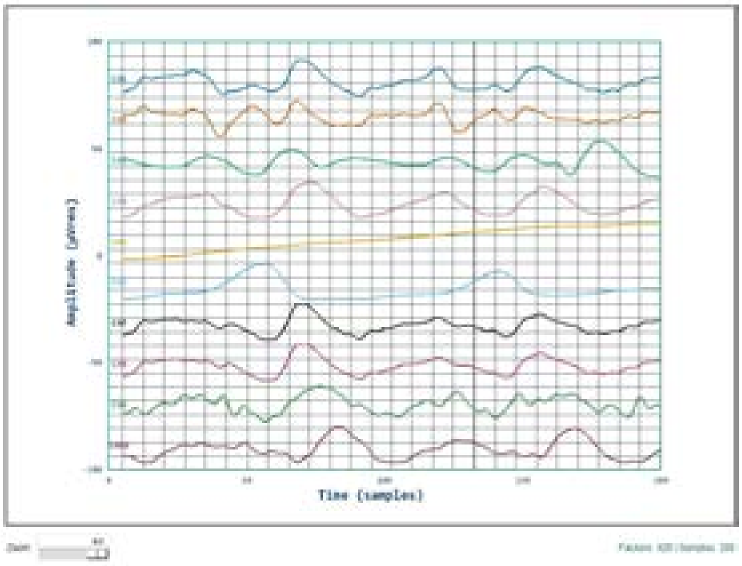

Figure 1: An oscilloscope-style display visualising the EEG channels from the Galea.

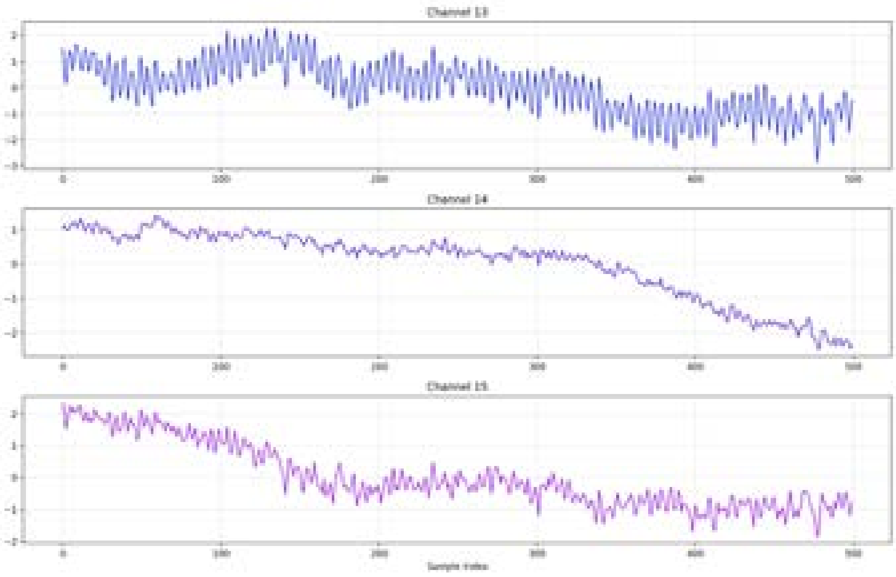

Figure 2: Brainflow EEG Multi-channel (13–15) visualisation plot, these channels refer to Parietal lobe EEG recordings, which is mainly responsible for spatial awareness, an area likely to be affected by Stroke.

Initial testing was designed to enable the commencement of a Galea session directly from within Python, bypassing the Galea GUI. The current infrastructure and parsing facilities already exist within the framework, the real-time monitoring application demonstrates the potential for the development of a stand-alone acquisition pipeline. This could reduce operator workload, eliminate the need for switching software during experiments and improve alignment between VR events and recorded physiological data.

A complementary offline visualisation pipeline was created to inspect recorded sessions. CSV files exported from the Galea GUI were processed by a Python script using the Brainflow Data-

Filter module to load the data and plot each EEG channel (Figure 2). Channels can be plotted individually or displayed as multi-panel figures, simplifying the interpretation of signal features across successive sessions. Basic normalisation was applied to highlight amplitude differences.

4. Discussion

Integrated Dry EEG Headset Procedure: Based on the studies conducted by the research team, we propose the following procedure for preparing an integrated dry EEG headset for optimal data collection.

First, prepare the headset by ensuring the electrodes are clean, residue-free, and the electrode straps have been undone; loosen the fasteners and encourage the participant to put the headset on themselves – visor first, then assist in moving the remainder of the headset into place. Secondly, tighten the rear strap and adjust the visor angle so the headset sits comfortably, then tighten the top electrode straps and fasten. Finally, attach the ear clips and check for any twisted, dislodged or removed electrodes.

The effective packet rate of 10.8Hz places clear constraints on the types of analysis that can be conducted in real-time. Whilst this rate is sufficient for monitoring electrode contact or identifying any unwanted signals, this would not be sufficient in its current capacity for applications requiring millisecond-level synchronisation, such as closed-loop neuroadaptive control of VR events. The use of UDP presents additional considerations, including packet loss and out-of-order arrival, which can be expected at lower packet rates. This reinforces that the stream should be treated as monitoring-grade in its current form.

The filtered time-series data stream also lacks metadata, such as time stamps, which limits its use for detailed signal interpretation. Although, the offline workflow shown in Figure 2, provides higher-quality visualisation for post-hoc inspection, it does not address the limitations of real-time stream. However, it does provide the output from the Galea GUI in a much more readable and user-friendly format.

Despite these constraints, the monitoring tool substantially improves participant preparation efficiency through the provision of immediate visual feedback. It enables the exploration of a Galea GUI-free session with the potential of developing a stand-alone acquisition pipeline that could inform real-time adaptation via neurofeedback.

5. Conclusion

This paper presents a novel approach to collecting and analysing data in near real-time, providing a foundation that could support adaptive environments and tasks within a closed-loop system, once higher-frequency or more informationally rich data streams are achieved. A procedure detailing the ideal prerequisites for collecting EEG data using an integrated dry EEG headset derived from findings and testing conducted by the research team. Finally, the limitations of the real-time monitoring approach are identified and addressed appropriately.

Future work in real-time monitoring will build upon the current platform by increasing robustness and informational richness of the data stream. The current stream rate of 10.8Hz is adequate for setup and quality checks, but higher-frequency streaming or time-stamped packets are required for use within a closed-loop neuroadaptive application or synchronisation with VR events. In terms of the networking framework, exploring alternative transport layers or adaptive buffering strategies could reduce packet loss at low rates, while extending initial work on a Galea GUI-free session would enable a stand-alone acquisition pipeline. Together, these suggested developments have the potential to advance the workflow from a monitoring-grade tool to a flexible, research-ready platform capable of supporting closed-loop neuroadaptive control and more advanced experimental designs.

Future studies will continue to focus on incorporating integrated dry EEG headsets, resulting in a deeper evidence base for future iterations to the optimal practices established within this paper. Examples of intended future work by the authors include:

- A Biosensing-Enhanced Neuroadaptive XR Rehabilitation system informed by the biosignals provided by the Galea to infer a user's physiological state and adapt accordingly in real-time.
- A Platform-Agnostic Multimodal Neurophysiological Sensing in Game-Based Interaction to regulate and identify autistic traits among adults.
- A Highly-Realistic Human Avatar based approach to detecting differences in Facial Emotion Expression Recognition, both in terms of ability and cognitive processing, focused on observing differences between the general population and people with Autism.

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A Conceptual Mechanistic Framework for Biosensing-Enhanced VR Rehabilitation

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Abstract

Biosensing-enabled Virtual Reality including electroencephalography, electromyography, electrodermal activity, heart-rate variability and other multimodal physiological signals is the next frontier of adaptive and personalised VR rehabilitation systems. This paper reviews the mechanistic evidence of 32 studies utilising biosensing-enabled VR, identified in a broader systematic review, investigating how EEG-based motor imagery, EMG biofeedback, and autonomic biosensors can effectively modulate sensorimotor engagement, volitional activation, emotional and attentional states. This framework outlines neural intention decoding, muscular activation reinforcement, autonomic state modulation, and multimodal integration as potential pathways for incorporating biosensing and closed-loop adaptivity into VR rehabilitation systems.

1. Introduction

Virtual reality (VR) rehabilitation has been shown to be effective in a number of outcome domains for neurological and musculoskeletal conditions. There is increasing use of physiological biosensing modalities, specifically electroencephalography (EEG), electromyography (EMG), electrodermal activity (EDA), and heart-rate variability (HRV), to enable adaptive, personalised closed-loop therapy. However, mechanistic evidence for the use of biosignals in VR-based rehabilitation interventions remains scarce.

A set of 32 mechanistic studies, identified within a broader systematic review, offer a valuable opportunity to consolidate mechanisms across the available literature, including EEG-based motor imagery (MI) (Aamer et al. 2019, Achanccaray et al. 2018), EMG-driven virtual reality (VR) interfaces (Ma et al. 2009, 2010), autonomic biofeedback systems (Rahman et al. 2022, 2023, Parente et al. 2023) and multimodal VR-brain–computer interface (BCI) platforms (Vourvopoulos et al. 2019, Harris et al. 2024). Although these studies are conducted predominantly in healthy adults, each system reports mechanistic outcomes relevant to neurological or musculoskeletal rehabilitation. Despite the informative nature of the mechanistic evidence base, it remains heterogeneous and difficult to synthesise. The absence of a cohesive model integrating neural intention decoding, muscular activation reinforcement, autonomic state modulation, and multimodal integration limits the design of physiologically informed VR systems and their translation into clinical practice.

The results of the 32 biosensing-integrated VR studies were synthesised to produce a theoretical mechanistic framework that describes how physiological signals can promote adaptive VR rehabilitation and the mechanistic pathways through which biosensing can promote closed-loop interaction. This framework forms a reference point for the design, assessment and implementation of biosensing-integrated VR rehabilitation systems into modern clinical practice.

2. Methods

Mechanistic evidence was gathered from a selection of studies included in a systematic review of VR-based rehabilitation systems that use physiological biosensing. For this analysis, studies offering mechanistic, physiological, or system-level insights were classified as mechanistic, regardless of whether they reported clinical outcomes. Figure 1 provides further detail into how the studies were obtained, screened and selected for synthesis.

To qualify, studies needed to:

- Use a physiological biosensing method (EEG, EMG, EDA, HRV or a combination)
- Employ VR or XR as an interactive experience, not just as a response mechanism.
- Apply to neurological or musculoskeletal rehabilitation, even if tested in healthy adults.
- Report mechanistic outcomes such as neural activation patterns, MI classification accuracy, EMG activation, physiological autonomic measures and system performance.

The studies excluded were those focused solely on usability, entertainment, navigation, cognitive neuroscience tasks, and those identifying biosensing outside of the VR system.

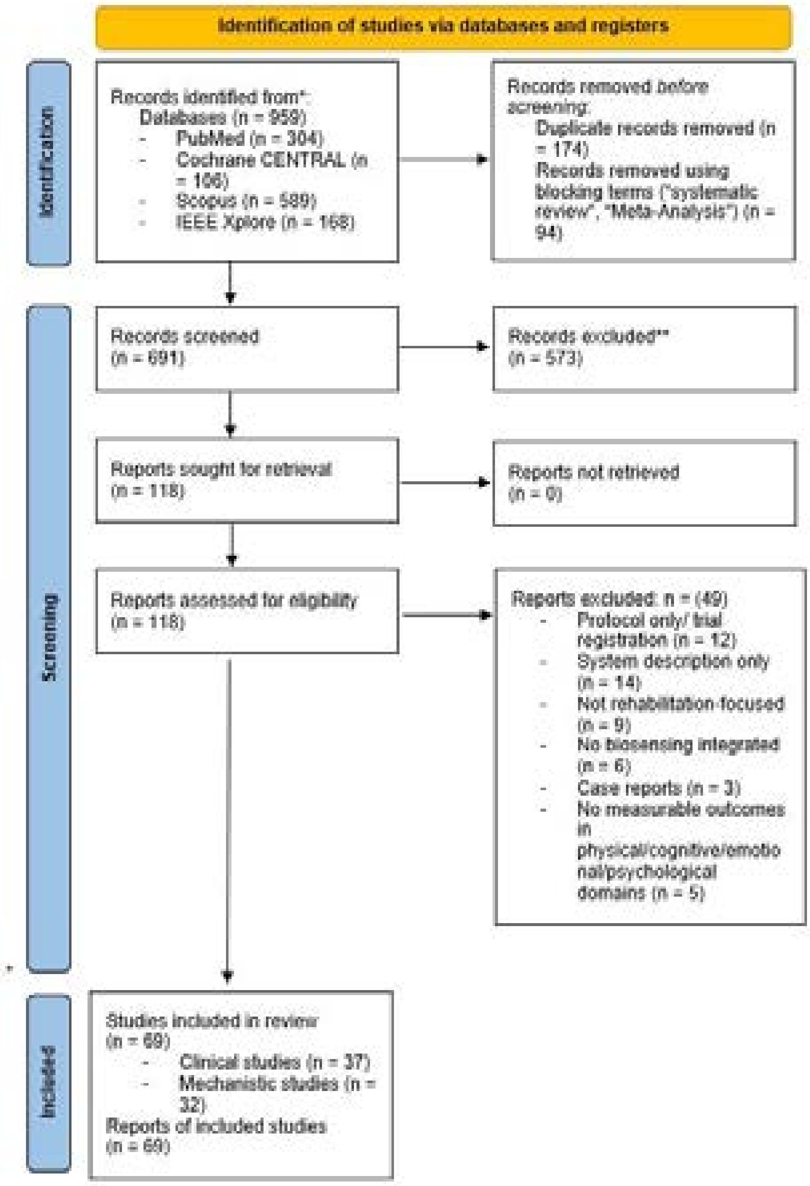

Figure 1: A PRISMA flow diagram detailing the study selection process.

Reference databases were searched using formulated strings of which 32 studies were found to meet the initial criteria, and mechanistic findings were therefore, extracted from each study. The findings were categorised into four neurophysiological domains: Neural Intention Decoding, Muscular Activation, Autonomic Modulation and Multimodal Integration. These findings were combined to create an integrated mechanistic framework that illustrates how biosensing drives the use of VR-based rehabilitation for neurological and musculoskeletal conditions.

3. Mechanistic findings

Neural Intention and Engagement Mechanisms (EEG): Several trends were observed in VR studies based on EEG. MI tasks appear to influence sensorimotor activity in VR environments, and clear ERD (Event Related Desynchronisation) patterns were recorded during MI tasks. Additionally, studies indicated an improved neural engagement when MI is applied to other VR tasks (Achanccaray et al. 2018). Other studies showed a high MI classification accuracy in VR-based

MI-BCI games, indicating that such systems can differentiate MI-related brain signals and decode MI-related activity robustly (Aamer et al. 2019, Karácsony et al. 2019). Supporting evidence comes from increases in cortical activity and power spectral density during active movements in VR (Blanco-Mora et al. 2019, O'Keeffe et al. 2024).

Overall, these findings suggest that EEG can decode motor intention and enhance cognitive engagement in VR rehabilitation systems.

Muscular Activation and Volitional Control (EMG): EMG-driven VR systems consistently showed that VR tasks can help users activate their muscles. For instance, EMG input methods have demonstrated EMG-based control and targeted muscle activation during VR tasks such as hand rotation, grasping and upper-limb movements. This indicates that VR environments can enhance the quality and consistency of muscular activity (Ma et al. 2010, Guo et al. 2016).

An EMG-based interaction, with high accuracy for detecting intention, could be used in real-time to control VR tasks. This would allow for the adjustment of task difficulty specifically for the user's current state (Chatragadda et al. 2023, 2025). In earlier EMG-biofeedback systems, real-time feedback suggested improved specific muscle activation, especially in rehabilitation setups involving repetitive training with feedback (Ma et al. 2009).

These results suggest that EMG-driven VR tasks are associated with increased motor engagement and specific muscle activation in VR rehabilitation.

Autonomic and Psychophysiological Modulation (EDA/HRV): Autonomic biosensing in VR rehabilitation can measure emotional and attentional states. Heart-rate-based biofeedback has been used to adapt game difficulty in real-time, reporting increases in mental focus and engagement with biofeedback enabled (Parente et al. 2023).

Though fewer in number, these studies highlight how autonomic signals are associated with emotions, motivation and attention, with the potential to influence them. These factors can impact adherence and success in rehabilitation, but are often ignored in the design of rehabilitation systems.

Multimodal Integration and Closed-Loop Adaptation: Several studies highlighted the use of multimodal biosensing to enhance the responsiveness of VR rehabilitation systems.

EEG-based assessment showed stronger mu (μ) and beta (β) ERD and increased coherence when VR mirror therapy was combined with robot-assisted upper-limb intervention (Liu et al. 2024). This shows consistency with enhanced sensorimotor involvement and engagement. In gait-oriented systems, EEG-based decoding of lower-limb movement intention has enabled real-time control of avatars during VR tasks, with potential applications in closed-loop control for locomotor rehabilitation (Luu et al. 2016).

These multimodal approaches illustrate how neural, muscular and autonomic signals could be combined to support more responsive and personalised rehabilitation interventions.

4. Hypothesised mechanistic framework

The patterns observed in the reviewed studies provide theoretical evidence that biosensing could enable adaptive VR rehabilitation. Although current evidence is limited and heterogeneous, emerging evidence suggests EEG, EMG, and autonomic signals could provide information for estimating motor, cognitive, and emotional states.

In VR, EEG-based MI models have shown sensorimotor rhythm modulation, a potential mechanism for intention decoding. EMG-based interfaces have provided evidence for volitional muscle activation during task execution within VR. Autonomic measures, such as HRV and EDA, can provide insight into arousal and attentional state, offering the potential of making adaptive changes that impact the task itself, but currently there is insufficient evidence to fully support this and these relationships require further validation.

Multimodal systems integrating neural, muscular and autonomic data represent opportunities to provide richer closed-loop interactions, though available studies are exploratory and limited to small, healthy samples. Taken as a collective, these findings support a testable hypothesis that biosensing could enable VR systems to adapt to a user's cognitive, motor and emotional states in real-time.

A potential pipeline could consist of acquiring the aforementioned biosignals to infer a user's physiological state and use machine learning to classify these in real-time. Thus, providing opportunity for closed-loop feedback within a virtual rehabilitation environment or real-time monitoring to enable physicians to adapt tasks accordingly. A visualisation of the described pipeline is depicted in Figure 2

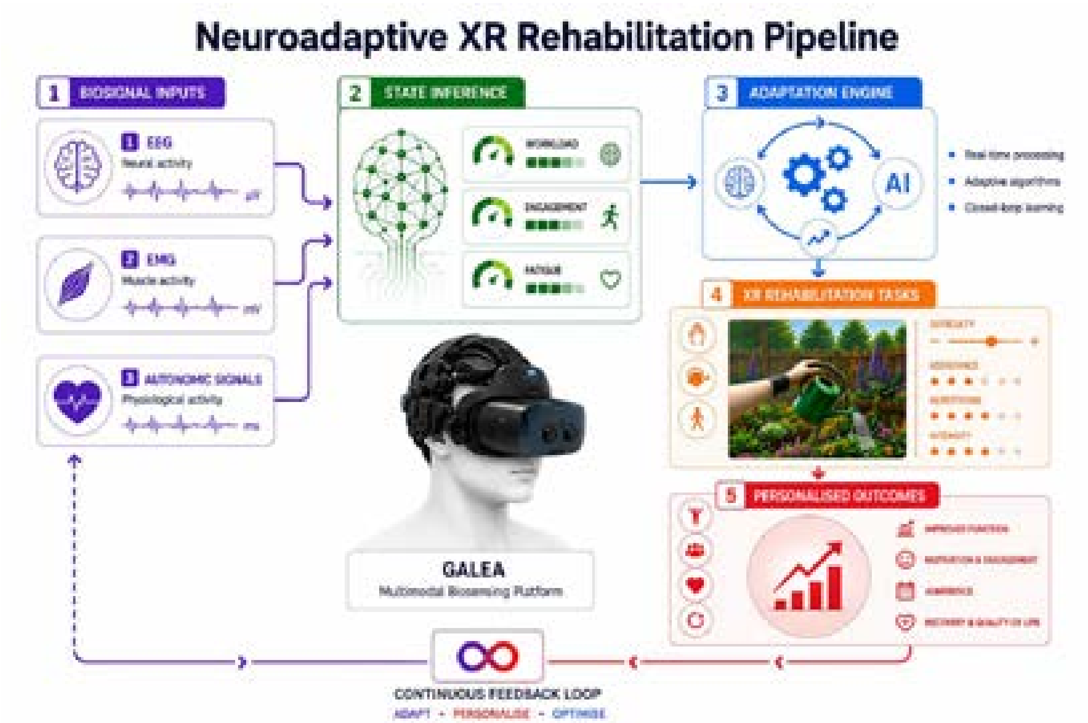

Figure 2: A Neuroadaptive XR Rehabilitation Pipeline Visualisation.

5. Discussion

The synthesis of mechanistic findings across the 32 biosensing-integrated VR studies highlights several potential pathways in which physiological signals can inform real-time adaptation within VR-based rehabilitation interventions. EEG-based MI tasks consistently modulate sensorimotor rhythms and indicate the possibility of decoding intention using EEG within VR rehabilitation. When EMG-driven input was used, a general increase in VR task engagement was demonstrated which can be inferred from a corresponding increase in muscular activity. HRV and EDA correspond to arousal and attentional engagement and are an alternate source of information that could be used to adjust tasks within VR.

Despite the similarities across modalities, the evidence base remains preliminary, heterogeneous, and largely based on small, healthy samples. As such, the proposed pathways should be interpreted as conceptual mechanisms rather than established causal processes. However, the recurring trends across integrated EEG, EMG and autonomic systems provide a coherent foundation for formulating mechanistic hypotheses regarding how biosensing can contribute to closed-loop neuroadaptive VR rehabilitation. Further empirical work is required to evaluate these mechanisms and determine their relevance within clinical rehabilitation

6. Conclusion

This work proposes a preliminary set of mechanistic pathways (Neural Intention Decoding, Volitional Muscle Activation, Autonomic State Modulation and Multimodal Integration) as a collective mechanistic framework derived from the convergent patterns identified across 32 biosensing-integrated VR studies from a broader systematic review. These pathways represent testable hypotheses regarding how physiological signals could inform adaptation within VR rehabilitation interventions rather than as definitive mechanisms.

Future research should evaluate these hypotheses within clinical contexts, examining their generalisability across various populations, and explore their potential for the design and development of personalised, closed-loop VR rehabilitation systems. Furthermore, the pipeline discussed as an example of the framework should be pursued in further detail to evaluate the capability of combining mechanistic insights with VR rehabilitation for the vulnerable target populations undergoing rehabilitation.

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VR & EEG – Mixed Computer Science Methods in the evaluation of Facial Emotion Expression Recognition

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Abstract

Facial Emotion Expression Recognition is widely agreed to be one aspect of social function that is impaired within the usual characterisation of Autism Spectrum Disorder. The ”Reading the Mind in the Eyes” test is used to this day in the diagnostic process. However, it disregards temporal data, has potential test format effects, and only observes performance rather than underlying behavioral triggers. With the increasing prevalence of VR and EEG tools, including this temporal data and investigating brain activity during testing may result in novel methods to investigate impairments in social function. This paper outlines a study protocol to be used to investigate the application of said tools to this purpose.

1. Introduction

Autism Spectrum Disorder (ASD) is a neuro developmental disorder characterised in part by persistent and recurring deficits in social interaction, including impaired social skills, weak communication skills, and repetitive behaviours (American Psychiatric Association (2022)).

An aspect that is applied both in the diagnosis and in the care of people with Autism is social understanding. A long standing canon of research has been performed investigating theory of mind, emotional understanding, and emotion identification, from developmental stages through adolescence and into adulthood. Common broad stroke diagnostics include self-reporting of a patient’s experiences with emotional connection to others, and measurements of the ability to observe, process, analyse and identify emotions in the face of other people. The latter is a key component of one of the formative tools for the diagnostic process regarding ASD, the “Reading the Mind in the Eyes” test or the RMET. This, alongside other tests of its kind, are named tests of “Facial Emotion Expression Recognition”, or FEER. However, some research contests the consistency and reliability of these tests, specifically when attempting to diagnose ASD (Vellante et al. (2013), Higgins et al. (2026)).

Other research also investigates the use of Electroencephalography (EEG) to examine and study the causes of deficits in FEER – however, there is a persistent problem with low power and poor repeatability. In particular, a verifiable and easily communicated standard is needed.

This paper will describe an ongoing study that expands the investigation of the technologies examined in the previous study, investigating the impact of spatial-temporal information on brain mimicry processes. It will also specifically examine the use of VR and High Realism Human Avatars in the standardisation of FEER assessment tools, utilising low-cost motion capture solutions to create a replicable research tool.

2. Background

EEG can be used to capture social-action / observation differences relative to Autism; a significant amount of research has already found some connection between the "Mu rhythm" and Autism, but the evidence is not yet strong enough to consistently differentiate ASD from typically developing persons consistently (Bernier et al. (2007)). The Mu rhythm is an alpha-band sensorimotor rhythm that is often suppressed during action observation, and some studies found reduced mu attenuation in Autism during observation tasks, with links to imitation ability (Fox et al. (2016)).

Some research has found that there are anomalies in Mu Rhythm when a person with Autism completes a motor mimicry task (Bernier et al. (2007)). Other studies show that there is a significant difference in cognitive processing detected by EEG (Wagner et al. (2013)) in general. However, it remains unclear whether these signals have diagnostic sensitivity (Bender et al. (2025)), in part due to the poor power in most studies on the subject (Hobson & Bishop (2017)).

For these reasons there is a need to develop a standardised methodology for the creation of FEER tasks – whilst there appears to be some consensus that there is a potential for a medium-sized effect relating ASD and Mu Rhythm Attenuation during emotional recognition tasks, there are few studies with sufficiently high power in and of themselves – and in general studies are not using sufficiently comparable methods to allow for inter-study validation. Using a method which can precisely measure or define the strength of the stimuli – say, highly realistic avatars, such as that in Epic Games' MetaHuman framework (Fang et al. (2021)) – will improve the ongoing quality of research into social-emotional recognition.

There are also novel technologies within Brain-Computer-Interfaces that provide some new avenues for research. Research headsets such as the Galea (OpenBCI (2026)) couple visualization and multi-modal data collection – including EEG, with the Mu rhythm in theory able to be captured. However, as these headsets use dry electrodes, there are complications with obtaining consistently clean data – which could complicate group separation if we only look at Mu. However, due to the multi-modal aspects of the headset, as well as recent advances in the construction of dry EEG electrodes, it may be more plausible to filter out unclean data and artifacts resulting from head movement, eye movement and arm movement.

Other research proposes that Mu Rhythm and EEG in general, could provide a highly sensitive perspective on understanding internal perception of emotion, especially if integrated into multimodal systems (Huang et al. (2017)). As such, later research could combine Mu band metrics with eye tracking, response time, task completion accuracy, facial action captured through Electromyography (EMG), and broader EEG features, many of which are also shown to have strong links to emotion processing (Wall et al. (2026)).

The main intent of the planned study is to identify if such a multi-modal system is viable, starting with an intensive evaluation of the presence of the Mu Rhythm, doing so by proposing a standard method of FEER evaluation creation.

3. Methodology

3.1. Participants

The recruitment of participants for this study is ongoing. 24 have been recruited so far (April 2026) from an open recruitment call within Nottingham Trent University, UK. More participants will be recruited from recruitment calls at two partner specialist schools, recruiting a range of students with ASD, with the school itself providing verification of a diagnosis of ASD in these cases. Four further participants have been recruited this way to date. The remainder will be recruited from a wider recruitment call in mainstream education throughout Nottinghamshire. Where a verified diagnosis is not available, self-reporting will be utilized.

In addition, 10 volunteers were recruited from Nottingham Trent University to aid in the creation of the testing software prior to data collection – specifically generating the example avatars and animations themselves. These were recruited to try and ensure a reasonable range of age and sex, with any self-reported ASD diagnoses noted.

3.2. Avatar Creation

The MetaHuman toolkit Fang et al. (2021) allows for humanoid models to be generated using a facial scan generated by a depth sensing camera. In this case, the TrueDepth camera and the LiDAR scanner on Apple's iPhone products were used, utilising Epic Games' integrated solution for generating MetaHuman assets and motion capture, Live Link Face (Games (2023)). This was connected to a target device running Unreal Engine 5.6 via a local wireless network connection. The subject who was to be made an avatar of was handed the recording device, and asked to hold it at approximately chin height, and then stood with their back to a plain, clear, consistent depth background, about a meter away to avoid depth sensing artifacts. The connected PC device was then told to start recording and the participant was taken through a standardised procedure in which they were asked to follow the researcher's finger with their face and gaze while keeping their body steady. The process is adapted from official guidance by Epic Games.

The participant was first to look straight ahead so their gaze passed over the recording device, then slowly (over about 3 seconds in each direction) directed to turn their head to the left and right. Once this is done, the connected device stops recording. Then, a specific frame was chosen based on the visibility of the participant's ears – when both ears were equally visible (or presumed to be so if obstructed by hair), that frame was chosen to form the neutral pose. This was then used to generate a facial mesh, a 3D model of the face, which was then sent to Epic Games for full processing, before being made into a MetaHuman properly.

For the volunteers, the same application was used to record a set of seven facial emotion expressions. These were translated into motion capture using other tools within Unreal Engine. These were invoked using neuropsychologist approved prompting, and based on the eight options used in the test as decribed below. These eight options are common forms of the seven emotional adjectives used in the Facial Action Coding System (Ekman (1992)) plus Neutral. Five of the seven active expressions were chosen at random. This is based on the theory that, rather than strictly impaired emotional processing, people with ASD have a different emotional model of understanding. Therefore, beyond using the adjectives as a baseline, it was decided to avoid strictly validating the animations for this experiment to capture the breadth of potential data sequences. This then avoids one of the primary criticisms of the RMET – namely that is is soley based in a ”Neurotypical” understanding of emotion.

3.3. RA-FEER-VR

The Realistic Avatar based assessment of Facial Emotion Expression Recognition utilising Virtual Reality (the RA-FEER-VR application) was developed for use in this study. In this application, the participant is placed into a plain game world – a box room with neutral white walls, and a white table in the centre. Projected from this table is a simple interface of eight purple buttons with white text. On these buttons were listed Happiness, Sadness, Fear, Surprise, Anger, Disgust, Contempt and Neutral. In the case of non verbal participants, a version with small pictograms of the relevant expressions was used. A short way behind this table is a small plinth, on which a Purple button with START written on it in white text is projected.

The player interacts with this environment through a HTC Vive VR controller – for simplicity, only the trigger is used, used as a pointer. A representation of the player's hand is displayed in the environment, with a red laser projecting from it. The player can interact with the buttons in the environment by pointing the laser at it and pressing the trigger.

After pressing the start button, a purple wall with a white fixation cross is raised. After approximately a second, it is lowered again, revealing one of the captured MetaHumans, performing one of the captured animations. The player, in their own time, points to and selects the word that they think best fits the expression shown. The wall is then raised again, and the process is repeated – 5 times per model, for 10 models, for a total of 50 tasks.

3.4. Experimental Protocol

After initial briefing and the collection of consent, the Galea headset was shown to the participants. The Galea Beta headset is an integrated ExG and VR system that can be utilised for rapid collection of electrographical data – including EEG data – during VR experiments such as these. Once the participant was comfortable, they were encouraged to put the headset on themselves before the researcher fastens it, ensuring the participant's comfort at all times.

At this point, following a short test to ensure that the EEG sensors were collecting clean data, the test application was started, and the participant was encouraged to move to a place in the game world where they are comfortable, whilst the test was explained. Then they were encouraged to select the ”Start” button and begin the test.

They were then encouraged to complete the task on their own whilst the headset recorded data. The system also captured the response times. Once this task was completed, the participants were debriefed.

Participants also took a Medical Survey. This was a short questionnaire asking the participant to self-report diagnoses of ASD, ADHD, DCD, Prosopognosia and other relavant cognitive affects, as well as handedness and gender (to compensate for artefacts these can cause in EEG (Darvishi-Bayazi et al. (2025) Ramos et al. (2025))). This questionaire also included the AQ50 (Baron-Cohen et al. (2001)) and the Social Phobia – Adult (LeBeau et al. (2016)) diagnostic tools.

4. Discussion

Data are currently being collected and are expected to be completed and analysed prior to presentation at the conference. However, we have the following expectations, based on previous research:

- In prior research, subjects in a general population see a drop-off in the presence of EEG signals at a specific frequency – the Mu Wavelength – during emotional recognition tasks. We expect this to persist broadly in VR.
- Participants with ASD in previous research see less Mu attenuation. We expect this to persist broadly in VR.
- Previous research used only models that have been validated within a neuro-typical emotional framework. We expect to see some changes in task performance (assessed by responses and response time) and mu attenuation within each group for ASD face models.
- However, it is worth noting in advance the following limitations:
- Aside from diagnoses confirmed by the partner institutions, this study relies on the AQ-50 and self reporting. The self reported ASD phenotype varies substantially from that which is clinically diagnosed. However, if we discover large within-groups variation but small between-groups variation, we can more accurately monitor these differences.
- Dry EEG electrodes have issues with poorer signal quality, and can be disturbed by hand and head movement. The Galea does integrate other forms of ExG, and this can be used to filter some movement artefacts. In many ways, this study is attempting to validate the technology and identify potential improvements and best practice, as outlined elsewhere in these proceedings.

Based on prior research, we are expecting to see a somewhat large effect of ASD on Mu Desynchronisation. Prior to the study, we estimated approximately 26 participants per group would be needed for this study to have sufficient power ($\alpha = 0.05$, $\beta = 0.2$, $d = 0.7$, right-sided test). This estimate appears to be supported by early analysis of the data.

5. Conclusion

Depending on the outcomes of this and other studies performed in the same project, the use of a highly standardised system to create, pose and evaluate social expessions on a humanoid model can be validated as useful for this kind of work. If this is the case, it opens up possibilities for wide-reaching multi-institutional research, enabling much faster progression in investigating various aspects of social perception and interaction. If face tracking can be done whilst a VR headset is being worn, this could extend this approach even further by opening up the possibility of a fully immersive social interactive experience, with facial gestures of all participants being monitored at all times – enabling objective evaluation of facial action, over the time-consuming and unreliable methods of expert witness currently used.

As an alternative, a multimodal approach to understanding FEER deficits could be investigated, analysing EEG, heart rate, broader ExG, etc., in order to gain a fuller image of the nature and variety of these deficits. This could assist in differentiation between often confused disorders or symptoms, increasing availability, and improving the nature of support. Multimodal systems such as this, in this case, would be a very clear avenue for future research within BCI.

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C&Look: A platform supporting children with oculomotor dysfunctions

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Abstract

Oculomotor dysfunction (OMD), a coordination problem between a child's left and right eyes, is rarely diagnosed and even less frequently treated. This research presents C&Look, an eye-tracking (ET)–based platform that uses serious games to generate objective measurements of eye movements and reveal coordination problems. The platform supports identification, analysis, and, when needed, vision training, while outlining the current state of the art of its development. We argue for its future use as a disruptive innovation in schools. This extended abstract highlights key aspects of C&Look's development and the potential for integrating ET technologies into school-based vision screening.

1. Introduction

Visual attention is considered a facilitator of the development of complex cognitive skills and a particularly salient predictor of academic outcomes. A well-documented problem in vision and eye care is the lack of attention to vision diagnostics for children, for examining oculomotor dysfunction (OMD), a coordination problem between the eyes. Identifying OMD is about how one's vision system functions; it is rarely done during routine health and vision checks for children. Parents and guardians rarely notice the problem; a child may not be aware of it, or her complaints may be misdiagnosed, such as dyslexia or behavioral problems (Wilhelmsen, 2016). Vision specialists familiar with OMD (eye-care practitioners) are few and lack the resources to screen all school-aged children (Eide et al., 2019). The screening requires a time-consuming consultation with the child's specialist, which relies on the specialist's observations. This screening is time- and resource-intensive and rarely includes assessment of children's functional vision unless it is obviously severe. The last mandatory health check at ages 4–5 includes vision screening, yet their vision is still developing when they begin school. 25–30% of school-aged children have vision problems (EuroSTAT, 2014), and up to 85% of these problems go undetected (Falkenberg, Langaas, & Svarverud, 2019; Johnson, Blair, & Zaba, 2000; Kocur & Resnikoff, 2002). OMD, as a vision impairment, can cause later impediments to academic success, the education system, the public health system, and social well-being (Ali et al., 2021; Zaba, 2001).

This study focuses on sketching the main steps of a solution that can help children's vision, also with OMD, between the ages of 6 and 14, a critical period in their vision development (Dodick et al., 2017; Gunvor Birkeland Wilhelmsen & Marion Felder, 2021), to: a) **identify** such vision problems, b) help with **training or therapy** towards better vision, since many of the functional vision problems, such as OMD, can be corrected by training. While many patients with non-severe OMD can train their vision and see better (Eide et al., 2019; Gunvor B Wilhelmsen & Marion Felder, 2021), enabling support for the c) **analysis** of these problems needs further examination.

The aim of this extended abstract is to present C&Look, a platform developed to support identification, training, and the analysis of vision functions using affordable eye trackers and software applications. While the hypothesis is that the solution works for adults as well, many of the studies included in the development and testing of C&Look focused on children in their early school years. This extended abstract summarizes lessons from studies conducted during the development of C&Look, while a more coherent description and argument for its intended use and current possibilities should be presented in a longer paper.

2. The possibility of screening vision at schools

To effectively help children through training or therapy and ensure they have the necessary resources, having C&Look, or similar tools, to support professionals like clinicians, vision specialists, opticians, etc., is not enough; they still lack the resources to monitor all children's vision. Children's vision should be screened more frequently at the start of school, when their vision is developing, and their main activities are changing. For example, they need to begin working longer periods at closer distances, such as writing and reading. Given the insufficient number of required screenings across countries, this work suggests including vision screening as part of school activities. Figure 1 illustrates this possibility.

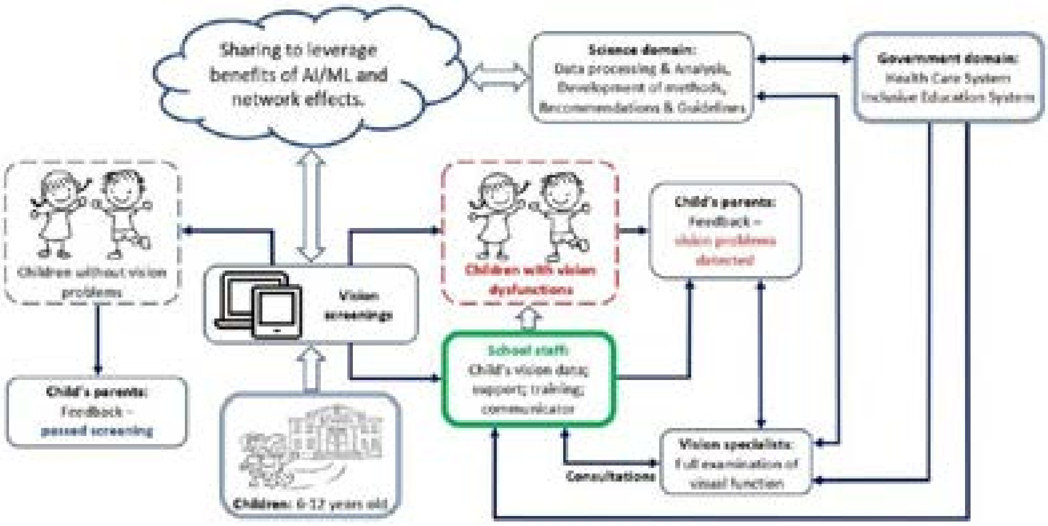

Figure 1 The illustration shows that OMD identification can be done at schools. Since ET technologies can detect healthy vision, children with possible vision problems will be referred for further examination. The image is done together with Gunta Krumina and Vlad Fomin.

As Figure 1 illustrates, to implement screening in schools, several issues beyond the affordable "system" (ET, software, computers) are necessary, such as assigning responsibility for screening, determining when and to whom to report results, addressing vision disturbances, and planning vision training. This means handling an ET-based screening as a disruptive service innovation (Gomolka, Kordos, Dudek-Dyduch, & Twarog, 2025). Ensuring competence and resources in schools can also mean taking some responsibility away from clinicians. While we posit that school staff do not need to be health experts, they will still need to assist with health issues in their daily work with children (Little et al., 2025). To use C&Look, school management should empower school staff to address children's vision by providing a supportive framework for vision support and coordination of all involved stakeholders (Ali et al., 2021; Heldal et al., 2021). Since there are several ET-based screenings for several vision functions, C&Look can later address several vision disorders, for example, non-strabismic accommodative and vergence dysfunctions (Wajuihian & Hansraj, 2015).

Approximating broader impact can be achieved through a preliminary cost-benefit analysis based on 2021 data, calculated after screening over 400 children with vision teachers, and informed by statistics from Tanzania and Norway. If all school-age children underwent vision screening annually and those with positive results also received vision training, the estimated rate of vision problems would be 30%, of which ⅔ would be previously undetected. Without such a vision screening system, a specialist would need 30 minutes per child for screening, 20 minutes for positive cases, and 10 hours of face-to-face training. With C&Look, they will still need 15 minutes for diagnosis confirmation and 1 hour for treatment follow-up, according to earlier studies (Eide et al., 2019). School personnel need 15 minutes for screening and 10 hours for training supervision for each group of 8 positive children. Thus, the screening time spent on each child will be about the same, divided between the health and school systems, saving the specialist time and lowering the total cost. Importantly, this solution will eliminate the waiting time to see a specialist, which can be several months, according to the Euroscreen report (EUScreen, 2019). The training time will be reduced from 10 hours face-to-face to 1 + 10/8 = 2,25 hours per child on average, again at a lower cost. On a national level, this results in significant savings while contributing to a systematic vision care system.

3. Technical possibility

Nowadays, several studies suggest that eye-tracking (ET) technologies can enable faster assessments of functional vision. There are multiple research- and profit-driven organizations working on solutions to support the identification or treatment of OMD or other functional vision problems, but these technologies are designed for clinicians and require specific technical settings and software. Most ET devices are from commercial developers and using them demands additional knowledge to adapt to the environment and users. Identifying OMD issues, providing training and therapy, and understanding analysis needs require distinct skills, especially when supported by technology. Many commercial solutions use fixed technologies and software; upgrades, modifications, and adjustments are often difficult. According to our current knowledge, there are no computer-supported vision screening and training programs at schools. There are a few computer-supported programs (e.g., RightEye, or VisionBuilder, or Thomson's solutions) for OMD, devices supporting autorefraction (e.g., SureSight, Plusoptix, SPOT 2), photoscreeners (e.g., MTI photoscreener, iScreen 3000), or mobile-based software programs (e.g., VERA, EyeSpye) testing certain aspects of vision, or Lexplore (testing reading ability). These are all parts complementing a thorough vision screening or training. The cost of these is often too high for schools to use, or they are too complex for non-specialists. Existing AI-based tools and techniques (e.g., CNN, VGG16, AlexNet, DeepID, iTracker) for eye tracking do not yet focus on the current diagnosis (e.g., OMD, spasm of accommodation diagnosis) and thus can only be considered in the development of the techniques as a reference point for future/further development.

4. Snippet from the basic parts of C&LOOK

The Project addresses children's vision problems holistically by tackling the network of stakeholders' responsibilities in children's health care (parents, schoolteachers, school nurses, vision care specialists) and soliciting schools' participation for a real-life demonstration of feasibility. Figure 2 illustrates a person reading and highlights four eye movements. Here (not shown), the x-axis is time, and the y-axis is horizontal POG distance from the left of the screen. As shown in this plot, fixations are nearly horizontal lines, i.e., the eyes are focused on a single point over time. On the other hand, saccades and regressions are nearly vertical lines (in opposite directions), indicating rapid movement from one point to another. Lastly, we observe glissades that correct the previous saccade/regression. Smooth pursuit is not shown here, but it would look like a diagonal line with no acceleration.

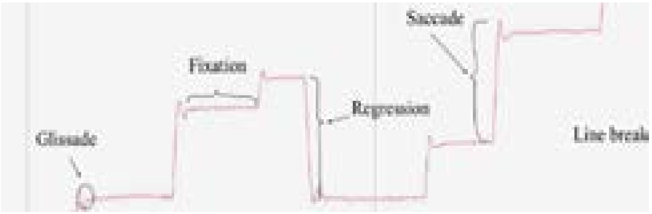

Figure 2. The four important eye movements registered by an ET during a reading task.

The tasks involve tracking objects on the screen and comparing the movements of the objects with the movements of the left and right eyes. These need to be coordinated, and a simplified version of the horizontal movements is shown in Figure 3.

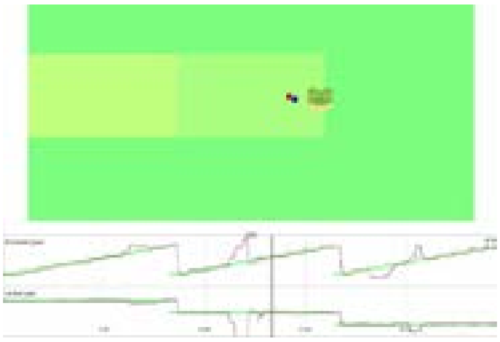

Figure 3. The video follows the frog's graphical representation on the screen, superimposed with the eye-gaze representations from the left and right eye. The dark green shows correct coordination.

5. Future work and corrent lessons

In the final paper, we argue for both the technical feasibility and the institutional relevance of the C&Look platform. The results will demonstrate how ET-based screening can be integrated into everyday school routines without overloading existing health services. The preliminary findings suggest that such an approach can improve early detection, reduce waiting times, and create a more equitable pathway to vision care for children. Overall, these insights indicate that C&Look has the potential to serve as a disruptive innovation that transforms how societies understand, organize, and provide children's vision services. Future work will focus on developing and validating an integrated system that shows technological robustness, measurement accuracy, economic viability, and institutional feasibility. Such a system would establish a solid foundation for large-scale national and international adoption, enabling network effects and ongoing improvements in diagnostic accuracy and training effectiveness through advanced AI models.

This work also highlights the value of an interdisciplinary approach, involving researchers from social science, organizational science, computer science, and vision science, along with practitioners who develop health technologies and conduct vision screening.

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07

EMBODIMENT, PRESENCE & IMMERSION

Measuring embodied immersion through reactive and proactive postural adjustments during a telepresence cycling experience

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Abstract

Immersion is central to engagement in virtual reality, yet it's often measured through subjective reports. We examined whether motor behaviour could provide an objective, real-time measure of immersion during a first-person cycling experience. Twenty-one participants pedalled on a cycle ergometer while viewing 360° bicycle ride videos through a head-mounted display. Head movements and pedalling cadence were recorded during expected and unexpected stops. Participants reacted with downward head rotation and reduced cadence. Expected stops produced earlier, smoother head movements responses and stronger cadence reductions. These findings indicate motor measures could complement self-reports in assessing immersion and support applications in rehabilitation contexts.

1. Introduction

The effectiveness of VR applications depends, at least in part, on user engagement. A major determinant of engagement is the sense of presence, which is strongly influenced by the degree of immersion afforded by the virtual environment (Schuemie et al., 2001; Riva et al., 2004; Sanchez-Vives and Slater, 2005).

Despite its importance, immersion is typically assessed through subjective user experience (UX) reports, and objective, real-time measures remain limited. However, objective motor responses may provide important complementary evidence, because they may reflect embodiment (Sanchez-Vives and Slater, 2005; Saint-Aubert et al., 2023). Posture and movement may therefore offer informative readouts of the naturalness and congruency of VR environments. So establishing objective behavioural indicators of immersion would be valuable both for research and for rehabilitation applications, where continuous monitoring of user engagement may help optimize intervention delivery.

Given the increasing use of VR-based cycling applications in rehabilitation, including exercise programmes for older adults and long-term care settings (Anderson-Hanley et al., 2012; Arlati et al., 2019; Høeg et al., 2021; Loggia et al., 2021; de'Sperati et al., 2023; www.telecyclette.eu), it seems important to determine how posture and movement during virtual cycling are shaped by visual cues, particularly optic flow (visually-evoked motor responses, VEMRs; Bronstein, 1986). Previous research on optic flow during simulated cycling, however, has mainly focused on perceived or exerted effort (Parry et al., 2012; Yasukawa et al., 2021; Otten et al. 2025).

In this preliminary report, we compared VEMRs elicited by unexpected and expected stops during an immersive first-person virtual bicycle ride. Because VEMRs can be modulated by expectation (Bronstein and Buckwell, 1997; Guerraz et al., 2001; Cooper et al., 2018), we distinguished reactive motor adjustments (RMAs), driven by optic flow changes, from proactive motor adjustments (PMAs), which depend on anticipation. We hypo-thesised that unexpected stops would mainly evoke RMAs, whereas expected stops would mainly evoke PMAs.

2. Methods

1.1. Participants

Twenty-one volunteers recruited by convenience sampling participated in the study (11 males; age range, 21–35 years). History of epilepsy or motion sickness was considered an exclusion criterion. Written informed consent was obtained from all participants before the experiment.

1.2. Stimuli and task

The stimuli consisted of two 12-min pre-recorded 360° videos of a bicycle ride in a suburban area, filmed along the same route in opposite directions. The videos were recorded in 4K resolution at 29.97 fps using a Ricoh Theta Z1 camera mounted on the handlebar. Each video included 12 stops: 6 expected stops, signalled by road signs, and 6 unexpected stops, presented without anticipatory cues. The two videos were counterbalanced across participants.

Participants pedalled on a cycle ergometer with both hands on the handlebar while viewing the pre-recorded cycling video through a Meta Quest 3 head-mounted display (HMD; Fig. 1). Pedalling cadence modulated video speed in real time. Original video speed was attained at a cadence of 50 rpm (maximum video speed = 1.5x).

UX ratings were also collected, including cybersickness assessed with the Simulator Sickness Questionnaire (total score range 0–203), sense of presence assessed with items derived from the Igroup Presence Questionnaire (range: 0–6), and a self-rating of perceived equilibrium during steering (EQ; range: 0–6).

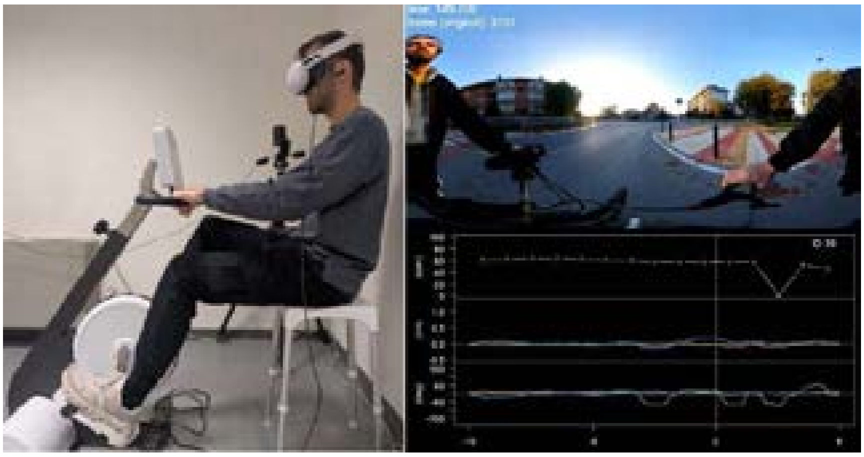

Figure 1: Left: Experimental setup. The participant pedalled on an exercise bike while viewing the 360° video. Right: video frame showing an approaching expected stop (top panel), with concurrent recordings of cadence (top trace) and head movements (middle and bottom traces). In this example, the participant briefly stops pedalling after the cyclist stops at the stop sign (vertical dashed line).

1.3. Data analyses

Head movements were recorded using the HMD tracking system and down-sampled at 90 Hz, whereas pedalling cadence was recorded with a pedal-mounted sensor at 1 Hz.

For each stop, we extracted baseline head position, defined as the mean head position during a 1-s interval beginning 3 s before the stop; head-movement amplitude, defined as the maximum deviation from baseline during the interval from 2 s before to 3 s after the stop; and head-movement onset, defined as the time point preceding the peak at which head position crossed 10% of the maximum excursion. Mean onset times and amplitudes were compared between expected and unexpected stops using two-tailed t-tests.

For each stop, we extracted cadence values at 2 s before the stop, at stop time, and 3 s and 6 s after the stop. Cadence was analysed using a repeated-measures ANOVA with the within-subject factors Time (4 levels) and Stop type (2 levels), with Greenhouse-Geisser correction where appropriate.

2. Results

Participants reported a relatively high sense of presence (M = 4.0, SD = 1.3) but with some cybersickness symptoms (total score: M = 50.8, SD = 45.6), possibly partly due to discomfort related to loss of equilibrium during observed steering (M = 4.7, SD = 1.5). Informal complaints for lack of bike control were also noted.

During the virtual ride, participants tended to rotate the head downward and reduce pedalling cadence when the cyclist stopped, with some notable differences between expected and unexpected stops (Fig. 2). To avoid possible smoothing effects in the average traces due to trial-by-trial asynchronies, individual measures were taken trial-wise (Tab. 1).

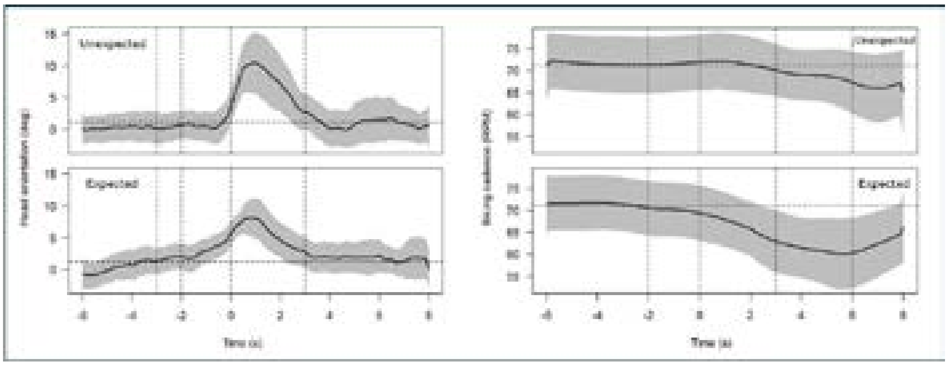

Figure 2: Left: mean head orientation (black line) ± SD (grey area) around stop time in the video (t = 0). Positive values indicate downward rotation, with 0° representing the mean head orientation across the entire 12-min recording. Right: mean cadence (black line) ± SD (grey area). Horizontal lines denote average baseline level across all trials. Vertical dashed lines indicate the time points used for statistical analyses.

Head movements differed significantly between stop types. Movement amplitude was larger for unexpected than for expected stops ($t19 = 2.193$, $p = .041$), whereas movement onset occurred earlier for expected than for unexpected stops ($t19 = 2.634$, $p = .016$).

Cadence decreased around both expected and unexpected stops. The ANOVA revealed significant effects of Time ($F(3,57) = 10.07$, $\varepsilon = 0.492$, $p = .001$), Stop type ($F(1,19) = 11.87$, $\varepsilon = 1.0$, $p = .003$), and their interaction ($F(3,57) = 5.12$, $\varepsilon = 0.707$, $p = .006$). Post hoc comparisons showed that cadence was already lower for expected than for unexpected stops at stop time, indicating anticipatory slowing in the expected-stop condition.

	Unexpected stop	**Expected stop**	t_{19}	**P value**
Head rotation in the sagittal plane				
t start (s)	-0.40 ± 0.35	-0.66 ± 0.39	2.634	0.016
amplitude (deg)	11.79 ± 10.46	7.55 ± 6.66	2.193	0.041
Cadence (rpm)				
Cadence at *t* = -2 s	71.26 ± 14.53	70.50 ± 14.00	0.726	0.477
Cadence at *t* = 0 s	71.95 ± 14.46	69.42 ± 14.09	2.865	0.010
Cadence at *t* = 3 s	70.08 ± 13.45	62.95 ± 16.02	3.203	0.005
Cadence at *t* = 6 s	67.32 ± 15.94	60.31 ± 18.14	2.958	0.008

Table 1: Head rotation and cadence (mean ± between-subject SD) and t-test results comparing expected and unexpected stops.

3. Discussion

The main aim of this study was to investigate VEMRs elicited by expected and unexpected stops during an immersive first-person virtual bicycle ride. More specifically, we asked whether these responses could dissociate reactive from proactive motor adjustments.

The results support this interpretation. Participants responded to the cyclist's stops with downward head movements and reduced pedalling cadence. Unexpected stops elicited clear downward head movements, followed by a moderate cadence reduction, consistent with a reactive response (RMA), whereas expected stops induced earlier and more moderate head movements, as well as earlier and stronger cadence reduction, consistent with anticipatory control (PMA). Thus, during simulated cycling, environmental predictability modulates otherwise automatic motor responses (Bronstein and Buckwell, 1997; Guerraz et al., 2001; Cooper et al., 2018).

Several limitations should be acknowledged. First, we did not find any strong correlation between objective and subjective measures of the sense of presence. However, no definitive conclusions can be drawn because of the small sample size of this study. Second, because the objective measures depended on the type of stops, future studies should include separate subjective assessments for VR experiences involving expected and unexpected stops. Finally, our study used pre-recorded videos rather than an interactive VR environment with real-time cyclist interaction, which may have influenced both the objective and subjective measures of the sense of presence.

These findings support the use of motor measures as a complement to self-report questionnaires in the assessment of immersion. Unlike retrospective ratings, such measures provide a real-time embodiment index of how users respond to a virtual environment. This may be especially relevant for VR applications, where immersion and engagement are important for rehabilitation use (Riva et al., 2004; Høeg et al., 2021; de'Sperati et al. 2023).

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Repeated immersion in a virtual forest: stability of benefits across multiple sessions

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Abstract

Forest environments reliably reduce stress and improve mood, and virtual forests are proposed as an accessible substitute when the real ones are out of reach. Most evidence, however, comes from single sessions, often between-subjects, leaving the durability of the benefit across repeated use untested. In this feasibility study, 11 adults (3 men, 8 women) from a university community completed 5–10-minute immersions in the same photorealistic virtual forest, one per week for 5 consecutive weeks. Restoration (ROS), mood (POMS-SF), heart rate, blood pressure, and cybersickness (VRSQ) were recorded before and after each session. Linear mixed-effects models indicated that psychological benefits remained stable across the five weeks, however the heart-rate benefit was modestly attenuated. Cybersickness did not diminish the psychological benefits. The findings tentatively support that repeated short VR-forest exposure provides a stable well-being intervention.

1. Introduction

Spending time in forests is associated with reduced stress, improved mood, and increased subjective restoration (Kotera et al., 2022). When access to real forests is limited, virtual renderings of natural environments have been proposed as an alternative (Frost et al., 2022; Spano et al., 2023). A growing body of work shows that single virtual nature sessions can reduce negative affect and elicit a restorative effect, although such effects tend to be smaller than those of real nature exposure (Hejtmánek et al., 2022; Reese et al., 2022). Most of this evidence relies on single-session designs, often between-subjects. Whether the benefit of virtual nature exposure persists with repeated use is poorly documented. We can assume two competing predictions. On the one hand, the novelty and unfamiliarity of the virtual forest may build fascination and interest, as per attention restoration theory (Kaplan & Kaplan, 1989), thereby contributing to the observed effects. In this case, repeated exposure should produce a fading benefit. On the other hand, repeated exposures may build a stable dosing effect comparable to that reported for repeated outdoor walks (Browning et al., 2023). Recent reviews note that longitudinal designs in virtual nature research remain scarce and that most studies use exposures of five minutes or less (Bolouki, 2024). In our previous study (Hejtmánek et al., 2022), we showed that a 20-minute exposure to a digital twin of a real forest produced restorative gains and reductions in negative affect. Building on that work, the present study asks a different question: when participants are repeatedly immersed in the same virtual forest, do the within-session benefits remain stable, fade, or grow?

2. Methods

2.1. Participants

Twelve participants were recruited from the university community and participated for bonus credit. Only 11 (with complete pre- and post-session data for at least one session) were retained for analysis (3 men, 8 women;age range 20–25), as one participant did not return after the first session. The study followed the Declaration of Helsinki and was approved by the Institutional Review Board of the Institute of Psychology of the Czech Academy of Sciences.

2.2. Procedure

Participants completed five immersion sessions in the same virtual forest, scheduled every Wednesday for five consecutive weeks. Three participants missed one session, but their data were retained for the analyses. Sessions were administered in a quiet, windowless, temperature-controlled room on a university campus. At the beginning of each session, participants completed questionnaires, and the researcher collected physiological measures (see 2.3 Outcome measures). Then, they were seated on a camping chair within an approximately 4x4-meter space and given the Meta Quest 3s tethered head-mounted display (HMD). During the intervention, they could stand at any time and walk within the area, or remain seated, as they chose to mimic similar experiences in forest bathing practice. A researcher silently walked behind them, making sure they did not trip over furniture or the cable. The duration of the intervention was set to 10 minutes as a compromise between session lengths typical of VR-nature studies (often short, few-minute interventions) and longer real-forest bathing protocols, while keeping the sessions tolerable (30 minutes including all measurements). The virtual forest was the same environment used in our previous research (Hejtmánek et al., 2022. It was a digital twin of a Central European oak-hornbeam forest, reconstructed from LiDAR scans of tree positions and dimensions, with spatialized ambient audio recorded on location. After the session, participants' physiological measures were taken, and questionnaires were administered.

Figure 1: Session intervention overview. VRSQ was collected only post-session.

2.3. Outcome measures

Before and after each session, participants completed the Restoration Outcome Scale (ROS; Korpela et al., 2008) and the short form of the Profile of Mood States (POMS-SF; Curran et al., 1995), from which we derived six subscale scores (anger, confusion, depression, fatigue, tension, vitality) and a total mood disturbance score (TMD). Heart rate and systolic and diastolic blood pressure were recorded with OMRON Evolve. Additionally, after each session, participants completed the Simulator Sickness Questionnaire (Kennedy et al., 1993), from which we calculated VRSQ subscores (disorientation and oculomotor) (Kim et al., 2018).

2.4. Analysis

Analysis of the intervention's effect during the first session was conducted using a paired t-test comparing pre-and post-session scores for each individual outcome. While the sample was small and the Shapiro-Wilk tests showed violations of normality in many psychological outcomes, the physiological measures and some psychological measures demonstrated fairly normal distributions, and Wilcoxon paired tests showed no differences in significance in any outcome measure from the parametric one, we opted to use the paired t-test to simplify results communication. To analyze stability across sessions, we fitted a linear mixed-effects model with the difference between post- and pre-session scores as the dependent variable (denoted as Δ in the results below), session as the fixed effect, and participant as the random effect. We also fitted a moderation model with VRSQ to see whether simulator sickness affected the results. With $n = 11$, results should be treated as exploratory, and effect sizes with 95% confidence intervals should be emphasized over p-values.

3. Results

3.1. Within-session effects at the first session

Looking only at the very first session, immersion produced expected reductions in total mood disturbance (Δ = −7.27, 95% CI [−11.70, −2.85], p = .004), tension (Δ = −2.27 [−3.62, −0.93], p = .004), and fatigue (Δ = −3.55 [−5.82, −1.27], p = .006). Restoration showed a positive but non-significant change (ROS Δ = +3.73 [−0.54, +8.00], p = .080), as did POMS vitality (Δ = +0.27 [−0.53, +1.07], p = .465). Other psychological values showed expected reductions, albeit non-significant in anger (Δ = −0.27 [−0.59, +0.04], p = .082), depression (Δ = −0.36 [−0.98, +0.26], p = .221), and confusion (Δ = −0.55 [−2.06, +0.97], p = .441). Heart rate showed an expected reduction at the first session (Δ = −4.36 bpm, 95% CI [−8.55, −0.18], p = .043), as did systolic blood pressure (Δ = −5.91 mmHg [−11.57, −0.24], p = .042). Diastolic blood pressure showed reductions but did not reach significance (Δ = −1.09 mmHg [−5.65, +3.47], p = .606).

3.2. Stability across sessions

The slope of Δ in the session was indistinguishable from zero for all psychological outcomes (all 95% CIs straddled zero), suggesting neither fading nor improvement of the effect. However, the change in heart rate Δ across sessions was small and positive (+1.37 bpm per session, 95% CI [+0.24, +2.51], p = .019), indicating a modest attenuation and suggesting that the positive benefits observed in the initial session faded over time. Systolic and diastolic blood pressure showed no significant slope, although they also showed a slight increase over time. The overall evolution of the main scales is shown in Fig 2.

3.3. Cybersickness as a moderator

For psychological outcomes, cybersickness did not significantly moderate session benefits, neither for the first session, nor across all measurements, although effects were mostly in the expected direction (i.e., higher VRSQ scores reduced benefits). Specifically, both restoration (ROS, First session: β = −0.264, 95% CI [−0.638, +0.111], p = .146; All-sessions: β = -0.023 [−0.372, +0.327], p = .896) and total mood disturbance (TMD, First session: β = 0.213 [−0.621, +0.196], p = .269; All-sessions: β = 0.034 [−0.256, +0.187], p = .754) showed no moderation by VRSQ scores. All other psychological outcomes similarly yielded no moderation effects. For physiological outcomes during the first session, VRSQ scores did not significantly moderate improvements in heart rate (β = 0.212, 95% CI [−0.596, +0.171], p = .242), systolic blood pressure (β = -0.163, 95% CI [−0.385, +0.711], p = .519), or diastolic blood pressure (β = -0.087 95% CI [−0.361, +0.534], p = .671). Across all sessions, pooled within-person cybersickness did not significantly moderate heart rate (β = -0.137 [−0.165, +0.438], p = .366) or systolic blood pressure (β = 0.246 [−0.808, +0.316], p = .380). However, a significant moderation effect was found for diastolic blood pressure across all sessions (β = 0.311 [−0.574, −0.049], p = .022), indicating that higher-than-usual sickness was associated with significantly lesser physiological benefit during those sessions.

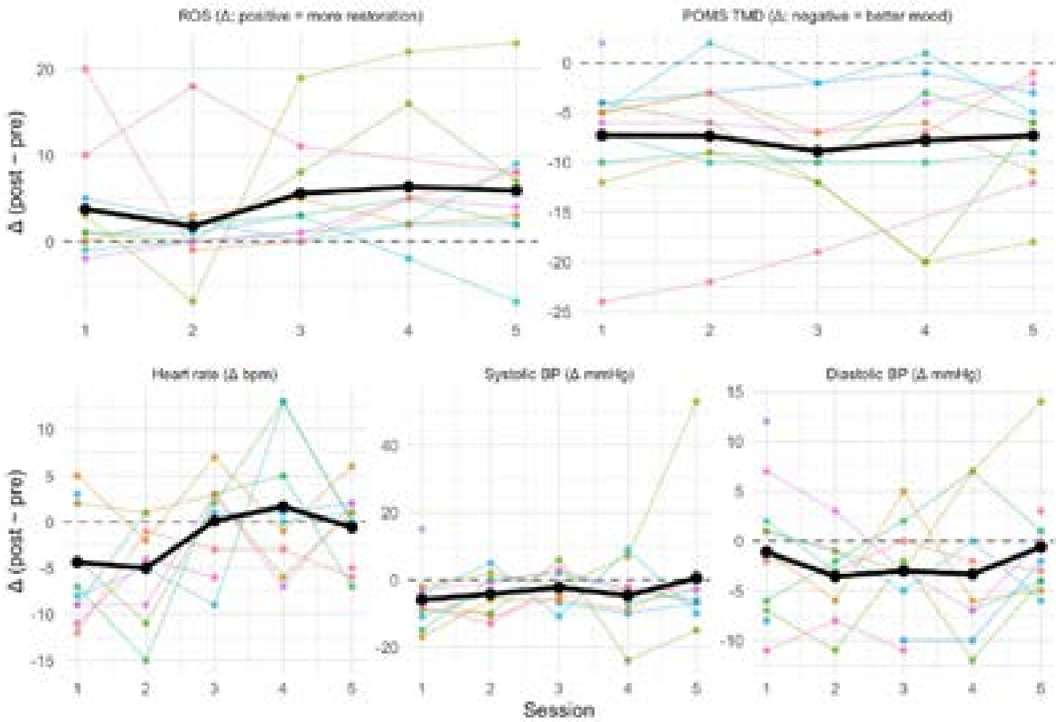

Figure 2: Evolution of the session benefits denominating pots– pre- session scores for the main outcome measures. Individual lines show participant trajectories, and the black line shows the general trend averaged across all participants.

4. Discussion

We observed first-session improvements in most psychological and physiological measures, although not all reached significance, and no detectable fading of these benefits across the five weeks, except for heart rate change, which increased in participants over the course of the study. However, in psychological measures, the change of the benefits across sessions was statistically indistinguishable from zero. Our limited data, therefore, do not show a significant attenuation of psychological benefits.

These findings support the use of repeated short VR-forest exposure as a simple well-being intervention. They also address a methodological concern raised in our previous work, in which individual responses to virtual and real forest exposure were only weakly correlated. Stability of the within-session benefit across sessions makes it less likely that the average effect of virtual nature is caused by a simple novelty response in a limited subset of participants.

Several limitations should, however, be considered. The sample (n = 11) is very small and may lead to false negatives for small attenuation effects. We omitted a control condition, so within-session change cannot be separated from rest or expectancy effects. Sessions were spaced one week apart, and we cannot speak to denser or sparser schedules. Replication with a larger sample and longer follow-up will be necessary as the next step.

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08

AGING & METHODOLOGY

Offline onboarding as a potential contributor to adherence in virtual reality interventions for hospitalized older adults

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Abstract

Virtual reality (VR) may support coping with passivity and reduced autonomy in hospitalized older adults, yet unsuccessful first encounters may reinforce withdrawal rather than support involvement. We developed a structured offline onboarding protocol as a brief preparatory phase to reduce uncertainty, support understanding of interaction logic, and help make the first VR encounter a positive experience. As a conceptual, practice-informed position paper, this manuscript frames offline onboarding as a potential mediating component between intervention design, user readiness, and sustained involvement, to be examined in future research. By addressing cognitive, emotional, and interaction-related factors prior to immersion, offline onboarding may support accessibility and continued engagement with VR interventions in vulnerable populations.

1. Introduction

Older adults undergoing prolonged hospitalization are at increased risk of functional and psychological decline. Beyond medical factors, the hospital environment itself contributes to reduced activity levels, loss of independence, and limited opportunities for decision-making (Creditor, 1993; Covinsky et al., 2011). These conditions are associated with decreased perceived control and increased passivity, which may negatively affect motivation and engagement in both everyday activities and therapeutic processes. The concept of learned helplessness provides a useful framework for understanding how repeated experiences of non-contingency between action and outcome can lead to reduced initiative and withdrawal (Abramson et al., 1978). Restoring a sense of control has been shown to positively influence well-being and behaviour in older populations. Even small, structured opportunities for choice and agency can improve engagement and outcomes (Langer & Rodin, 1976; Bandura, 1977). VR interventions have emerged as promising tools in this regard, offering immersive environments in which users can actively explore and interact within otherwise constrained settings. In clinical contexts, VR has been associated with reductions in anxiety and improvements in mood, while also providing accessible and engaging experiences for older adults (Appel et al., 2020).

However, successful engagement with VR, especially among older and clinically vulnerable users, can be challenging. First encounters with immersive systems may involve uncertainty, anxiety, cognitive overload, or concerns related to physical discomfort (Huygelier et al., 2019; Saredakis et al., 2020; Schaumburg et al., 2025). These difficulties are consistent with broader findings showing that perceived complexity, usability, and self-efficacy influence technology acceptance among older adults (Chen & Chan, 2014; Schroeder et al., 2023). Because early exposure can shape user attitudes toward VR, the quality of the initial experience becomes particularly important (Huygelier et al., 2019). While prior work has emphasized usability and accessibility, less attention has been given to processes that prepare users before initial engagement. Onboarding refers to methods that support users in becoming familiar with a system and its use (Renz et al., 2014; Strahm et al., 2018), and may include pre-session preparation, in-situ guidance, or system-integrated tutorials (Chauvergne et al., 2023). In VR, onboarding may be particularly demanding for first-time users due to the novelty of both the device and the interaction paradigm (Liu et al., 2018), requiring users to learn unfamiliar interaction concepts such as navigation, controller-based input, object manipulation, and movement within a virtual environment.

In this context, particularly in older clinical populations where maintaining engagement is essential, we developed a structured offline onboarding protocol. This brief pre-exposure phase introduces the virtual environment, clarifies interaction logic, and establishes safety and control, supporting the formation of a coherent mental model of the experience. This manuscript is a conceptual, practice-informed position paper rather than a review. Its aim is to conceptualize offline onboarding as a potential mediating component between intervention design, user readiness, and sustained involvement, and to outline its relevance for VR-based interventions targeting hospitalized older adults. By addressing cognitive, emotional, and interaction-related factors prior to immersion, offline onboarding may play a key role in supporting engagement, particularly in populations at risk of passivity and disengagement.

2. Conceptual background

2.1. Loss of control and engagement in hospital settings

Hospitalization in older age is frequently associated with reduced autonomy, environmental constraints, and decreased opportunities for self-directed action (Creditor, 1993; Covinsky et al., 2011). In such constrained and externally structured environments, older patients may have fewer opportunities to experience a clear connection between their own actions and meaningful outcomes, a mechanism closely related to learned helplessness (Abramson et al., 1978; Seligman, 1975). In rehabilitation contexts, learned helplessness has been used to explain reduced motivation and engagement among older patients when repeated losses, disability, or limited control foster the perception that personal efforts have little influence on outcomes (Abramson et al., 1978; Seligman, 1975; Teitelman, 1982). Low engagement may therefore reflect not merely resistance to novelty, but a clinical context in which perceived control, competence, and initiative are already compromised. Interventions that reintroduce clear action–outcome contingencies may help counteract these effects by creating structured opportunities for choice and self-directed action. It has long been established that even small opportunities for choice can enhance engagement and well-being in older adults (Langer & Rodin, 1976; Bandura, 1977). In parallel, self-efficacy theory suggests that perceived capability and outcome expectations influence whether individuals initiate coping behaviour, how much effort they invest, and how long they persist when facing obstacles (Bandura, 1977). Restoring a sense of agency may therefore require environments that are predictable, controllable, and offer meaningful interactions as opportunities for choice rather than mandatory tasks, allowing users to decide whether and how to engage (Huygelier et al., 2019). Virtual environments can be designed to provide active, controllable, and choice-based experiences (Lundstedt et al., 2023), but access to these potential benefits is not automatic. For hospitalized older adults who may already experience passivity, reduced autonomy, and diminished perceived control, first-time VR use may create a paradox: while the intervention aims to support agency and self-efficacy, the unfamiliar technology may initially be experienced as an additional demand or competence threat. Offline onboarding should therefore be distinguished from the therapeutic mechanism of the VR intervention itself. Its role is not to directly reverse learned helplessness, but to prepare users for meaningful engagement with an intervention that may support agency, perceived control, and self-efficacy.

2.2. Virtual reality as a potential control-restoring intervention

VR offers the possibility to support psychological well-being by enabling active exploration and interaction for individuals with limited mobility or access to natural environments. Evidence suggests that immersive VR experiences may positively influence emotional health in later life (Appel et al., 2020). However, its effectiveness depends on the user's ability to meaningfully engage with the system. Initial encounters with VR may involve uncertainty, unfamiliar interaction logic, and concerns related to safety or performance. These early interactions can be understood as a critical phase during which expectations, cognitive load, and emotional responses are shaped and may influence subsequent engagement (Bharti et al., 2024; Huygelier et al., 2019; Saredakis et al., 2020). The control-restoring potential of VR can also be interpreted through Self-Determination Theory, particularly the needs for autonomy and competence, which are central to motivation, engagement, and well-being (Ryan & Deci, 2000). The relevance of these mechanisms for health-related interventions has been supported across a wide range of clinical and behavioural contexts (Ntoumanis et al., 2021). From this perspective, VR may be clinically relevant not only because it provides distraction, stimulation, or access to otherwise unavailable environments, but because it can offer opportunities to choose, act, explore, and experience the consequences of one's own actions within a constrained clinical context. However, this therapeutic potential depends on whether users are sufficiently prepared to engage with the system in the first place.

2.3. The role of preparatory processes in intervention effectiveness

In healthcare, preparatory interventions such as pre-procedural information and expectation management have been shown to improve patient outcomes by reducing anxiety and enhancing coping (Johnston & Vogele, 1993; Suls & Wan, 1989). These processes support expectation formation and perceived control, while patients' expectations and illness perceptions also influence treatment outcomes and engagement (Broadbent et al., 2009). Despite this, preparatory phases are rarely described in the VR literature. This observation also emerged in our scoping review (N = 349) of immersive VR interventions in older adults, where onboarding processes were largely absent despite extensive focus on interaction design (Chovanec et al., 2025). High exclusion rates reported among older and disabled users further highlight the importance of supporting early interaction (Galindo Esparza et al., 2025). In this context, we conceptualize offline onboarding as a structured preparatory phase that supports initial engagement and bridges intervention design and user experience.

2.4. Development approach and experiential basis

The offline onboarding protocol was developed through a practice-informed conceptual process rather than as a formal empirical study. The need for such a preparatory phase first became apparent during the first of three preparatory workshops preceding the development of Zenctuary VR+, which involved older hospitalized adults. Compared with younger users, these participants required more extensive explanation before entering VR, and it became clear that once the headset was already in place, explaining controller-based interactions and the logic of the virtual environment was considerably more difficult. In addition, one participant experienced fear of heights while watching a passive 3D video, despite not having been prepared for this possibility in advance. These experiences highlighted that preparation before immersion should address not only technical instructions, but also expectations, safety, emotional readiness, and perceived control. Following these observations, we examined relevant literature on VR onboarding, cognitive load, preparatory interventions, learned helplessness, perceived control, and disease- or context-specific factors related to hospitalized older adults. These experiential observations were not collected as formal research data and were not subjected to qualitative analysis; rather, they informed structured team reflections that were translated into a brief semi-structured onboarding sequence.

2.5. Design principles of onboarding

Drawing on the conceptual considerations and experiential observations outlined above, four core design principles guided our onboarding process: First, onboarding should reduce uncertainty and anxiety by providing clear and reassuring information about the upcoming experience (Johnston & Vogele, 1993; Suls & Wan, 1989). Second, it should support the formation of a coherent mental model of the virtual environment and its interaction logic, enabling users to understand how actions translate into outcomes (Liu et al., 2018; Chauvergne et al., 2023). Third, onboarding should emphasize perceived control by explicitly communicating user agency, including the ability to interrupt or modify the experience at any time (Langer & Rodin, 1976; Bandura, 1977; Abramson et al., 1978). Fourth, onboarding should limit cognitive demands by presenting only essential information, avoiding overload during initial exposure to VR (Liu et al., 2018; Sweller, 1988; Schaumburg et al., 2025).

2.6. Structure of the onboarding protocol

The offline onboarding is implemented as a short (approximately 5–10 minute), semi-structured procedure conducted prior to the first VR session. It is delivered by a researcher or clinician and follows a standardized sequence of steps, while allowing minor adaptations based on participant needs. The protocol was developed for the Zenctuary VR+ application, a nature-based intervention for older adults in clinical settings. The onboarding consists of four main components. First, the virtual environment is introduced using 2D visual materials and a brief verbal explanation that emphasizes safety and the absence of performance expectations. Second, basic navigation principles are explained, focusing on simple and predictable interactions. Third, interactive elements are presented in a limited and structured manner to support understanding without overload. Fourth, safety instructions are provided, including the option to interrupt or stop the experience at any time. The process begins with a brief assessment of prior VR experience, allowing the facilitator to identify potential misconceptions or previous negative experiences. As prior exposure does not necessarily translate into transferable understanding, onboarding remains relevant even for experienced users. The process concludes with an opportunity for participants to ask questions before entering the VR environment.

3. Discussion

This paper conceptualizes offline onboarding as a structured preparatory phase that may support engagement with VR interventions among hospitalized older adults. We position onboarding as a mediating component between intervention design, user readiness, and sustained involvement, particularly in populations with reduced autonomy and increased vulnerability to disengagement. From a clinical perspective, hospital environments may reinforce passivity and reduced agency, while VR interventions may offer active, choice-based, and controllable experiences. However, this potential is unlikely to be accessible if the first encounter with VR is experienced as confusing, anxiety-provoking, or overly demanding. A key implication of this framework is the distinction between the therapeutic potential of the VR intervention and the enabling role of onboarding. Offline onboarding prepares users to engage with an intervention that may support perceived control, competence, and agency. By establishing predictability, safety, and a basic understanding of interaction logic before immersion, onboarding may reduce the risk that unfamiliar technology becomes an additional barrier to engagement. The proposed approach has limitations as it was developed for a specific application and target population, and its relationship with longer-term engagement, adherence, and drop-out rates remains to be empirically tested. Future research should examine offline onboarding as a potential mediating factor influencing user readiness, engagement, and intervention outcomes in clinical VR settings. Despite these limitations, offline onboarding represents a low-resource and clinically relevant component that may improve the accessibility and effectiveness of VR-based interventions for older adults.

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"The technology works fine, but…" Barriers to involving older adults in co-design for digital health innovation: a structured case study reflection

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Abstract

This paper examines the barriers to involving hospitalised older adults in co-design for digital health innovation. It draws on ZenctuaryVR+, a research project funded by the Hungarian National Research, Development and Innovation Office (NKFIH), in which a nature-based virtual reality (VR) application supporting the wellbeing of older adults in long-term hospital care is co-designed together with patients and healthcare professionals and will subsequently be evaluated in a longitudinal randomised controlled trial (RCT). Applying the Nonadoption, Abandonment, Scale-up, Spread and Sustainability (NASSS) framework (Greenhalgh et al., 2017), we deliberately treat co-design itself, rather than the VR system it produces, as the innovation under analysis. Across four domains (technology, adopter system, organisation, and wider context) we identify compounding complexity arising from grant-funding constraints, ethical approval processes, hospital institutional structures, and ageist imaginaries embedded in gerontechnology design. Offered as a structured case study reflection based on seven interviews, two observation sessions and three co-design workshops, the paper argues that co-design in this context is not simply difficult but structurally complex in ways that resist disaggregation, and it draws practical implications for participatory VR research with hospitalised older adults.

1. Introduction

ZenctuaryVR+ is a digital health research project funded by the Hungarian National Research, Development and Innovation Office (NKFIH) under the HU-rizont programme, in which a nature-based virtual reality (VR) application supporting the wellbeing of older adults in long-term hospital care is co-designed together with hospitalised patients and healthcare professionals, and will subsequently be evaluated in a longitudinal randomised controlled trial (RCT). In this short paper we use ZenctuaryVR+ as a case study to identify the barriers of involving hospitalised older adults in a co-design process for digital health innovation. Our motivation is to point out that the bottleneck to effective VR health technology is often not the technology itself but the participatory design processes, or the lack of them, that determine whether a system reflects the actual needs, contexts of its intended users.

Our own position within the broader field of digital health innovation is a feminist posthuman one, drawing on what Manchester and Willatt (2024) describe as care-full co-design: an approach that attends to relationality, dependency and embodied vulnerability in design encounters, and that treats the affective and material conditions of participation as findings in their own right. Two further concepts structure our analysis. First, we understand digital health innovation as an *assemblage* (DeLanda, 2016): a heterogeneous whole in which policies, regulations, grant schemes, institutional routines, devices and contributors' motivations retain their autonomy while jointly producing effects that none of them produces alone (Lievevrouw et al., 2022). Second, we draw on Suchman's (2007) notion of *sociocultural configuration*, as developed for ageing and technology by Bischof and Jarke (2021), to describe how design processes configure people as particular kinds of users, joining together the imaginaries and the materialities of technology. Involving vulnerable groups in such assemblages is particularly challenging, as their position, capacities and motivations vary (Harrington et al., 2019); these two concepts allow us to trace that complexity systematically rather than treating it as anecdotal.

The common starting point of gerontechnology design, rooted in deficit imaginaries of frail ageing bodies, does little to engage with the complex network of factors that mediate experiences of ageing (Peine et al., 2021) such as multimorbidity, yet the RCT paradigm demands precisely this kind of reduction: specifiable, measurable outcomes derived from stabilised design decisions. In ZenctuaryVR+, the ambivalent relational dynamics of long-term hospital care, between older adult patients experiencing learned helplessness and the personnel responsible for their care, must be translated into design requirements for a VR and an RCT. This tension between the lived, relational and affective realities of institutional care and the procedural demands of clinical evaluation is aimed to be understood through feminist posthuman approach (Manchester & Willatt, 2024). We aim to avoid reinforcing the dependencies that one-sidedly designed technologies can create (Östlund et al., 2015), and instead to configure the user and the context of use together (Akrich, 1992).

2. Methodology: Identifying the barriers

This paper adopts a qualitative case study design centred on ZenctuaryVR+, in which co-design functions as both the methodological approach and the innovation under scrutiny. It is offered as a structured case study reflection: its contribution is analytic and cumulative without testing a hypothesis, providing a systematic way of describing the barriers encountered in a completed phase of work so that other teams undertaking participatory VR research with hospitalised older adults can anticipate them.

Our analysis draws on Greenhalgh et al.'s (2017) framework for theorising Nonadoption, Abandonment, and challenges to the Scale-up, Spread and Sustainability (NASSS) of health and care technologies. Before justifying this move, it is important to note that the conventional boundary between technology and methodology is less stable than it appears. Heidegger (1954/1977) argued that technology is not a category of object but a mode of revealing: a way of ordering and disclosing the world that shapes what can be seen, said and done within it. Co-design, understood this way, is technological: it discloses needs, configures who counts as a knower, and orders the conditions of participation. Our analytic move is to treat co-design as the innovation whose implementability is in question. NASSS was developed for technology-supported health and care programmes, and its domains address not only material artefacts but the programmes, value propositions and institutional arrangements in which artefacts are embedded; Greenhalgh et al. (2017) apply the framework to complex interventions and programmes rather than to devices alone. Framing co-design as the unit of analysis therefore allows us to ask not only whether ZenctuaryVR+ as a VR system can be implemented, but whether co-design as an innovation approach is itself implementable within the structural constraints of an acute hospital setting with older adults. When we refer to co-design as "the technology" in what follows, we use the term in this NASSS-specific analytic sense. NASSS is also suited to analysing the assemblage of actors, artefacts and institutional structures surrounding a programme, and the sociocultural configurations, including professional norms, power relations and cultural expectations, that determine whether an innovation can take root in a given context.

Data are drawn from semi-structured interviews with older adult participants, clinical staff and researchers (ethical approval no. BM/13742–3/2025) ; ethnographic observations of the clinical environment; and co-design workshops conducted in 2025 employing specifically designed generative tools and scenario-based prototyping, in which older adults participated as co-designers. Empirical data include seven interviews conducted between July and December 2025, field notes from two observation sessions and artefacts produced across three co-design workshops, each lasting approximately three hours. Analysis follows the four NASSS domains (technology, adopter system, organisation and wider context), classifying each as simple, complicated or complex, with particular attention to how complexity accumulates across domains simultaneously.

3. Results and discussion

3.1. The technology (co-design as the innovation under analysis)

While co-design was welcomed as the participatory logic supporting ZenctuaryVR+, its implementation was structurally conditioned: the project could only begin after a positively evaluated grant proposal, and research ethical approval. These introduced procedural constraints that complicated the democratic ambitions of co-design as an approach. This reflects a broader pattern identified by Glasziou and Chalmers (2016), who argue that 85% of health research may be wasted precisely because stakeholders, including patients, are excluded from the earliest stages where research questions and designs are defined. Goldsmith et al. (2019) demonstrate that co-production within RCT contexts is possible but requires deliberate negotiation, particularly around eligibility criteria and analytic plans, where experiential knowledge must be be subordinated, but combined with methodological requirements. Co-design methodology is well documented and its steps are in principle specifiable: in that sense it is manageable. What makes it unmanageable is not the method itself but the institutional context it surrounds. The RCT protocol defines the research design without co-design could shape it previously, while the ethics approval restricts who can be recruited, and grant timelines can also be limiting. Each of these is a property of this project's specific institutional setting, which is in accordance with Blandford et al.'s (2018) conclusion according to which traditional trial methodologies can render a participatory process obsolete before evaluation is even complete. In the NASSS framing, co-design should start as 'complicated' and becomes 'complex', but these categories point to the accumulation of pressures, not a judgment about the method.

3.2. The adopter system

The adopter system in ZenctuaryVR+ involved hospitalised older adults as co-designers, health-care professionals who moved between roles as participants and facilitators, and researchers. In our project the actual gatekeeping role fell not to clinicians but to care workers responsible for physically transporting participants to the workshop space, a structural barrier Baines et al. (2022) identify as recurring in digital health co-design. This shaped, but at times supported, our participants' involvement. Most co-design methods assume stable participants, yet hospitalised older adults break these assumptions: because health status can change, consents require agreement at each encounter, while the wards define available time. This reflects on Minogue et al. (2018), as they argue that the absence of meaningful stakeholder involvement remains one of the primary factors of avoidable research waste. One participant missed one of the three workshops due to a medical intervention scheduled at short notice: this is the "unstable participant" problem which one cannot anticipate while planning the co-design protocol. Endter et al. (2021) also warns that publicly funded user-centred innovation often reproduces deficit-oriented, paternalistic images of ageing, configuring older adults as manageable testers mobilised for market goals rather than full co-decision-makers. Within our project participants came back with the support of care workers but also because of the community dimension of the sessions: image elicitation, painting and landscape building as group activities gave participation a sense of reward that was independent of the technology, consistent with what Sanders and Stappers (2014) argue that generative tools can do. In NASSS terms the adopter system is unambiguously complex: the three sub-groups moved between roles unpredictably, and the logistical, clinical and participatory dimensions of involvement were difficult to separate. Fluctuating health status did not significantly disrupt our work, but this was a matter of circumstance: the structural vulnerability is real and other projects working with this population should try to plan for it explicitly.

3.3. The organisation

The organisational domain is shaped by the hospital setting, which imposes institutional work rhythms, professional hierarchies and regulatory constraints that are in tension with the participatory logic of co-design. Ward logistics, ethics approval processes and the physical infrastructure of care each added layers, that required ongoing adaptation. For us, this was most tangible in the dependency on care workers to transport participants and the need to schedule workshops around clinical routines. These are reported here as structural features of acute care that any participatory project in a comparable setting will encounter. In assemblage terms (DeLanda, 2016), the ward routines, the ethics timeline and its inflexibility, and the care worker gatekeeping role each have their own institutional logic. These produce a systematic compression of participatory time. Manchester and Willatt (2024) identify this as a core problem for care-full co-design: the assemblages shaping the politics of design are not external obstacles but the medium in which the work takes place. In NASSS terms the organisational domain is complex rather than merely complicated: its constraints interacted with the adopter system and the regulatory context, generating unpredictability that no advance planning could overcome.

3.4. The wider context (and the expectations of a grant scheme)

The project is funded by a major grant which shaped the co-design process. Beside factors in 3.1., concern here is different: it is about who gets to define the research problem. Rip and Schot (2002) argue that involving end-users in the design of a funding application is important when designing new services with new technologies, yet in these the research questions and methodological framework are fixed before the project begins, so co-design can only work when little shaping is possible. Health research co-design is structurally limiting (Slattery et al., 2020) and this is a property of the funding. In Bischof and Jarke's (2021) terms, the grant architecture is itself a sociocultural configuration, because it positions researchers and funders as the definers of the research problem and older adults as its objects, and it does this before any co-design encounter has taken place (Willatt et al., 2024). Similarly, Endter et al. (2021) point out that publicly funded innovation in ageing is routinely shaped by deficit imaginaries that frame older adults as a homogeneous group to be helped, which can be also applied to our project. To mitigate this, co-design workshops with healthcare professionals as a second end-user group were conducted in advance of the patient workshops (Bakk, 2024), ensuring that clinical constraints, therapeutic workflows as well as the professional expertise could have been embedded into the concept.

3.5. Implications for VR research with hospitalised older adults

The barriers identified above have direct consequences for VR research with this population. However less obviously, but our participants' engagement was driven primarily by the community dimension of the sessions and not necessarily by interest in VR itself, which suggests that the social setting may be as important for adoption as the application content (McLeod Daphnis et al., 2022). On the other hand, the low-tech generative tools used in the workshops (image elicitation, painting and landscape building) proved effective for eliciting design requirements for an immersive application and did not require participants to become expert in the technology, which can be a transferable practice for VR co-design with hospitalised older adults.

NASSS Domain	Key questions	ZenctuaryVR+ assessment	Classification
Technology (co-design as the innovation under analysis)	How well-defined and standardised is the technology? How adaptable is it to local contexts?	NKFIH HU-rizont grant constraints, with professional workshops conducted prior to patient workshops to embed clinical knowledge before fieldwork began.	Complex
Adopter system	Who are the users and what are their characteristics, motivations and relationships?	Three sub-groups: hospitalised older adults as co-designers, healthcare professionals moving between roles as participants and facilitators, and care workers as logistical gatekeepers controlling physical access to the workshop space. The same seven older women returned across all three workshops, driven primarily by the community dimension rather than interest in VR.	Complex
Organisation	How do organisational structures, resources enable implementation?	Acute hospital setting imposes rigid ward rhythms, professional hierarchies and resource constraints. Physical access to the designated workshop area depended on care worker availability, compressing session time and making longitudinal co-design structurally difficult.	Complex

Wider context	What institutional, societal and policy factors shape the programme?	NKFIH HU-rizont grant funding fixed the research design prior to implementation, leaving co-design to be tailored retrospectively. Ageist imaginaries in gerontechnology and the dominance of the RCT paradigm in Hungarian health research further marginalise experiential knowledge and participatory approaches.	Complex

Table 1: NASSS Framework Applied to ZenctuaryVR+: Four Key Domains
Note: Classification follows partially Greenhalgh et al. (2017).

4. Conclusion

In our paper we contextualized ZenctuaryVR+ and its co-design process in an acute hospital setting with older adults. Across all four NASSS domains we found the same answer although not because any single barrier is not too great to be overcome, but because funding constraints, ethics limestones, hospital logistics and gerontechnology imaginaries pile up on each other. The practical implication could be interpreted simply, but our main objective is to point out that participatory processes need to be part of the grant application, because when a protocol is approved, it is hard to tune. Throughout our process we encountered several positive accidents and a strong partnership and support from our partner, however this cannot be considered as a reproducable process, and in similar research projects these structural conditions can cause various complexities. We offer this analysis as a resource for plannig teams, so they can anticipate what they are getting into.

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Who Controls VR? A Thematic Synthesis of Studies That Directly Investigated Input Modality with Older Adults

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Abstract

Input modality, how users physically control and navigate virtual reality (VR), is largely treated as a secondary consideration in VR research involving older adults. In a broader scoping review of 349 studies, only six (fewer than 2%) were identified as explicitly investigating input modalities. This thematic synthesis of those studies indicates that embodied and familiar interaction techniques are consistently preferred and better tolerated by older adults. The findings further suggest that limited adoption is driven more by issues of acceptance than by inherent incapacity. Conventional handheld controllers appear poorly suited to this population, whereas alternatives such as cycling-based input, hand tracking, and augmented gaze demonstrate greater accessibility. These results highlight the need to position input modality as a central research focus in the accessibility, design and evaluation of VR interventions for older adults.

1. Introduction

Virtual reality (VR) has seen substantial growth as a tool for health interventions with older adults, with applications spanning physical rehabilitation, cognitive training, and social engagement. Despite this growing body of work, a fundamental question has received surprisingly little attention: how do older adults actually interact with these systems? The input modality, the physical means through which a user controls and navigates a VR environment, is typically treated as a background condition rather than a distinct research variable. The dominant VR input devices, handheld motion controllers with multiple buttons, triggers, thumbsticks, and trackpads, were developed by and for the gaming industry, optimized for younger, digitally fluent users with good manual dexterity and prior controller experience (Cook et al., 2019). Older adults have often been excluded from the participatory design of VR technologies, meaning their specific interaction needs have rarely shaped how these systems are built (Seifert & Schlomann, 2021). Boot et al. (2025) make this concrete in their framework for designing extended reality for older adults: successful technology requires matching system demands to user capabilities across motor, cognitive, and perceptual dimensions. When developers do not consider older adults' needs and abilities, the resulting mismatch is not evidence of older adults' incapacity but of technology's misfit (Boot et al., 2025).

As part of a larger scoping review of input modalities in immersive VR used with older adults (N=349) (Chovanec et al., 2025), we identified studies that explicitly investigated input modality as a central research focus.

Of 349 papers included, only six met this criterion. That figure is itself a notable finding. In a field where VR is increasingly deployed with older and potentially vulnerable populations, fewer than 2% of studies were identified as directly examining these systems. This paper reports a focused analysis of those six studies. Given that input modality constitutes the primary point of contact between user and system, its design has implications beyond usability alone. As the studies reviewed here suggest, poorly aligned input mechanisms can compromise safety, increase cybersickness, and ultimately undermine the therapeutic or health goals that VR interventions aim to achieve.

Accordingly, this paper addresses the following research question: **What insights about interaction design for older adults emerge from the limited body of research that directly investigates VR input modality?** To answer this, we examine three related sub-questions: (1) What methodological approaches characterize this body of work? (2) What types of input modalities are investigated? and (3) What findings are reported regarding usability, preference, and interaction outcomes?

2. Method

This paper reports a secondary analysis derived from a broader scoping review conducted in accordance with PRISMA-ScR guidelines (Tricco et al., 2018). Seven databases (PubMed, ACM Digital Library, IEEE Xplore, Google Scholar, Springer, Scopus, and OpenAlex) were searched in April 2025, yielding 4,682 records. Following duplicate removal, screening was supported by ASReview active learning software. Both title/abstract and full-text screening were conducted by SC and VV, with disagreements resolved through discussion among all authors. A total of 721 papers progressed to full-text assessment, of which 349 met the eligibility criteria for the main review. Studies were eligible if they employed head-mounted display (HMD) VR with adults aged 60 years and older.

Data charting was completed by all authors using a piloted form that was refined through calibration sessions. As part of this process, studies were flagged when input modality constituted a central research focus, defined as research explicitly designed to investigate, compare, or evaluate how older adults interact with VR through a specific input modality. Input modality refers to the physical technique or device through which users control and navigate the VR environment. Identification was embedded within the main review process: studies were flagged during charting when input modality appeared to be the primary object of investigation rather than an incidental characteristic of the experimental apparatus. Flagged studies were subsequently reassessed against the above criterion to establish the corpus for the present synthesis.

Studies with three or fewer participants were excluded. Such studies typically represent single-case reports or small feasibility series and do not provide sufficiently replicated evidence for synthesis of interaction outcomes across input modalities. One study that otherwise met the inclusion criterion for input-modality-focused research was excluded on this basis (Chirico et al., 2020). Six studies met the final eligibility criteria. A thematic synthesis was conducted following Thomas & Harden (2008), using NVivo 15. Analysis proceeded in three stages: (1) line-by-line coding of findings, (2) development of descriptive themes, and (3) generation of higher-order analytical themes capturing recurring patterns across studies.

3. Results

3.1. Study Design

Across these six studies, sample sizes were generally small, ranging from ten to twenty participants. The body of work is methodologically diverse, consisting of two qualitative evaluations (Coldham & Cook, 2017; Shah et al., 2022), two experimental studies (Chen et al., 2024; De'Sperati et al., 2023), one comparative study (Cook et al., 2019) and one usability study (Ribeiro et al., 2024). Direct comparisons across multiple input modalities remain exceptionally rare. Two studies utilized comparator arms (for comparing different levels of gain of the input (De'Sperati et al., 2023) or different tasks (Ribeiro et al., 2024)). Only one study in the corpus compared three inputs simultaneously (Chen et al., 2024), and none of the six compared four or more . In some evaluations, such as those examining direct hand manipulation (Shah et al., 2022), authors claimed comparison with controllers but provided no comparative data. Regarding user-centred design, only half of these studies (3/6) sought first-person feedback directly through quotes, ratings, and observations (Chen et al., 2024; Coldham & Cook, 2017; Shah et al., 2022), but none of the six employed formal participatory or co-design methods. Consistent with the critique by Seifert and Schlomann (2021), the lack of participatory design may reflect a broader orientation that treats older adults as passive recipients of technology rather than active users whose specific interaction needs should shape how these systems are built.

3.2. Types of Input Modalities

Beyond built-in head tracking that is universally present in HMD-based VR and was utilized across all six studies, the included studies investigated four specific alternative input modalities: i) conventional handheld controllers (5/6) (Chen et al., 2024; Coldham & Cook, 2017; Cook et al., 2019; Ribeiro et al., 2024; Shah et al., 2022), ii) cycling-based locomotion (2/6) (Chen et al., 2024; De'Sperati et al., 2023), iii) augmented gaze (enhanced head rotation) (1/6) (De'Sperati et al., 2023), and iv) direct hand manipulation (hand tracking) (1/6) (Shah et al., 2022).

3.3. Usability, Preference, and Interaction Outcomes

Physical challenges (mentioned in 5/6 studies) included high demands on thumb dexterity, grip, as well as difficulty operating closely spaced and uniform buttons (Cook et al., 2019). Additionally, physical constraints such as neck pain and other motor limitations (De'Sperati et al., 2023; Ribeiro et al., 2024), fear of electrocution from cables (Coldham & Cook, 2017), and the smooth material of the controller casing being perceived as fragile (Coldham & Cook, 2017), all generated user hesitancy. Cognitive barriers (mentioned in 5/6 studies) reported that participants frequently forgot button functions mid-task (Coldham & Cook, 2017), pressed the incorrect button (Chen et al., 2024; Ribeiro et al., 2024), found controllers too complex (Chen et al., 2024; Shah et al., 2022) and reported that managing the controller distracted from their engagement with the VR environment (Chen et al., 2024; Coldham & Cook, 2017). Furthermore, controller use, particularly continuous turning, was directly linked to motion sickness (Chen et al., 2024).

In contrast, embodied and familiar alternative inputs yielded substantially better usability and preference outcomes. For instance, cycling-based locomotion produced significantly higher spatial orientation accuracy compared to a handheld controller and promoted active environmental exploration, making it strongly preferred by older adults due to its physical engagement, perceived safety, and familiarity (Chen et al., 2024). To address physical constraints like neck pain, augmented gaze introduced software amplification of head rotation, which reduced necessary physical head movement by 18% while increasing visual exploration by 46%, successfully accommodating even the oldest-old and non-self-sufficient users without inducing cybersickness (De'Sperati et al., 2023). Furthermore, direct hand manipulation through hand tracking was found to be easier, less demanding, and more stimulating than using conventional controllers. The absence of physical hardware removed a major source of hesitancy, and the natural finger and wrist movements offered the added benefit of incidental exercise for users with reduced hand strength (Shah et al., 2022).

4. Discussion

The synthesized findings reveal a fundamental insight regarding interaction design: barriers to VR adoption among older adults are predominantly behavioural, not functional. The literature frequently relies on a "digital divide" framing that positions older adults as deficient or incapable users (Seifert & Schlomann, 2021). However, the sources demonstrate that older adults are not uniformly unable to use controllers; rather, they are often unwilling due to a mismatch between the technology's design and their needs. Hesitancy around cables, fear of breaking fragile equipment, reluctance to perform uncomfortable head and neck movements, and avoidance of inputs associated with dizziness represent acceptance failures rather than a lack of capacity. Ultimately, the problem to be solved is not older adults' incapacity but technology's misfit with their needs and capabilities (Boot et al., 2025; Chen et al., 2024). This is a distinction that older adults themselves appear to recognize, as they consistently report more positive than negative attitudes toward technologies they actually use (Mitzner et al., 2010).

To overcome these barriers, embodied familiarity emerges as the most practically useful design criterion. Inputs that map onto pre-existing physical experience and existing motor schemas, such as pedalling a bike, natural hand gestures, or looking around, are consistently preferred, better tolerated, and result in superior performance compared to inputs that require learning entirely new operational schemas. These principles translate into several specific design recommendations. For conventional controllers, designers should reduce button count, standardize spacing, differentiate button textures for tactile identification, and address smooth casing materials that generate fragility concerns (Coldham & Cook, 2017; Cook et al., 2019). It is also recommended to separate movement and turning across left and right controllers; Chen et al. (2024) identified 10 km/h forward speed and 10 degrees per second turning speed as ideally suited to older adults. For cycling, applications should use handlebar rotation for steering and entirely disable backward motion (Chen et al., 2024). For head-based input, augmented gaze can be added to any HMD application as a low-cost accessibility option (De'Sperati et al., 2023). Across all recommendations, multimodal combinations of embodied locomotion and gaze or gesture interaction, were identified as the most promising direction (Chen et al., 2024).

Although the six studies yielded consistent and actionable findings, the evidence base remains small. Direct comparison between multiple input modalities were rare, representing a key gap for future research, and several themes relied on single studies, including augmented gaze (De'Sperati et al., 2023) and hand tracking (Shah et al., 2022). The synthesis was restricted to studies in which input modality was the primary research focus. Consequently input-related observations reported incidentally in the wider corpus were not included and may qualify the conclusions presented here. Nevertheless, the small number of eligible studies is itself noteworthy: only six of 349 studies (<2%) explicitly and systematically investigated input modality in older adults' VR use beyond single-case reports. Because these studies were identified through a secondary analysis of a larger scoping review, some papers addressing input more implicitly may not have been captured. Findings from the broader corpus will be reported in the full scoping review.

5. Conclusion

Much VR research with older adults has focused on whether they can use the technology, treating them as recipients of fixed systems rather than active participants whose interactions must be designed for. This synthesis suggests that commonly used input paradigms, particularly hand-held controllers, are often poorly aligned with the physical and cognitive characteristics of older adults, while more embodied and familiar alternatives show promise despite limited evidence. Importantly, difficulties with VR interaction appear to arise less from incapacity and more from issues of acceptance and design fit. Advancing VR as a viable health technology for older adults therefore requires a shift in research priorities: input modality should be treated as a core design and evaluation consideration, with systematic comparisons of alternative approaches and the active involvement of older adults in the design of interaction techniques.

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Rigour Meets (Virtual) Reality: Balancing Robust Methodology and Real-World Implementation in a VR-Therapy Protocol for At-Home Dementia Care

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Abstract

Caregivers of people living with dementia (PLwD) experience substantial psychosocial burden, compounded by limited access to formal respite due to financial, geographic, and systemic barriers. Immersive virtual reality (VR) shows promise for alleviating behavioural and psychological symptoms of dementia while supporting caregiver respite. However, current VR studies are often constrained by restrictive eligibility criteria, high participant burden, and selective outcome measures that fail to capture routine use in practice. This paper offers methodological commentary on the VR&R study protocol, a 6-week randomized crossover trial comparing Solo-VR and Social-VR delivery in 50 caregiver–PLwD dyads. The primary outcome is respite, assessed as both objective time away from caregiving and subjective quality, along with secondary outcomes related to caregiver and PLwD well-being. Feasibility, accessibility, and implementation considerations were integrated alongside rigorous methodological features including randomized crossover allocation, mixed-methods evaluation, standardized outcome measures, and objective usage data, informed by advisors, community partners, and people with lived caregiving experience. Key adaptations included eligibility criteria based on functional capacity and assent, expanded caregiver definitions, flexible home-based delivery, and low-burden measures. By combining outcome evaluation with delivery models that reflect everyday care conditions, this study examines not only whether VR can support respite, but also how delivery models and intervention design shape its impact, uptake, and applicability in dementia care.

1. Introduction

Dementia is a leading cause of disability globally, with major impacts on individuals and caregivers. Behavioural and psychological symptoms of dementia (BPSD), including agitation, apathy, and depression, are major contributors to caregiver burden and reduced quality of life (Gitlin & Hodgson, 2015). Although respite services exist, access remains limited by financial, geographic, and systemic barriers. Immersive virtual reality (VR) has emerged as a promising tool for therapeutic engagement among people living with dementia (PLwD), offering safe, customizable experiences deliverable in the home. Emerging evidence suggests VR is feasible, acceptable, and may support mood and engagement in PLwD (Appel et al., 2023), with prior VRx@Home work informing this protocol. However, existing studies are constrained by small samples, short durations, and lack of comparator designs, often relying on global burden or quality-of-life scales (e.g., HRQoL-14) that do not capture real-world use. More critically, VR engagement has not yet been systematically examined as a mechanism for caregiver respite – a priority identified by community partners, lived experience collaborators, and prior VRx@Home participants (Appel et al., 2023). Dementia trials also frequently exclude individuals with advanced impairment due to rigid eligibility criteria, limiting generalizability and reinforcing inequities (Franzen et al., 2021). Recruitment and retention are further constrained by participant burden, particularly for highly strained dyads (Appel et al., 2023; Saryazdi et al., 2024). There is increasing emphasis in trial methodology on designing studies that reflect real-world care contexts (Loudon et al., 2015). To our knowledge, this is among the first randomized trials to evaluate immersive VR as a mechanism for caregiver respite in dementia care.

In this protocol, we describe the VR&R study, a pragmatic randomized crossover trial evaluating whether VR engagement by PLwD can provide meaningful caregiver respite in home settings. Drawing on broader conceptualizations of caregiver relief and support (Gitlin & Hodgson, 2015), respite was operationalized as both objective time away from caregiving and subjective quality. The study compares Solo-VR (caregiver-supported) and Social-VR (RA-facilitated) models to examine differences in use and respite. The primary objective is to assess respite quantity (time in VR vs time away from caregiving) and quality (perceived relief, reduced vigilance, activities completed). The comparison tests a mechanistic hypothesis that caregiver respite depends not only on PLwD engagement, but on the caregiver's capacity to disengage. Social-VR is designed to reduce caregiver vigilance through external facilitation, while Solo-VR relies on caregiver-mediated supervision, allowing us to examine the role of caregiver substitution in generating respite. Secondary objectives assess caregiver and PLwD well-being across functional, neuropsychiatric, burden, and psychological domains, alongside feasibility of implementation. The study also examines how variability in use and delivery shapes outcomes. In this paper, rigour refers to both internal validity and real-world applicability, supported through a randomized crossover design, mixed-methods evaluation, and objective usage data. Together, these elements enable both causal inference and ecological validity in a home-based context. Supplemental Materials *(SM)* including study procedures, training resources, recruitment materials, and a full list of measures and data collection tools can be accessed here: (https://osf.io/d2c5e/files/osfstorage).

2. Methods

2.1. Study Design

The VR&R study is a 6-week open-label randomized crossover trial involving 50 caregiver–PLwD dyads (n=100). Participants are randomized to Solo-first or Social-first conditions, each delivered over two weeks followed by a two-week follow-up *(SM – Study Timeline)*. This allows observation of each dyad under both delivery models while maintaining flexibility. Data collection began in February 2025 and will continue through January 2027.

2.2. Eligibility and Recruitment

Participants are recruited through community organizations, clinical services, and outreach channels *(SM – Recruitment Flyer; Information for Recruitment Partners)*. Eligibility is based on the PLwD's ability to signal discomfort or disengage, including through non-verbal cues, rather than strict cognitive thresholds, aligning with person-centered care principles (Gitlin & Hodgson, 2015). No language restrictions are applied for PLwD, and research assistants (RA) are matched by language when possible; alternative communication strategies are used when needed. Caregivers include both informal and formal providers, reflecting real-world care contexts *(SM – Eligibility Screening; Consent Forms)*. This inclusive definition was adopted to reflect heterogeneity in caregiving arrangements across home and community settings, in addition to stakeholder input and interest.

2.3. Intervention Design and Delivery

The intervention uses a Meta Quest 2 head-mounted display paired with a caregiver-controlled tablet interface and caregiVR software (caregiVR Inc., 2026), which provides access to a large library of curated 360° content (e.g., nature, travel, music), developed in alignment with therapeutic recreation principles. Content selection and design were optimized for home-based use through iterative user feedback and implementation, with a focus on viewer experience, engagement, reminiscence, and emotional safety (Appel et al., 2023). The platform enables a shared experience through casting to the tablet, supports a range of cognitive and physical abilities through a simplified caregiver interface, and minimizes interaction demands by removing the need for handheld controllers *(Figure 1, SM – Video Links)*. The intervention protocol allows dyads to determine timing, duration, supervision, and engagement mode *(SM – Baseline Session)*. Participants are encouraged to engage in 30-minute sessions 2–3 times weekly, though use is flexible. PLwD retain choice over content, duration, and feedback. In Solo-VR, caregivers initiate and supervise sessions, while in Social-VR, a trained RA acts as a friendly visitor to facilitate sessions *(SM – Social Visits)*. The two delivery models were designed to reflect real-world variability in dementia care, where support may be either caregiver-mediated or externally facilitated depending on available resources and caregiver capacity. Initial onboarding is conducted in-home by the study coordinator. PLwD are introduced gradually with ongoing assent via verbal and non-verbal cues. Caregivers receive training on setup, supervision, and safety, and a one-page tip sheet with instructions on session flow and technology set-up. The research coordinator proactively checks in with the caregiver throughout the study and caregivers are encouraged to reach out for technical support *(SM – Tip Sheet)*.

2.4. Low Burden and Context-Sensitive Measurement

Caregivers complete a paper-based respite log after each session and a targeted set of brief questionnaires (Clinical Frailty Scale, PAQ-8, NPI-Q, ZBI-6, WHO-5, CD-RISC, SUS). The primary outcome is respite, defined as objective time away and subjective quality. PLwD complete no formal questionnaires; their experience is captured via brief mood ratings, experience scores, caregiver proxy, and RA observations. Passive headset data quantify use. Qualitative interviews *(SM – Interview)* and RA notes capture contextual influences including engagement, safety, and relational dynamics *(SM – Outcome Measures)*.

Figure 1: Social-VR session setup. A trained RA facilitates a Social-VR session with a PLwD using the Meta Quest 2 and caregiVR platform on a paired tablet for real-time casting and content selection.

3. Discussion

Despite rapid growth in VR dementia research, translation into practice remains limited. VR can support momentary mood and engagement, but evidence for sustained clinical effects is limited by small samples, short durations, and variable designs (Wang et al., 2025). Standardized scales may have limited sensitivity to episodic, context-dependent changes in caregiver relief. VR is also highly sensitive to how it is delivered. Unfamiliarity, caregiver mediation, and safety considerations are key limitations that open a gap between efficacy under controlled conditions and effectiveness in real-world home care settings.

The VR&R protocol addresses these challenges through flexible design, expanded eligibility, and implementation-informed adjustments. These reflect the realities of home-based dementia care, where variation in use is expected (Franzen et al., 2021). Data collection and intervention design were built on prior VRx@Home pilot refinements to enhance ecological validity in home settings. A key mid-study refinement was to define eligibility based on the ability of the PLwD to communicate discomfort or the desire to stop the intervention for safety reasons, rather than using a fixed cognitive cut score, thereby broadening inclusion to individuals able to safely participate and potentially benefit. A further contribution is operationalizing respite as both time and experience, capturing when caregivers step away and how meaningful that relief is. The comparison of Solo-VR and Social-VR and participants' choice in actual usage addresses feasibility and respite mechanisms, treating the intervention delivery model itself as a variable that shapes how respite is realized. Understanding whether respite emerges depends not only on intervention efficacy, but on the degree to which caregivers can safely disengage during use, which is itself shaped by delivery models and contextual constraints. Solo-VR offers flexibility but may be limited by vigilance and technical demands. Social-VR enables greater disengagement through facilitation and support. Rigour is supported through a randomized crossover design, mixed-methods evaluation, standardized outcomes, objective usage data, and pragmatic implementation. Key determinants of success include usability in the home environment, caregiver capacity to support or disengage from sessions, and participant comfort during gradual onboarding.

Although the trial design prioritizes pragmatic delivery and minimizes participant burden, this approach entails trade-offs in control and standardization, particularly in a home-based crossover context where variability in use is expected. The short intervention periods may be insufficient to detect sustained changes in caregiver burden or well-being, and caregiver-focused outcomes may not fully capture broader or longer-term impacts. PLwD outcomes are assessed primarily through proxy reports and brief observational measures, limiting insight into direct subjective experience and longer-term effects. More generally, established standardized scales may have limited sensitivity to episodic, context-dependent aspects of caregiver relief and respite, consistent with limitations in capturing real-world care outcomes. While widely used measures were retained for comparability across studies, interpretation must consider the constraints of measurement sensitivity and timeframe in dementia care research.

4. Conclusion

This protocol demonstrates how clinical trial methodology can be integrated with design choices that reflect the realities of dementia care, including structural, ethical, and practical barriers such as language, cognitive inclusion, and caregiver burden (Franzen et al., 2021). By prioritizing accessibility, minimizing burden, and embedding measurement within use, the protocol supports evaluation approaches suited to complex, home-based care. Home-based VR also introduces practical considerations, including setup and maintenance, and long-term adoption will depend on embedding these processes into care systems (Appel et al., 2023). More broadly, the study contributes a model for designing interventions that are both clinically promising and implementable, and for examining how delivery context shapes outcomes (Loudon et al., 2015; Wang et al., 2025). Together, these principles extend beyond VR and dementia care, offering guidance for trials seeking to generate meaningful and actionable evidence in practice.

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Disclosure

Authors SLF, DT, and LA are shareholders in the caregiVR Inc. company. During the preparation of this manuscript, the authors used ChatGPT (OpenAI) for language and structural editing, including sentence shortening, clarity improvement, and identification of repeated information. The authors reviewed and edited the output and take full responsibility for the content of this publication.

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09

COGNITIVE ASSESSMENT & TRAINING

Enhance VR behavioural metrics capture age-dependent reaction time delays

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Abstract

Enhance VR is a library of games based on neuropsychological principles. Each session generates Scores and Moments. While Scores reflect the player's overall performance, Moments are designed to capture behaviour. Here, we compared the reaction times between two age groups in sessions with identical Scores. In line with the literature, we found delayed reaction times in the older population, indicating that Moments capture age-dependent changes. These results show that Moments from Enhance VR provide valuable data for studying behaviour, aiming to better understand the players decision-making processes, and laying the groundwork for the potential development of cognitive biomarkers.

1. Introduction

Besides higher ecological validity, experiences in virtual reality (VR) have the potential to generate and collect richer datasets than screen-based solutions. The unique combination of full control over the environment, the presentation of stimuli, and the high temporal resolution tracking and recording of players' actions could provide important insight into their underlying behavioural strategies and cognition (Parsons, 2015).

At Virtuleap, we have developed Enhance VR, a cognitive training and monitoring solution in VR (Brugada-Ramentol et al., 2022). With a growing library of seventeen games based on validated neuropsychological principles, Enhance VR covers eight cognitive categories: memory, attention, information processing, motor control, problem solving, spatial orientation, social cognition, and flexibility. Each game on Enhance VR generates two different types of outcomes, providing two layers of information related to the cognitive ability they target.

At a first level, each Enhance VR game session generates a Score, a value between 0 and 100, that similarly to traditional scoring systems, provides in-game feedback to maximize engagement while reflecting the players' overall performance at the end of the session. Although these Scores evaluate major variables related to the game's cognitive ability of interest, they are restricted in the amount of behavioural information they integrate.

On a second and deeper level, Enhance VR collects rich behavioural data within game-specific structures that record key events from both the app and the users' side during gameplay. These structures called "Moments" output scientifically informed variables that could be stored to reproduce and analyse gameplay offline. Collecting this information opens the possibility to study the players' behaviour in detail with data science methods, aiming to better understand their decision-making processes and the potential creation of next-generation cognitive biomarkers.

2. Methods

The Enhance VR app has 76k+ registered users. Every time a session is played by one of those users, session's Scores and Moments are stored in our cloud-based database. In addition, demographic user's information (age, gender, educational level, etc.) is collected at sign in and cross-referenced to gameplay outputs. In this manner,

Scores and game-specific behavioural metrics extracted from the analysis of Moments could be compared across different demographic segments.

Each session of Drummer was completed by a different subject, ensuring no user contributed more than a single data point to the study. For each session, the mean reaction time (RT) across all successful Go trials was calculated (trial count range, younger group: 18–29, older group: 16–29). To compare subjects/sessions with identical Scores, the population mode was used to determine the representative Score value. This value was selected because it maximized the number of samples per group (younger group: n=28; older group: n=20) from a total of 122 screened sessions. Statistical comparisons between groups were conducted using the non-parametric Mann-Whitney test.

3. Results

Drummer is an Enhance VR game focused on response inhibition, within the category of cognitive flexibility. It is inspired by the Stop Signal Task (SST, Fig. 1A) (Logan et. al., 1984). In this task, a white screen presents a fixation point followed by a directional Go stimulus (e.g., an arrow) pointing to the left or to the right. The subjects are instructed to press a left/right button in accordance with the direction of the stimulus within a short time window (Go trial). Additionally, in a proportion of trials, a Stop signal appears a brief period after the Go stimulus, in which case subjects must avoid pressing the button (Stop trial). This same logic was translated into Drummer, where players need to hit specific drums on a set following arrows that appear on a central device after a fixation period (Fig. 1B, top row). Consistently with the SST, in some trials, the arrow and drums change their colour to orange while a salient tone is played, indicating that the drum hit must be stopped (Fig. 1B, bottom row).

In this article, we present the case of Drummer as an example for the potential of Enhance VR to differentiate younger vs. older populations with identical Scores based on their Moment-derived RTs. Since it is well established that RTs increase with aging (Fozard et al., 1994; Woods et al., 2015), we investigated if Moment-derived variables could detect such performance differences that are not evidenced by the Scores. For that, we first selected a population of young players (age range 15–25 years-old) and another one of elder players (age range 55–65 years-old) whose Scores were identical after playing a single session in Drummer (see methods). Next, we processed these sessions' Moment data and calculated the players mean RT when correctly hitting the target drum in a Go trial. As expected, this analysis showed that the elder population had significantly longer reaction times when compared to the younger population (Fig. 1C).

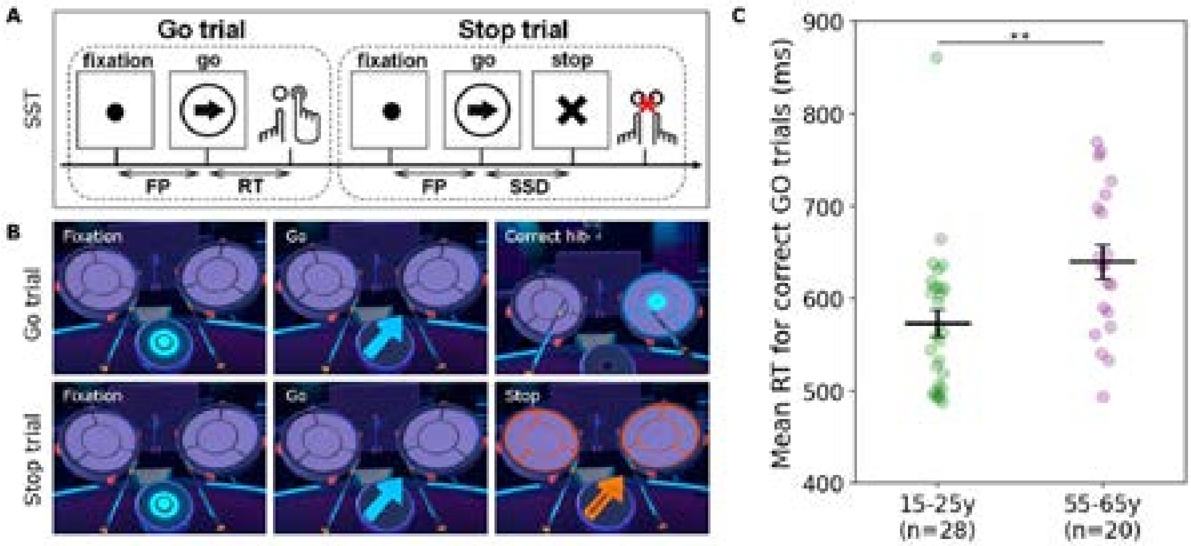

Figure 1: **A.** *Go and Stop trials structure in the Stop Signal Task. FP, fixation period; RT, reaction time; SSD, stop signal delay. Adapted from Logan et. al. 1984.* **B.** *Images from Drummer showing Enhance VR's translation of SST to a VR environment and the key events from Go and Stop trials in the game.* **C.** *Mean session reaction time for correct Go trials in Drummer for the younger and older populations, Mann-Whitney U test comparison of mean reaction times between age groups, p=0.004. Each datapoint represents a single session from a different subject. Black horizontal lines: mean. Error bars: SEM.*

4. Discussion

In line with the literature, our data shows that reaction times increase in an age-dependent manner. In the last decades, several groups have reproduced this phenomenon using a variety of paradigms (Fozard et al., 1994; Hardwick et al., 2022; Woods et al., 2015). Slower processing, decreased motor speed, and greater cautiousness are some of the reasons proposed to underlie these changes in the elder population. However, the subject is still under debate, and, in our case, we should also consider a possible contribution of lower digital literacy.

Our results show that Moments in Drummer capture subtle changes in reaction times across the studied groups. This finding highlights the importance of incorporating data structures that record timings, accuracies, error types, and related metrics when designing cognitive activities. These variables provide more granular information about players' behavioural strategies, potentially offering deeper insights into their cognitive processes. This is particularly important when compared to more traditional performance scores, which, as shown by our data, do not always reflect subtle differences between groups.

It is worth noting that this paper presents an individual example of a single metric from only one of our games. However, Enhance VR currently covers eight cognitive categories with seventeen games from which dozens of behavioural metrics could be extracted. Thus, similar metrics from different games (for example, reaction time) could help develop new measurements across games when transversally integrated, revealing more insights on players' behavioural strategies than when isolated.

Although the data presented here focus on a single session at one point in time, Enhance VR's capacity to store longitudinal data enables the evaluation of metrics across sessions as a time-series progression. This approach allows for longitudinal follow-ups that can be accessed through Virtuleap's organizational dashboard, which provides both tabular and graphical access to Moment's data in a navigation friendly interface (www.virtuleap.com). This is especially interesting for healthcare professionals using Enhance VR games to monitor patients because, if further studies confirm the sensitivity of our behavioural metrics, or a combination of them, they could potentially work as biomarkers of cognitive deficits in the future.

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Towards a fusion of control and ecological validity in virtual reality based cognitive testing: pilot results from our QuestMarket game

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Abstract

Virtual Reality (VR) devices have been extensively utilized in neuropsychological evaluation in recent years, however, their comparability to traditional neuropsychological tests is always compromised. One reason is researchers tend to utilize stimuli rich virtual environments which can alter performance. To overcome this problem, we created a VR based shopping game, QuestMarket, which employs a real-life mimicking setting but with very minimal environmental stimuli and compared its variables to six traditional neuropsychological tasks. Our study showed moderate comparability between certain cognitive tests and QuestMarket variables indicating that VR based cognitive tests may still measure different functions even in very plain environments.

1. Introduction

Virtual reality (VR) based cognitive testing represents a groundbreaking and promising approach to evaluating individuals' mental capabilities both in research and clinical settings (Pieri et al., 2023). The tool allows a more ecologically valid way of assessing people compared to classical paper-and-pencil based tasks whilst traditional tests tend to be better at maintaining control over the testing session (Kourtesis et al., 2021; Parsons, 2015). Despite its many potentials, though, the novelty of the device and methodology necessitates a deeper understanding of participants' user experience, enabling researchers to comprehensively grasp and customize VR software according to the needs of the participants. This evokes the question of how controlled testing scenarios and ecological validity can be brought closer together.

One key point in VR based cognitive testing is concrete and targeted measurements besides recording the performance indicators in the VR task. Researchers currently tend to employ questionnaires to evaluate participants' cybersickness symptoms, user experience and emotional states (Kourtesis et al., 2021; Kourtesis et al., 2023; Maeng et al., 2021) with a few of them applying biophysiological measurements (Lee et al., 2023; Xue et al., 2024; Zsebi et al., 2025) but only a handful of them making direct comparisons between classical and VR based neuropsychological performance. These approaches may serve as good additions to explaining contextual factors of cognitive performance in VR based settings, however, in order to have a more continuous nature of scientific results and make studies more comparable to each other, traditional and modern methods must find a way to be comparable. However, considering the novel nature of VR based tests, more exploratory ways are needed to set the grounds for future studies as it is currently not fully clear which variables of complex and stimuli rich VR environments can be compared to (Bürkner et al., 2019). Unfortunately, traditional neuropsychological data also has its limitations with measurement methods being vulnerable to sample size, test environmental factors and individual physiological differences (Immanuel et al., 2023; Raghavendra, 2025).

In summary, VR based tests and traditional tests have a distinction between them with the former utilizing more ecological validity for less controlled processes and the former having more control but not real-life mimicking tests whatsoever. Moreover, these two distinct categories of tests hardly ever get compared and examined in the same continuum of professional perspective, practically creating two simultaneously existing but non-merging fields. In order to overcome this problem, we created a VR based cognitive test, named QuestMarket, in which participants must navigate around a shopping mall buying items from a shopping list. The shopping mall's environment is intentionally made very plain with as few environmental parts as possible to minimize any potential distractor effect they might cause. In this way, the software allowed us to directly examine and analyse the efficiency of VR based cognitive testing and compare it to six traditional neuropsychological tasks.

2. Methods

2.1. Participants

28 participants were enrolled in our study recruited from a Hungarian university's students between ages 18–35 (Mean: 22.66, SD: 3.035). Participants were free from all neurological and psychiatric disorders and had normal or corrected-to-normal vision.

2.2. Materials

2.2.1. Virtual Reality Device and Task

An Oculus Quest 2 headset was utilized for the task on which the software ran. The QuestMarket game was created in Unity and was started by the participants using the set's controller. The game consisted of a small shopping mall with a hallway in the middle of it (the player started here) and three shops opening from different parts of said hallway: a consumables store, a bathroom items store and a kitchen store. Players could open a shopping list using the controllers in which they could see the different items to be bought listed as well as their required quantity. Players were instructed to memorize the list and buy all items needed from memory, although they were also told they were allowed to open the list as many times as they required. Using either joystick's buttons, the player could get a red basket into their hands which they could use to put items in it. All shops consisted of plain blue shelves and brown wooden tables with no further decoration to them. The shops also all had a self-serving checkout machine players could use to scan and pay for their items. An item was only considered bought if the player successfully scanned it and pressed the button on the machine stating "Pay". Generally, all skins used on the environment and items were very plain and slightly cartoonish, with almost all items only consisting of a single colour (Figure 1 and 2) During playthrough, participants' gameplay was recorder using the Oculus device's built-in recorder and was later analysed by hand by the experimenters. Variables recorded during playthrough were total time required to finish the shopping spree, number of looks participants took on the shopping list, number of items correctly bought from the list, number of items falsely bought from the list and number of items left out from the list.

Figure 1 and 2: Screenshots from the game. The left picture shows one of the shops with consumable items and the lower picture show the main hallway with the shopping list open.

2.2.2. Traditional Neuropsychological Tasks

The traditional neuropsychological testing consisted of six classical cognitive tests, namely the Corsi Block-Tapping Task, the Backward Corsi-Block Tapping Task, the Tower of Hanoi task, the Stroop task, the Iowa Gambling Task and the Rey Auditory Verbal Learning Task. All tasks except for the Rey task was administrated on PsyToolkit using a standard PC and a Chrome Web Browser. The Rey task was administrated by the experimenter using a printed version of the task. In both of the Corsi tasks, the length of the longest successfully recalled sequence was considered the final score; in the Tower of Hanoi task, the number of steps required to finish the task the score; in the Stroop task, participants faced 40 trials of different words and their final score was the number of correctly identified stimuli; in the Iowa Gambling Task, their final score was the final amount of money they finished the task with; and in the Rey task, their final score was the sum of all words recalled throughout all sessions.

2.3. Procedure

After filling out basic demographic data (sex, age, education level), participants either started with the neuropsychological testing first and then went on to finish the QuestMarket task or vice versa for which order they were randomly assigned to. Participants managed to do the QuestMarket task three times. First, they did it on easy mode for which they were told it was a practice run to get familiar and comfortable with the settings and the game. After that, they did the game once again on easy mode, this time, however, they were told it was an actual testing run. In reality, it was still a practice run and their performance was not recorded. We did this double practice run because in our pilot testing phases, we found that participants' performance shuffled due to the fact they thought it was a testing phase, likely due to the anxiety the testing caused. Thus, in order to get them used to being in an actual testing phase, we let them run the easy mode two times so that they could both get used to the controls first and then lower their test related anxiety level. Finally, after the two runs on easy mode, they went on to do the task on medium difficulty which was the actual, recorded run we later analysed. The game also consisted of a hard mode, however, in our pilot phases, we found that it was so hard, most performance scores appeared to be a floor effect for which reason we excluded it from our final procedure.

3. Results

All data were analysed using Jasp software 0.95.1. Considering the explorative nature of our study, we used Spearman's correlation for analysing potential connection between all variables. Ultimately, only two comparisons emerged as significant with a considerable effect size. The first one is between the Backwards Corsi Block-Tapping Task and the number of items correctly bought from the list positively correlated (rho=0.389, p=0.041) (Figure 3). Secondly, the Iowa Gambling Task negatively correlated with the number of shopping list looks (rho=-0.435, p=0.021) (Figure 3 and 4).

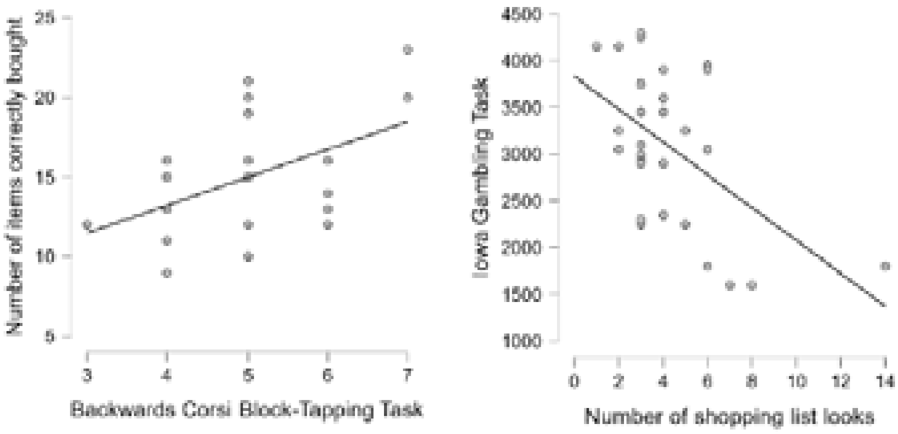

Figure 3 and 4: The upper figure shows Spearman's correlation between the score of the Backwards Corsi Block-Tapping Task and the number of items correctly bought during the QuestMarket task. The lower figure shows Spearman's correlation between the scores of the Iowa Gambling Task and number of shopping list looks during the QuestMarket task.

4. Discussion

In the present study, we investigated the comparability between VR based cognitive testing and traditional methods. In order to solely rely on the virtual task and minimize the effects virtual environments might evoke in participants, we created QuestMarket, a shopping game with a very plain and minimalistic virtual environment. Our results showed very little connection between QuestMarket variables and traditional cognitive test scores suggesting an altering effect for virtual environments even with very little environmental stimuli to influence participants. This gives rise to the potentiality that virtual environments fundamentally alter participants' performance on a variety of tasks. On the other hand, though, it can also mean that traditional neuropsychological tasks do not measure real-life comparable performance scores and their scores reflect very little of how a person would perform in a real life, cognitively demanding situation. Nevertheless, further studies are needed to confirm these initial assumptions, preferably with similar, plain virtual environments.

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Using Cognitive Map Theory to Create a Serious Game Assessment for Cognitive Dysfunction Post-Brain Injury

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Abstract

There is a clinical need for ecologically valid neuropsychological testing for cognitive deficits post-traumatic brain injury. Serious games provide interactive, safe, and replicable virtual environments to assess real-world skills. This paper outlines how the theory of cognitive maps and landmarks were used to provide a methodological framework for the map and design of a novel serious game, the Comprehensive Assessment for Executive Function (CAED). The development process with descriptions of each iterative phase is outlined. Overall, three iterations of the map were designed utilizing both tier one and two landmarks to form the final version of the CAED interactive design.

1. Introduction

Traumatic brain injury (TBI) remains a primary global cause of chronic cognitive disability, yet current gold-standard neuropsychological assessments often lack the ecological validity required to predict real-world functional outcomes after such injuries (Gioia, Kenworthy, & Isquith, 2010; Suchy et al., 2024). Traditional diagnostic tools rely on static, abstracted tasks that isolate cognitive domains into highly controlled silos, thereby stripping away the environmental context essential for engaging cognitive behaviors such as executive functioning. To address this gap, recent advancements have shifted toward "serious games," research-focused virtual tasks that facilitate the measurement of "cognition-in-action," by providing a safe, replicable, and highly controlled environments, for assessing the complex integration of multi-sensory information and translatable skills underutilized in current clinical practice (O'Brien et al., 2025; Suchy et al., 2024).

A central theory of cognitive deficits following brain injury involves disruption of the central executive system, which supports organizing, planning, monitoring, and repairing goal-directed behaviour. One approach to examine this is to through the formation and utilization of cognitive maps, mental representations of one's environment that allow for flexible navigation and spatial reasoning (O'Keefe & Nadel, 1978). Successful navigation requires an individual to not only recognize specific visual markers (landmarks) but also to integrate these into a coherent, relational framework (Tolman, 1948). Consequently, the inability to navigate to a goal location serves as a critical proxy for broader executive dysfunction, as successful navigation relies on planning, working memory, monitoring, error correction, and cognitive flexibility. This makes cognitive map formation a practical means of evaluating executive functioning during realistic tasks.

This paper outlines the methods and iterative process of utilizing the theory of cognitive maps and landmarks to create an interactive serious game, the Comprehensive Assessment for Executive Dysfunction (CAED). The CAED is designed to examine higher-level cognitive deficits often missed by traditional neuropsychological assessments by presenting a complex, yet realistic environment that allows individuals to navigate real-life tasks, thus allowing a clinician to assess higher-level executive deficits in a safe, replicable, and controlled environment. To support this, a town environment was created that is familiar in structure yet novel in layout, requiring users to rely on landmarks to plan and navigate between multiple goal locations in a controlled and replicable manner.

2. Methods

2.1. Tools

2.1.1. Game engine and software tools

The CAED platform was developed using the Unity game engine to support rapid iteration and deployment to tablet-based hardware (i.e. an iPad) which are commonly used in clinical settings. To reduce installation requirements and facilitate updates throughout development cycles, the system was deployed using Unity's WebGL pipeline to run the game in a standard web browser (i.e., Safari). Unity allowed for the integration of behavioural logging and performance metrics directly into the game, which captured measures such as route travelled, time-to-completion, task completion accuracy, and the frequency of map and to-do list access. Upon completion of gameplay, the data is exported automatically to a Google Sheet for analysis and inspection to support the broader goal of quantifying executive function behaviours during functional navigation tasks. In addition to Unity, several tools were used to support asset design and development. Blender was used to create and animate a customizable 3D avatar model. Static meshes, including buildings, props, and items, were created using the Probuilder plugin in Unity. Textures and UI elements were created using GIMP, while the map layout was designed using Draw.IO.

2.2. Development

2.2.1. Project Members and Development Strategy

To support the development of this project, a multidisciplinary research and development team was established, integrating clinical expertise in TBI and cognitive rehabilitation with software engineering and game design. This collaborative framework was supported by a rotating cohort of graduate and undergraduate research assistants who filled specialized functional roles, including programmers, artists, and UI/UX designers. The development of the virtual environment was managed through a granular task-allocation strategy, wherein map and landmark designs were decomposed into discrete subcomponents and assigned to specific team members. Progress was coordinated through weekly plenary meetings, with project versions maintained on GitHub and supporting materials, including storyboards, sketches, and notes, stored in a shared Google Drive.

The design phase utilized iterative storyboarding to define the CAED layout, UI, and the mechanics of user-environment interaction. Once group consensus was reached for the storyboards, conceptual sketches were transitioned into a functional prototype within the Unity game engine to create the CAED world. The research team then play-tested the environment to evaluate the navigational feasibility of the virtual landscape. This testing occurred across both Windows and macOS platforms to ensure cross-functional stability. The final stage of development involved a validation check on an 11-inch iPad Pro (3rd Generation) to optimize the interface for mobile clinical delivery and confirm the platform-agnostic stability of the final application.

2.2.2. Design of the world map

The primary theory used as the foundation of the CAED design stemmed from the three-part "Parallel Map Theory" proposed by Jacobs (2003), which outlines two processes that combine to form the cognitive map: the bearing map and the sketch map. The bearing map serves as a grid of boundaries, providing rough estimates of a position, whereas the sketch map allows the individual to incorporate topographical markers (tier 2 landmarks described below) through an egocentric, first-person view. In combination, the two form the final cognitive map. Both the bearing and sketch maps provide directional and locational cues, albeit from different perspectives. The bearing map provides a bird's eye, allocentric view, whereas the sketch map provides the first-person, egocentric perspective that serves to scaffold the initial route details.

In addition to outlining the theory guiding the design of the serious game, it was important to establish the type of environment the CAED would present. While other serious games presented singular environments such as grocery stores, shopping lanes, libraries, and offices (Caglio et al., 2012; Jacoby et al., 2013; Knight et al., 2006; Krch et al., 2013; Renison et al., 2012), it was important to present a larger "world" which would allow for the assessment of diverse skills such as withdrawing funds from an ATM, buying a sandwich, delivering a food order, or organizing multiple errands. To accomplish this, a town comprised of a neighbourhood, an office building, a park, a grocery store, a bookstore, a restaurant, a gym, a coffee shop, and other locations traditionally found in a classic town centre was designed. Based Jacob's (2003) framework, an aerial map was included that could be referenced to plan a route, which would need to be easily accessible during gameplay to aid in the monitoring or repair of the route when needed. Three guidelines for the design of the map were established: 1) It needed to be sufficiently difficult and present multiple routes to navigate between locations; 2) It needed to include realistic landmarks that could be used to form and track a route; and 3) Each location needed to have a specific purpose for assessment. For example, a user may be instructed to withdraw money, purchase specific items, and deliver those items to another location, which require route planning, task sequencing, working memory, monitoring, and error correction while navigating between multiple destinations.

2.2.3. Landmark Incorporation

Landmarks describe physical markers in an environment that can be used to mark progress of a route and allow individuals to form their sketch map (Jacobs, 2003). They include signs, buildings, landscaping, decorative items, and anything that is fixed in its location. To meet the second guideline for the CAED map design, landmarks were designed and placed in two functional tiers. Tier 1 landmarks were defined as global, salient reference points, such as buildings, parking lots, or landscape fixtures (i.e. a fountain), that were visible from both the map UI as well the third-person view of the environment. These landmarks served as anchor points for large scale spatial orientation and support the formation of a mental cognitive map. In contrast, tier 2 landmarks consisted of localized cues such as smaller shop signs, environmental props (i.e. light poles, park benches, garbage cans), or street signs that assist with route formation at specific points in the map. Unlike tier 1 landmarks, tier 2 landmarks are not intended to aid in the initial planning of the route (these are not visible from the aerial map) but instead, support the formation of route memory and allow the player to retrace their steps when recalling their route. The diversification of the landmark tiers allowed for the assessment of different cognitive skills in the player's ability to initially plan and organize their route, monitor their progress, and in the case of errors, utilize tools to reverse their route, track their progress, and reroute when necessary.

3. Results

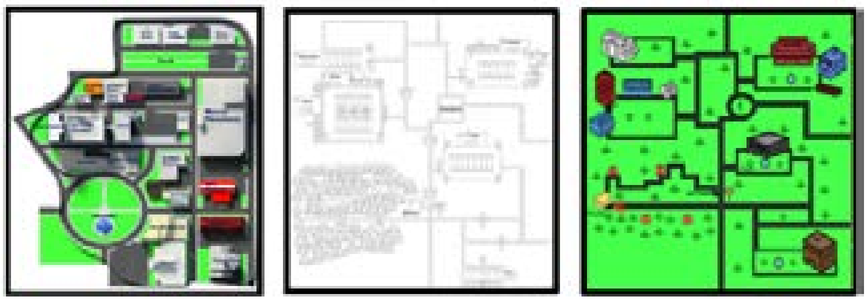

Figure 1: Map Versions 1, 2, and 3 (placed in order from left to right).

3.1. CAED Map

The spatial design of the CAED map evolved through three iterations which were driven by both the theoretical considerations of Jacobs (2003) and more practical usability constraints identified through feasibility tests run by the research team. The first iteration of the map was designed for navigation via a vehicle where users drove between locations. However, it was determined that this introduced excessive motor and attentional demands that would detract and overly complicate engagement with the CAED. To reduce this burden, the navigation was simplified to a walking-based model that utilized a single joystick for movement. To make the environment more ecologically plausible, the team designed a walkable town modelled after a New England municipality. This second iteration of the map emphasized pedestrian travel and featured clustered districts and parks spaced apart to ensure that travel distances remained realistic, yet feasible, for an average assessment session (>60 minutes). Traversal time between key locations (i.e. home to park, bank to café) was assessed through multiple testing sessions with the research team. This testing revealed satisfaction with the overall road layout, but issues with the spacing of the buildings and the density of the landmarks were raised. Multiple rounds of "playtesting" revealed that the buildings were clustered too closely which made it difficult to identify them individually, and that the density of the trees was distracting which made it difficult to see where the houses were located. It was also felt that the monochrome colouring of the map increased the difficulty of identifying locations. The third layout of the CAED map included brightly coloured and simplified districts, each connected by primary and secondary pedestrian streets, along with multiple routes to each district as well as significantly reduced tier 1 landmarks. To support orientation within the town and to reduce the working memory burden and minimize spatial disorientation, a player location marker was added to indicate the player's position on the map in real-time. Figure 1 showcases each iterative version of the map.

3.2. Landmarks

Tier 1 landmarks were incorporated into the first iteration of the CAED map, which consisted of a town environment designed for traversal by vehicle. Tier 1 landmarks included only roads, buildings, and a fountain. Since the modality of travel within the game was modified to walking, landmarks were not modified for this version of the map. In the second iteration of the map, tier 1 landmarks included buildings, parking lots, trees, and streetlamps. When discussing this map with the research team, it was determined that tier 1 landmarks were too dense and could unnecessarily distract the player. Additionally, the inclusion of parking lots, while realistic, was not purposeful (thus violating the third guideline) since there were no vehicles in the game. The third iteration of the map presented a more simplified design that included buildings, roads, trees, and landscape fixtures, but with less density so as to not distract the player. However, testing the third person view of the CAED world revealed that, although the minimalistic design of tier 1 landmarks may have been beneficial, tier two landmarks may had been oversimplified. During testing of the third-person view, players struggled to differentiate the roads to travel to and from locations because there were few salient landmarks to mark their path. To address this, additional features such as neighbourhood signs, park signs, and road signs were added to provide more realistic visual cues to aid in the formation of the cognitive map and allow for easier navigation to and from locations. This final phase of testing among the research team also resulted in a refined interface, as initial versions featured text labels too small for comfortable viewing on tablet devices. Additionally, the map interface elements such as the player location marker lacked sufficient contrasts, which made orientation difficult. Subsequent revisions increased the label size, enhanced contrast, and improved the visibility of the player location icon.

4. Conclusion

This work presented how we applied cognitive map theory to develop the framework for the CAED, an interactive serious game designed for individuals with traumatic brain injury (TBI). Through an iterative design and testing process, the team refined a "bearing map" – a minimalistic, aerial allocentric view using tier 1 landmarks – to provide essential directional and positional cues. To supplement this, tier 2 landmarks such as street signs and environmental features were integrated into a 360° first-person view, acting as a "sketch map" to help users build a detailed 3D mental representation of their environment. These changes provided the interactive framework for participants to perform daily tasks such as navigating to the grocery store, bookstore, or office building. Each respective location correlates with a set of realistic tasks such as buying food on a budget, ordering coffee in a distracting environment, finding an office location, and other daily tasks that are reliant on sequencing, cognitive flexibility, working memory, inhibition, planning/organizing, monitoring, and repair of behaviours. This final iteration is currently undergoing a feasibility study with speech-language pathologists and individuals with TBI to evaluate its effectiveness as a clinical tool for cognitive assessment.

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An Initial Study on Enhancing AR Physical Coaching: Multimodal Posture Feedback Using Local ML and LLMs

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Abstract

This preliminary study presents an Augmented Reality (AR) coaching application for physical rehabilitation. Using a Meta Quest 3 and an iPhone, the system offers a low-strain environment for home exercises. In a user study (N=11), participants performed shoulder presses guided by a 3D avatar. A local machine learning model analyzed their form, triggering personalized audio feedback via a Large Language Model (LLM). NASA-TLX evaluations showed minimal user exertion. Despite minor tracking and API limits, the system demonstrates strong potential for integrating immersive, multimodal AR into accessible physical therapy.

1. Introduction

The integration of immersive technologies and artificial intelligence (AI) is opening new frontiers in healthcare, particularly in physical rehabilitation and preventive medicine. For patients recovering from injuries or individuals training for medical reasons, maintaining proper form during physical exercises is crucial to build strength and prevent secondary injuries. However, home-based rehabilitation often lacks the real-time, expert supervision required to ensure movements are executed correctly, and adherence to home exercise programs remains a well-documented challenge (Argent et al. 2018). Augmented Reality (AR) headsets combined with mobile tracking devices, offer a promising solution by providing immersive, real-time visual guidance, and prior review work suggests that AR can support engagement and rehabilitation-related outcomes in physical therapy contexts (Gil et al. 2021).

When designing AR applications for physical exertion, the choice of interaction methods is a critical factor, as it directly affects user strain, occlusion, and overall usability. Research by Goh et al. highlights the advantages and limitations of various interaction types (touch-based, mid-air gesture-based, and device-based) in mobile AR environments (Goh et al. 2019). Given that wearable headsets can cause fatigue during prolonged usage, interactions must be designed to minimize physical burden. To address these limitations, Nizam et al. emphasize the importance of multimodal interaction techniques, which combine different input methods to make applications more intuitive and less straining (Nizam et al. 2018). Since physical rehabilitation requires users to move their bodies freely, relying solely on physical or manual interactions can be restrictive and counterproductive.

Despite these advancements, there remains a need for accessible, hands-free AR systems that provide intelligent, multimodal feedback without interrupting the user's physical flow. This paper addresses this gap by introducing an AR application designed to help users optimize their form during exercises, such as the shoulder press, for medical rehabilitation or personal health.

The aim of this preliminary study is twofold: first, to develop an AR-based virtual coach that tracks user form via an iPhone and provides multimodal (visual and auditory) feedback through a headset; and second, to compare the accuracy and latency of a local machine learning (ML) model against a Large Language Model (LLM) in generating personalized feedback. To guide this preliminary study, we formulated the following research questions:

1. How suitable is AR as a platform for providing usable and low-strain guidance during physical rehabilitation exercises?
2. How can a local machine learning model and a cloud-based Large Language Model (LLM) be practically integrated to provide multimodal feedback in an AR coaching system?

2. Methodology

2.1. System Overview and Setup

The proposed AR coaching system comprises an iPhone application for body tracking and a Meta Quest 3 headset for the main AR interface. As shown in Figure 1a, users are guided by a 3D avatar (downloaded from Mixamo[1] and animated through a prerecorded motion capture animation) that visually demonstrates a standing shoulder press. Concurrently, the iPhone's camera tracks the user, overlaying a red skeleton on their body using Unity's AR Human Body Manager, and streams this video to the headset via a peer-to-peer WebRTC connection using SimpleWebRTC[2]. The user interface incorporates a movable panel displaying this video stream (Figure 1b), ensuring users can monitor their movements without experiencing severe visual occlusion.

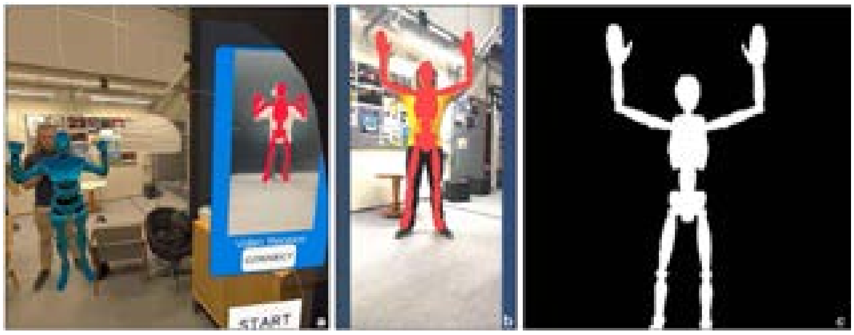

Figure 1: System architecture: AR interface, tracking, and ML pipeline.

1 https://www.mixamo.com/, accessed 2026-01-05
2 SimpleWebRTC, Unity Asset Store, https://assetstore.unity.com/packages/tools/network/ simplewebrtc-309727, accessed 2026-01-05.

2.2. Data Pipeline and Classification

To analyze the user's form without imposing a heavy computational load on the headset, frames from the video stream are extracted twice per second (yielding 84 images per set) and sent as Base64 strings to a local Python server via WebSockets. The server processes these images using color thresholding to isolate the red skeleton, yielding a normalized, centered black-and-white image (Figure 1c). This segmented image is then split into grids to extract feature vectors. A Support Vector Machine (SVM) classifier, trained on 1,013 collected images and categorized into five distinct posture classes (e.g., lower good, left bad, upper good), evaluates the vectors to predict the user's real-time form.

To verify the classifier's reliability, a subsequent evaluation was conducted using a newly collected dataset of 152 images. The SVM model achieved an overall classification accuracy of 76.87%. While the accuracy for correct posture classes was highly reliable (exceeding 92%), performance dropped for specific incorrect postures (e.g., 41.9% for "right bad"). This discrepancy is primarily attributed to class imbalance within the training data; since participants naturally performed well during the initial data collection, the model lacked sufficient examples of erroneous postures to train on.

2.3. Multimodal Feedback Generation

To ensure accurate and non-intrusive guidance, the system aggregates the posture classifications over each 8-repetition set. If the count of a specific error (e.g., the left hand being lower than the right) exceeds a predefined threshold of 5, the system triggers corrective feedback. This classified error is fed into a prompt for Google Gemini via its API, generating concise, personalized, and encouraging text instructions. This text is subsequently converted to audio using Google Cloud Text-to-Speech (TTS) and played to the user between sets, providing a seamless, multimodal coaching experience without interrupting the physical flow.

2.4. User Testing Procedure and Demographics

To evaluate the system, a preliminary user study was conducted with 11 participants aged 23–35 (8 male, 2 female, 1 preferred not to say). The sample primarily consisted of students with generally low prior AR experience (9 out of 11 participants rated their experience below 5 on a 0–10 scale). Participants performed two sets of eight shoulder presses using only their body weight to minimize injury risk. The study aimed to assess the system's usability, the classifier's accuracy, and overall user exertion. Data were collected through direct observation and an anonymous questionnaire incorporating the NASA Task Load Index (TLX) (NASA Human Systems Integration Division n.d.) to evaluate cognitive and physical workload demands.

3. Results

3.1. Workload, Usability, and Feedback

As summarized in Table 1, the perceived workload measured via the NASA-TLX form was notably low, with all average scores falling below 4 out of 10. This indicates that the overall load and demand of using the application were quite manageable. Participants generally felt successful in accomplishing the exercise tasks, rating their performance an average of 7.00. However, responses for performance were somewhat divided, with four participants rating their performance a 5 or below.

Metric	Score	Metric	Score
Usability & Feedback		*Workload (NASA-TLX)*	
Using Intuition	8.55	Temporal Demand	3.63
Coach Helpfulness	8.55	Physical Demand	3.45
Setup Intuition	6.91	Effort	3.36
Stream Helpfulness	5.18	Mental Demand	2.27
Audible Helpfulness	5.00*	Frustration	2.18
Audible Accuracy	4.91*		

Table 1: Average Scores for Workload, Performance, and Usability (Scale 0-10).
**Affected by API technical errors. Adjusted averages excluding outliers: 6.88 and 6.75.*

3.2. Usability and Feedback

The intuitiveness of using the application was rated highly (8.55), though the setup process scored slightly lower (6.91). Regarding the feedback modalities, the 3D coach avatar was the most preferred and helpful feature (8.55), with 9 out of 11 participants favoring it over the video stream and audible feedback.

Initially, the audible feedback received low scores for helpfulness (5.00) and accuracy (4.91). However, this was skewed by a technical failure where the LLM (Gemini) ceased to provide feedback during three test runs due to API limits. Excluding these outliers, the adjusted scores for audible helpfulness and accuracy rose significantly to 6.88 and 6.75, respectively.

The video stream was perceived as less helpful (5.18). Four participants found the red skeleton overlay intrusive or annoying, with one noting that the large overlay obscured the presented feedback. Additionally, several users found it difficult to look at the video stream and the avatar simultaneously. Interaction with the stream panel also proved challenging; although the panel was movable, the pinch-to-move mechanism was hard to grasp for novices, and some participants required assistance to interact with the virtual buttons.

4. Discussion

Overall, the usability of the application and the users' performance in relation to their exertion suggest that the AR coaching concept works effectively. However, qualitative feedback highlighted specific interaction and technical issues that affect the overall experience.

Given that the application is designed for physical workouts, it was expected that physical demand would be a notable part of the overall exertion. Differences in user fitness levels and their perception of the headset's weight likely contributed to the variance in physical demand scores. Mental demand was generally low, indicating that the instructional design was not overwhelming. However, one outlier reported a mental demand of 6/10, which may indicate that technical glitches or the specific test scenario induced stress. Frustration levels were also low on average, but qualitative feedback suggested that the pace of the tests and the positioning of the video stream which required users to constantly shift their gaze were the primary sources of annoyance for the outliers.

Interactions with virtual buttons and panels proved unintuitive for some users, directly contributing to the mental demand and setup frustration. For instance, one user with very little AR experience attempted to press virtual buttons using their entire hand rather than a finger, failing to activate them. Furthermore, the pinch gestures (using the thumb and index/middle finger) required to reposition the stream panels were highly unreliable. Even when users performed the instructed gesture, the system registered it inconsistently. Improving the reliability of these interactions or automating the panel placement is crucial for users to comfortably view both the avatar and themselves without manual adjustments.

Several significant technical problems were discovered during testing. The temporary failure of the Gemini API severely hindered the audible feedback loop. More importantly, the 2D-to-3D body tracking was less accurate than expected, struggling with diversity in body disposition, clothing, and background noise. Since multiple real-life postures could translate to the same overlaying skeleton pose, this inaccuracy cascaded into the local classification model, occasionally confusing users with incorrect visual feedback. Finally, users experienced application rotation issues, where the Quest 3 headset would unexpectedly change its orientation when removed and put back on between test runs.

5. Conclusion and future work

This preliminary study suggests that AR can be a promising platform for guiding users through physical rehabilitation and exercises. The system successfully provides a low-strain, functional environment where users receive real-time visual guidance and post-set audible feedback.

Despite its functional state, several technical challenges were identified and partially addressed. During development, the audible feedback system encountered API rate limits with Gemini 2.5 Flash, which caused the feedback to halt. This was resolved by transitioning to a more lightweight model (*gemma-3-4b*); while this restored uninterrupted functionality, it presented a trade-off with a slight risk of reduced feedback quality. Additionally, to combat the 3D body tracking inaccuracies, the local ML classification model was updated with a broader dataset of user images, yielding a slight but notable improvement in accuracy.

To further optimize the system for clinical-grade reliability and seamless user experience, future work will focus on three main architectural improvements. First, regarding **Tracking and Overlay**, the 3D skeleton overlay will be replaced with a 2D skeleton, allowing for more precise, transformable joint tracking that better matches user disposition, which will require new data collection to rebuild a fitting classification model. Second, to improve **UI Integration** and eliminate the need for users to look back and forth, the video stream panel and the avatar will be designed to overlap. By making them semi-transparent, users will see their own movements in direct correlation to the dynamic size of the avatar. Finally, for **System Stability and Evaluation:** A "reset view" functionality (similar to Meta's native controls) will be implemented to fix application rotation issues upon removing the headset.

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10

ACCESSIBILITY & INCLUSION

Redesigning a VR Group Intervention to Support a Mentalising Stance in Professional Caregivers of People with Intellectual Disabilities

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Abstract

This paper presents the redesign of a virtual reality (VR) group intervention aimed at supporting professional caregivers' mentalising stance during emotionally intense care interactions with people with intellectual disabilities. Prior to evaluating the intervention's effectiveness, this study explores how the intervention can be adapted with and for professional caregivers. Therefore, professional caregivers assessed the previous and/or adapted VR group intervention and provided feedback on multiple occasions. This resulted in an adapted intervention featuring more engaging informational content on mentalisation prior to the VR interactions, more authentic VR interactions due to the transition from pre-scripted to AI-driven avatars, and better structured reflection sessions following each VR interaction to encourage shared learning.

1. Introduction

Professional caregivers play a crucial role in establishing meaningful, trusting relationships with people with intellectual disabilities (Rinaldi et al., 2023). Key to fostering these relationships is mentalisation; the ability to understand and interpret mental states in oneself and others (Bateman & Fonagy, 2016). In everyday interactions, mentalisation is enacted through a mentalising stance: an open, curious, non-judgmental attitude in which people acknowledge uncertainty, stay flexible, and actively attend to the mental states underpinning behaviour rather than solely focusing on observable actions (Sharp et al., 2020). Maintaining this stance can be demanding, especially in care settings. For one, professional caregivers need to be particularly sensitive to the meaning of their clients' behaviour and the underlying needs or internal states, as people with intellectual disabilities often have difficulty communicating about and reflecting on their internal experiences (Derks et al., 2019; Reinders, 2010; Schuengel et al., 2010; Scotland et al., 2015; Simons et al., 2020). Second, professional caregivers in today's disability care face many emotionally demanding and stressful situations (Baker et al., 2024; Olivier-Pijpers et al., 2020). As stress is known to suppress one's mentalising capacity (Luyten et al., 2019), professional caregivers may more easily lose their mentalising stance in daily interactions with clients. Training and education in mentalisation are therefore essential to adequately support professional caregivers in maintaining and strengthening their mentalising skills. However, mentalisation is still insufficiently embedded in current educational curricula (Fagerbakk et al., 2023; Jansen et al., 2023) and accessible opportunities within the workplace to practice and strengthen mentalising skills of professional caregivers remain limited. Taken together, these considerations led to the development of a Virtual Reality (VR) group intervention to support professional caregivers in practicing mentalisation. Practicing mentalisation in VR enables professional caregivers to rehearse challenging, high-arousal interactions in a safe and controlled environment (Cho et al., 2024). Evidence from our prior randomised trial indicated that the VR group intervention is promising, although adjustments are needed. That is why this study aimed to further develop the VR group intervention and to identify the refinements that emerged from this process.

2. Methods

The initial intervention consisted of three components: (1) knowledge clips and an article providing background information about mentalisation, (2) VR interactions with a pre-scripted avatar dealing with difficult situations or stressful circumstances, and (3) a group reflection moment following each participants' VR interaction, which were iteratively refined using a design-based approach. This design-based approach involved two heterogeneous groups of approximately eight professional caregivers, including team managers, developmental psychologists and support staff, who participated in co-creative sessions (see Figure 1), following the principles of design thinking and, more specifically, the CeHRes Roadmap (Kip et al., 2025). During the first two design sessions, the first group of participants experienced the intervention and provided feedback on user experience, relevance, and implementation conditions. In the third design session, a second group of participants provides feedback on the intervention. Afterwards, individual interviews are conducted with participants from this second group to explore how they apply what they have learned in daily practice, what changes they experience in their interactions with clients, and what meaning they attribute to these changes.

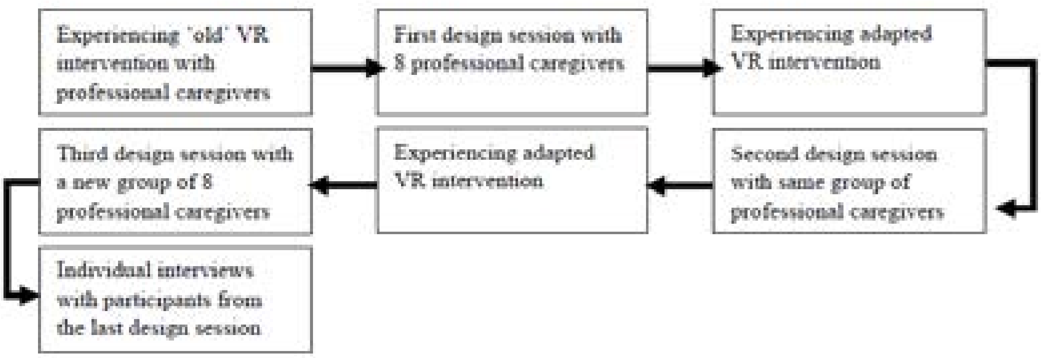

Figure 1: Design-based methodology of adapting the VR group intervention.

3. Results

Based on professional caregivers' feedback, we identified facilitating and hindering factors across the intervention core components that shaped the next iterations. First, feedback on the length and content of the knowledge clips led to the development of shorter and more targeted clips. Feedback on the outdated article resulted in its replacement with a more recent article. Participants emphasised the importance of embedding the intervention within what is already familiar in the care organisation and how mentalisation differs from other conversational skills, such as solution-focused communication. Second, feedback on the VR component highlighted the importance of more natural interactions and more responsive avatars. In the initial VR app, the avatar's responses did not always align with participants' verbal input, disrupting the flow of the interaction and reducing its perceived realism. To increase conversational naturalness, we partnered with a VR company to integrate AI-driven avatars, allowing responses in the simulation to be delivered more rapidly and to be better adapted to the user's input. Third, feedback on the reflection session indicated the need for more structure with clearer and more concrete guidance, leading to the use and testing of predefined reflection formats. Based on ongoing feedback, further adaptations are currently being made in preparation for a third iteration, for which a new group of participants will be recruited. Consequently, outcome data and completed qualitative analyses are not yet available at this stage.

4. Discussion and conclusion

This study showed that the further development of the VR group intervention was not only a process of practical refinement but also provided insight into the conditions needed for the intervention to be meaningful in practice. First, the findings suggest that background information about mentalisation should be offered in an appealing and accessible way. In addition, the findings suggest that implementation may be strengthened when the VR group intervention is clearly connected to the care facility's vision and ways of working and when its position in relation to familiar conversational approaches (e.g., solution-focused communication skills) is made explicit. Second, the findings underline that the quality of the VR interaction is crucial. As the intervention is designed to practice and train mentalising skills, a more natural and flexible VR experience is essential for enabling meaningful interactions and achieving the intervention's intended purpose. The choice for AI-driven avatars was therefore deliberate, as they are intended to enable more dynamic, responsive, and realistic conversational practice than would be possible in more fixed or scripted formats. This aligns with emerging work on AI-driven virtual patients in healthcare education, suggesting they may offer flexible, repeatable, and potentially realistic opportunities for communication skills training (Bowers et al., 2024). Finally, the study highlights the importance of structuring reflection sessions, as more structure may help shift reflection from a descriptive discussion of events towards the exploration of underlying mental states and shared meaning-making, thereby strengthening its relevance for mentalising. Taken together, these findings led to adaptations to the VR group intervention, creating a better fit with what professional caregivers indicated would enhance its learning potential. In this way, the VR group intervention may optimally support professional caregivers in making sense of behaviour in terms of underlying mental states and to ultimately engage in meaningful interactions with people with intellectual disabilities. Future research will evaluate whether the redesigned intervention effectively contributes to professional caregivers' mentalising stance.

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Enemy Localization Tools for VR Games Accessibility to Blind and Low-Vision Players

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Abstract

Virtual reality (VR) offers new opportunities for accessible interaction, yet action-oriented gameplay remains largely inaccessible to blind and low-vision (BLV) players, especially in multi-enemy combat requiring rapid situational awareness. This ongoing project investigates audio-based assistive tools for enemy localization in VR shooting games. We designed a VR shooting platform integrating three localization tools: a radial shockwave, a joystick-controlled scan, and a controller-attached detection cone. In this work in progress, we present the system and an experimental protocol combining gameplay sessions on a dedicated mini-game with post-hoc focus groups, aiming to understand how BLV players perceive and use these tools to iteratively refine them.

1. Introduction

Video games are a major cultural and social medium, yet they remain largely inaccessible to blind and low-vision (BLV) players due to their reliance on visual information. Despite this, BLV players have expressed a desire to participate in these games and become part of these communities (Andrade et al. 2019), making use of assistive technologies and developing their own compensatory strategies (Gonc¸alves et al. 2023). Recent advances in game accessibility have improved inclusion, particularly through audio-based features in mainstream titles such as *The Last of Us Part II (TLOU II)* and *Diablo IV*. However, these solutions remain limited and inconsistently implemented, especially in situations requiring rapid decision-making, such as multi-enemy combat.

In a preliminary investigation, we conducted interviews with 12 BLV players to explore their experiences with action-oriented games. The results highlighted persistent difficulties in rapidly understanding surrounding threats, even when accessibility features are available. Participants reported relying heavily on spatial audio cues and expressed appreciation for existing localization tools, while also identifying limitations in their precision, timing, and level of control, particularly when automation constrained their ability to plan and execute strategies.

Virtual reality offers a promising context to address these challenges through embodied interaction, spatial audio, and motion-based input (Mott et al. 2019). Designing accessibility features early in the development of VR systems may enable more inclusive interaction paradigms. However, accessibility features for BLV players in VR remain scarce (Aich et al. 2025). Building on these findings, this work investigates the following research question: how can enemy localization techniques from traditional games and prior research be adapted to support situational awareness in VR combat scenarios for BLV players? To address this question, we design a VR-based study in which participants interact with a shooting mini-game integrating multiple enemy localization techniques. These methods are evaluated through gameplay sessions, followed by a focus group aimed at collecting qualitative feedback and refining the proposed approaches for VR use.

2. Related work

Video game accessibility research has long identified barriers faced by BLV players and proposed early guidelines for inclusive design (Bierre et al. 2005). Studies show that while these players demonstrate strong interest in video games, many accessible experiences rely on simplified mechanics or automated assistance, which can limit player control and reduce the complexity of gameplay, particularly in dynamic situations (Andrade et al. 2019). A substantial body of work has demonstrated that non-visual gameplay is feasible through spatial audio and multimodal feedback, enabling players to perceive game events and navigate environments without vision (e.g., Atkinson et al. (2006)). More recent studies show that BLV players rely on compensatory strategies such as memorization, timing, and audio cues when interacting with mainstream games, while still facing significant accessibility limitations (Gonc¸alves et al. 2023). Prior work on fast-paced interaction further highlights the importance of prioritizing critical information and providing concise auditory feedback in real-time gameplay (Smith & Nayar 2018). However, the effectiveness of these approaches in highly dynamic scenarios such as multi-enemy combat remains insufficiently understood.

Situational awareness refers to the perception of environmental elements, the comprehension of their meaning, and the projection of their future states in dynamic contexts (Endsley 1995). In games, this involves continuously tracking multiple entities and anticipating threats under time constraints. Existing work has focused mainly on spatial awareness in navigation contexts, where tools such as *NavStick* and *Surveyor* provide structured auditory feedback to support exploration and environmental understanding (Nair et al. 2022, 2024). Although effective for navigation, these approaches are typically designed for low time-pressure scenarios and do not directly address the constraints of fast-paced gameplay.

Research has explored navigation and spatial awareness in VR for BLV, as well as more interactive experiences such as sports-oriented applications and systems supporting environmental awareness (Furtado et al. 2025, Ribeiro et al. 2024). However, these applications are generally limited to structured or low-pressure scenarios. Accessibility in dynamic VR gameplay, particularly situations involving multiple moving entities, time pressure, and rapid decision-making, remains largely underexplored. This highlights the need to investigate how existing techniques can be adapted to support situational awareness in VR combat scenarios.

3. VR Platform and assistive tools

Building on preliminary interviews investigating BLV players' experiences in action-oriented games, we aim to address the difficulty of rapidly understanding the spatial distribution of multiple enemies during combat. While existing accessibility features in traditional games provide partial support, they often fail to support fast-paced decision-making. To address this, we developed a set of assistive tools aimed at supporting enemy localization in VR combat scenarios. These tools are inspired by both accessibility features found in commercial games and techniques proposed in prior research, and are adapted to leverage VR-specific interaction capabilities. To evaluate these techniques, we developed a VR shooting mini-game designed to reproduce controlled yet dynamic multi-enemy combat situations, allowing us to collect both usage observations and qualitative feedback from players.

3.1. VR Combat Assistive Tools

We implemented three complementary assistive tools designed to support enemy localization through different interaction strategies, ranging from global scanning to directional and embodied exploration.

Radial Shockwave (M1): The radial shockwave, inspired by scan-based mechanics found in *TLOU II*, is activated by pressing a button and generates an expanding sphere centered on the player up to a fixed range. When colliding with enemies, spatialized audio cues are emitted from their positions, providing a global overview of nearby threats.

Joystick-Controlled Zone (M2): The joystick-controlled method, inspired by the *NavStick* (Nair et al. 2021), allows players to actively probe their surroundings by holding a directional input. It defines a cone-shaped detection zone oriented according to the absolute direction of the joystick, independently of head or controller orientation. This approach enables rapid and targeted scanning of specific directions without requiring physical movement.

Controller-Attached Zone (M3): The controller-attached method provides a continuously active cone-shaped detection zone aligned with the orientation of the VR controller, similar to a flashlight beam. By directly coupling detection with hand movement, this technique supports embodied exploration of the environment and may enhance spatial understanding through physical interaction.

3.2. VR Shooting Mini-Game

We developed a simplified VR shooting mini-game in which the player must survive by eliminating multiple enemies approaching from all directions. Idle robots spawn around the player at predefined positions. The player can then use the localization tools to assess the surrounding enemies. Upon the first shot, enemies become active and move toward the player while continuously emitting spatialized footstep sounds as they advance. Upon reaching the player, enemies inflict damages. The player has a limited number of lives, and must eliminate all enemies before losing all health points. To reduce motor and aiming constraints, the weapon uses an adjustable SphereCast-based shooting system, increasing projectile size to mitigate the difficulty of precise aiming in VR. Levels vary in terms of number of enemies, movement speed, and spatial configuration. Specific configurations are designed to challenge localization abilities, including enemies at similar distances but different orientations and enemies at similar orientations but different distances.

Figure 1: Left: First-person view of the player with a controller and weapon, and multiple enemies positioned around the player. Right: Top-down view illustrating the spatial configuration of enemies and the sphere of a localization tool (radial shockwave).

4. Ongoing experiments

4.1. Hypotheses

(H1.a) M1 is expected to require multiple successive activations to progressively build a mental representation of enemy distribution, before the first shot. **(H1.b)** M2 & M3 are expected to be used more frequently during combat, as they provide a direct localized and rapidly accessible information that supports real-time decision-making.

(H2) M3, which relies on active body movement, is expected to improve players' understanding of relative enemy positions, but may also be perceived as more physically demanding over time.

4.2. Experimental Procedure

Each session lasts approximately an hour. The three localization methods (M1, M2, and M3) constitute the experimental conditions. Participants only test one method per block. For each block, a short training phase allows participants to explore the technique with idle enemies placed around them, ensuring proper understanding of the interaction. This is followed by a combat phase in which participants must eliminate all enemies before losing all health points. The difficulty increases progressively through variations in the number and speed of enemies. Throughout the experiment, quantitative data are collected, including the number of levels successfully completed or failed, player movement trajectories, tool activations, robot eliminations, and level completion times. After each condition, an oral questionnaire is conducted to capture immediate impressions regarding usability and perceived effectiveness. Short breaks are provided between conditions. We aim to recruit at least eight blind and low-vision participants.

4.3. Focus Group

A semi-structured focus group is conducted remotely within one week of the individual sessions to facilitate scheduling and collect delayed feedback after participants have had time to reflect on their experience. Each focus group consists of up to four participants. The discussion provides an opportunity for participants to revisit and collectively exchange on their experiences with the different interaction techniques. The session is structured around several themes (1) perceived effectiveness and preferences across methods, (2) contextual factors influencing usability (e.g., number of enemies, speed), (3) physical and cognitive load,(4) strategies developed to compensate for limitations, (5) perceived contribution of VR compared to traditional games. The discussion also explores how these techniques could be adapted to different gameplay situations.

This participatory approach aims to involve users directly in the design process and to iteratively refine assistive tools based on their feedback.

5. Conclusion

The aim of this ongoing study is to collect feedback from BLV players on prototype assistive solutions within a VR shooting mini-game. Through post-experiment discussions, we seek to iteratively refine these tools in order to design solutions that are usable and effective in VR combat situations. Additionally, this work aims to explore the potential relevance and appeal of virtual reality games for BLV players. Beyond this study, several research directions emerge. First, future work will involve integrating and consolidating complementary assistive techniques, both those proposed in this paper and existing approaches from prior work (Nair et al. 2021, 2024, Apavou et al. 2024), into unified systems. A key challenge will be to understand how these techniques can effectively complement each other while avoiding redundancy and preventing auditory overload within already dense game soundscapes, potentially by distributing information across modalities such as haptics. Second, extending localization tools with obstacle and environment awareness could support a more complete understanding of scene layout, enabling players to develop more advanced strategies. Finally, these approaches may generalize beyond gaming contexts to VR applications where situational awareness is critical, such as social and collaborative virtual environments.

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An Interaction-Centered Perspective on Audio-Based Gameplay for Blind Players

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Abstract

Audio is a key modality for blind players to navigate and interact with digital games. This paper presents a qualitative study of blind players engaging with commercial games to examine how audio supports the interaction process. We introduce an interaction-centered perspective structured around a four-stage loop: affordance, actionability, execution, and feedback. Our analysis demonstrates that interaction breakdowns occur when this loop is disrupted, including failures in perception, unclear actionability, problematic execution, and ambiguous feedback. We further identify two design tensions: accessibility vs. challenge and automation vs. player agency. Together, these findings provide an interaction-centered account of audio-based gameplay and highlight how actionable design supports functional presence in immersive virtual environments, forming a foundation for a broader framework of audio-based interaction.

1. Introduction

In non-visual gaming, audio serves as an important link between the player and the virtual world, facilitating everything from basic spatial navigation to complex system engagement. While current research often focuses on overcoming sensory barriers through feature-level accessibility [Yuan et al. (2011)], designing effective interaction remains a challenge in dynamic gameplay where players must continuously interpret cues and act in real time. In virtual reality (VR) research, the sense of presence (the subjective experience of being there) is tied to the player's ability to act meaningfully within the environment [Slater (2009)]. This suggests that accessibility is not only about information access, but about maintaining the continuity of the interaction process, from perceiving affordances to acting and interpreting system feedback.

This study adopts an interaction-centered perspective to examine how audio supports (or fails to support) blind players across diverse gameplay situations. Based on think-aloud and observational data from blind players engaging with commercial titles, we analyze how players move from perception to action and understanding. As a step toward a broader framework, we introduce a four-stage interaction loop structured around **affordance, actionability, execution, and feedback.** Our analysis shows that breakdowns frequently stem from disruptions within this loop, including gaps in actionability, missing or conflicting cues, and ambiguous feedback. We further identify two design tensions: between accessibility and challenge, and between automation and player agency. We argue that accessibility in immersive systems depends on supporting actionable understanding and functional presence, ensuring the player remains a capable agent within the virtual world.

2. Related work

Game accessibility research primarily addresses barriers in navigation and progression through feature-level adaptations [Yuan et al. (2011), Westin et al. (2020)]. While essential, this remedial approach often overlooks the preservation of core gameplay loops and the holistic player experience [Heron (2016), Power et al. (2012)]. Audio-specific research, including sonification and audio-only games, demonstrates that sound can effectively convey spatial and event-based information in non-visual contexts [Vickers (2011), Hermann et al. (2011)]. However, this work typically focuses on how information is encoded and perceived, rather than how it supports ongoing interaction processes.

Interaction theory offers a broader perspective by examining how users move between perception, action, and interpretation through the gulfs of execution and evaluation [Norman (2013)]. While this model captures the general structure of interaction, it does not account for how users derive actionable input mappings from non-visual cues, a challenge that becomes important in audio-based gameplay. Although immersion in virtual environments is tied to meaningful action [Slater (2009)], these processes are rarely examined in terms of how they break down in non-visual contexts. We draw on embodied interaction [Dourish (2001)] and the concept of *actionability*: the knowledge required to translate perceived affordances into meaningful action [Gaver (1991)]. Building on these perspectives, we model interaction as a structured process spanning multiple stages and examine how breakdowns emerge across this process. This interaction-centered account addresses a gap in current literature by explaining how non-visual interaction unfolds as a coherent system rather than a set of isolated features.

3. Method

3.1. Participants and Data Collection

The study is based on 4.5 hours of video recordings of six blind gamers (aged 29–58), five of whom were born blind and one who had been blind for the last 20 years as a consequence of an accident. The sessions followed a semi-structured format in which participants were invited to play games of their own choice to showcase their typical gaming experiences and the specific interaction challenges they encounter. Participants were encouraged to think aloud, sharing real-time reflections and reasoning as they interacted with the game environment. A sighted researcher was present, occasionally asking clarifying questions and providing minimal assistance when necessary. In Table 1, we present the specific games that the six gamers chose to demonstrate, categorized by their respective genres.

Genre	Games Represented
Action-Adventure	The Last of Us, Assassin's Creed, God of War
RPG / Adventure	Final Fantasy, Brok the Investigator
Specialized Audio Games	The Vale: Shadow of the Crown, A Hero's Call
Strategy / Simulation	Stardew Valley, RimWorld
Rhythm / Casual	Bits & Bops

Table 1: Commercial Games Selected and Played by Participants.

3.2. Data Preparation and Analysis

The recordings were segmented into discrete interaction episodes and documented as two types of logs: think-aloud (TA) logs capturing players' reflections, and observed (Obs) logs capturing interaction sequences and break-downs observed by the co-present sighted person. In total, the dataset comprised 163 think-aloud logs and 64 observed logs. Throughout this paper, participants are referred to as G1–G6, while specific data excerpts are indexed as TA1–TA163 for think-aloud reflections and Obs1–Obs64 for observed interaction sequences.

The analysis followed an iterative and inductive approach inspired by thematic analysis [Braun & Clarke (2021)]. Interaction events from the think-aloud and observed recordings were manually coded by one researcher in separate coding schemas and logged in Excel sheets. The coded material was grouped into clusters, abstracted into higher-level patterns, and finally synthesized into cross-cutting dimensions. These dimensions were later refined in a workshop with five researchers, where they were checked against the original data and adjusted where necessary.

4. Preliminary findings

Our analysis identifies a set of dimensions describing the structure of audio-based interaction for blind players, relating to a fundamental loop:

Affordance → Actionability → Execution → Feedback

Stage	Definition	Data-Backed Breakdown Example
Affordance	The player perceives via audio that an interaction is possible.	A required affordance is not perceived: a hole in the floor enabling progression is missed(G1, TA14).
Actionability	The player understands how to execute the intent using specific inputs.	Player presses buttons at random to find a combat action for a door (G4, Obs38).
Execution	The physical act of performing the command.	Player hears the "Press R1" assassination prompt, but cannot process and execute the input before the time window closes (G1, TA25).
Feedback	Non-visual confirmation that the action succeeded or failed.	After picking up an item, the player is unsure if the action was registered or if progress was saved (G1, TA24).

Table 2: The Interaction Loop: Evidence-Based Interaction Breakdowns.

Breakdowns emerge when one or more stages of this loop are disrupted, including failures in perceiving affordances, interpreting required actions, executing inputs, and understanding system feedback. As shown in Table 2, these disruptions manifest across all stages of the interaction process. In some cases, players are unable to perceive an affordance due to missing or misleading cues. For example, a player did not detect a hole in the floor required for progression, as the character automatically jumped over it without providing a non-visual cue (G1, TA14). In other cases, players perceive an affordance but lack guidance on how to act, resulting in an actionability gap. This often leads to trial-and-error behavior, such as pressing buttons at random and accidentally striking non-player characters (G4, Obs38). Execution can also break down when the required action is known but cannot be performed within the available timing window, such as when a player hears the "Press R1" assassination prompt but cannot execute the input before the opportunity disappears (G1, TA25). Finally, breakdowns also occur at the level of feedback, where players are unable to interpret whether an action has succeeded or how the system state has changed (G1, TA24). Conversely, when audio supports actionable understanding, players move through the environment with significantly higher independence.

Key Tensions in Audio-Based Interaction

The interaction loop is mediated by two central tensions: **Accessibility vs. Challenge** and **Automation vs. Agency**. Our data shows that players value *meaningful challenge* when it is grounded in interpretable information. In *The Last of Us*, the player described the difficulty of finding hidden trophies as highly rewarding precisely because the items are not explicitly marked (G2, TA54). If these challenges were removed via automation, the sense of achievement would disappear. The difficulty transitions into frustration only when the interaction loop is broken by missing information, turning a test of skill into an unfair external barrier.

A second tension exists between *automation and agency*. While features like GPS-guided navigation and auto-aim are essential for progression, they risk shifting the player from an active agent to a passive follower. Players frequently utilize automation to manage low-level tasks, such as a horse automatically following a path (G1, TA32). However, they also express a need to regain control for high-level decision-making, such as turning off navigation assistance to explore optional areas. Successful design must therefore ensure that accessibility features function as a support for the player's intent rather than a total substitution of their agency.

5. Discussion

While our study examines mainstream titles rather than VR-specific environments, the results have implications for non-visual immersion in VR. Presence is traditionally defined by Mel Slater through two components: Place Illusion (PI), the sensory feeling of being in a space, and Plausibility Illusion (Psi), the belief that events in that space are actually occurring [Slater (2009)]. Accessibility research has largely focused on PI by ensuring that blind players can perceive environmental elements [Yuan et al. (2011)]. However, our data suggests that for blind users, presence is a functional achievement rooted in interactional fidelity: the seamless completion of the interaction loop.

When this loop is disrupted, presence breaks down. Failures in perceiving affordances, forming actionable understanding, executing inputs, or interpreting feedback shift the player's focus away from the virtual environment and toward troubleshooting the interaction itself. As a result, players transition from situated actors within the virtual world to managing the interface, undermining the plausibility of the experience.

We argue that the design of inclusive immersive systems must extend beyond high-fidelity 3D audio. Psi is sustained not only by how a world sounds, but by how reliably it responds to a player's agency. Supporting a continuous and responsive interaction loop is therefore important for enabling blind players to maintain a consistent and meaningful sense of presence in virtual environments.

6. Conclusion

This paper presented an exploratory qualitative analysis of how audio supports interaction for six blind players in digital games. By examining think-aloud and observational data, we identify a four-stage interaction loop: affordance, actionability, execution, and feedback. Our findings show that breakdowns arise not only from missing sensory information, but also from failures in actionability, execution, and feedback.

The tensions between accessibility and challenge, and between automation and agency, further show that meaningful interaction depends on balancing system support with player independence. Players do not seek the removal of difficulty, but the actionable information needed to overcome it. We introduce interactional fidelity as a pre-requisite for maintaining plausibility in non-visual immersive systems, arguing that the virtual world remains meaningful when the interaction loop is continuous and responsive to the player's intent.

As ongoing work, these findings provide a foundation for a broader interactional framework for audio-based interaction. We will next analyze interviews with the six recorded participants and three additional blind participants who participated in interviews only. This analysis will be compared with the findings from the gameplay recordings to examine whether the current dimensions are reinforced or whether additional dimensions emerge. Finally, the resulting framework, with dimensions mapped onto the interaction loop, will be translated into a questionnaire-based instrument to support systematic evaluation and design of audio-based interaction in games and immersive systems.

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Beyond Control: Access, embodiment, and therapeutic interaction in VR for older adults – insights from a co-design workshop

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Abstract

This paper examines interaction design challenges in virtual reality (VR) therapeutic applications for older adults in geriatric and palliative care. Drawing on a co-design workshop with six clinical psychologists, the study explores how interaction unfolds across the full trajectory of therapeutic VR use – from preparation and onboarding through immersion to post-session reflection. The findings reveal that interaction emerges through the ongoing negotiation of diverse embodied conditions, therapeutic mediation, and clinical environments. Informed by disability studies and critical access perspectives, the paper argues that therapeutic VR systems actively shape conditions of participation, autonomy, and engagement, advancing an understanding of participation as a situated, interdependent, and care-dependent achievement.

1. Introduction

Virtual reality (VR) is increasingly used in healthcare, particularly in mental health, pain management, and palliative care (Appel et al., 2021). Systematic review evidence suggests that VR interventions in palliative care are feasible, generally well tolerated, and associated with improvements in pain, psychological well-being, and emotional distress, though evidence remains methodologically limited and highly heterogeneous across technologies, intervention formats, and clinical contexts (Mo et al., 2022; Moloney et al., 2023). For older adults which we define as individuals aged 65 years and above, in line with standard gerontological usage, VR offers access to otherwise unreachable environments and the possibility of influencing affective and psychological states (Li et al., 2024). Engagement with immersive technologies is shaped by perceptions of autonomy and control, both of which may be affected by age-related changes in health and everyday functioning (Langer & Rodin, 1976; Bandura, 1977). VR interventions are frequently framed as tools for restoring agency, however we cannot predict whether interaction will be successful, especially for users with limited prior experience with immersive technologies (Huygelier et al., 2019; Saredakis et al., 2020). In therapeutic VRinteraction unfolds within complex relations between users, systems, and care environments. Implementation studies (Kouijzer et al., 2023) point out that organisational resources, staff training, workflow integration, and local infrastructures all influence how VR is introduced and sustained in healthcare settings. This paper examines how interaction emerges in practice through a co-design workshop with clinical psychologists working with older adults in geriatric and palliative care. Drawing on disability studies and critical access scholarship (Hamraie, 2017; Titchkosky, 2011; Garland-Thomson, 2011; Jain & Bayerlein, 2026), the paper argues that therapeutic VR systems actively configure participation – embedding assumptions about bodies, perception, and control that shape who can engage and how.

2. Methodology and workshop context

As this study is qualitative and exploratory in design, we conducted an exploratory co-design workshop with six clinical psychologists (all women, mean age approximately 45) who have more than ten years of clinical practice and direct experience using immersive VR with older adults. All held specialist qualifications in clinical psychology and had incorporated VR into their practice on an exploratory basis without formal VR-specific training. Participants used HMD-based immersive VR, including commercially available applications, 360-degree video experiences, and in one case self-recorded nature videos, to support relaxation, reminiscence, and therapeutic engagement. The workshop was based on the method of narrative inquiry (Clandini & Connely 2000). It followed a structured co-design process, recognising participants as domain experts in the generation of design-relevant knowledge (Sanders & Stappers, 2008; Ng et al., 2024). It consisted of four phases: (1) mapping a typical VR therapy session; (2) identifying common barriers and breakdowns; (3) analysing these challenges through a multi-dimensional analytical framework developed by the first author (see Table 1); and (4) recalling situations in which VR had worked particularly well. Data were generated through guided group discussion, structured worksheets, and facilitated reflection. Workshop outputs were reviewed and synthesised to identify recurring barriers, enabling conditions, and interactional patterns. Given the small and contextually specific sample, the findings are exploratory and context-bound rather than generalisable.

Dimension	**What it captures**	**Example issues from workshop**
Communication	Understanding instructions, therapist– patient interaction	Lack of shared vocabulary (e.g. "controller"); verbal guidance difficult without screen mirroring
Cognition	Memory, attention, comprehension	Interaction logic not adapted to varied prior experience; multistep structures create confusion
Technology	System performance and usability	Calibration errors, crashes; unstable internet; video lag; device not properly configured
Body position	Physical posture and stability	Device design does not accommodate non-seated positions or postural variability; dizziness risk
Interaction	Input methods and control	Difficulties using controllers; unclear interaction affordances; discomfort with navigation
Emotional responses	Affective reactions	Anxiety, frustration due to technical delays; fear in unexpected situations

Social/ therapeutic support	Role of therapist	Continuous facilitation required; therapeutic mediation integral to interaction; loss of connection without mirroring
Physical comfort	Sensory and bodily comfort	Headset weight and fit not designed for diverse body sizes; fatigue from extended wear
Infrastructure/ context	Spatial, temporal, and organisational conditions	Lack of dedicated space; long setup time; limited time for session and reflection

Table 1: Multi-dimensional analytical framework of VR therapy use in clinical contexts.

3. Findings

3.1. Interaction as relational achievement

The workshop revealed that interaction in therapeutic VR is not given, but must be continuously achieved. The multi-dimensional framework highlights how therapeutic VR use unfolds through embodied, relational, and infrastructural conditions that shape participation, access, and therapeutic engagement. Breakdowns frequently occurred in relation to headset placement, controller use, physical stability, misunderstood instructions, and fatigue or dizziness. This indicates that interaction depends on the alignment of diverse embodied conditions, system design, and contextual support. Such breakdowns reflect normal conditions of use, extending beyond the immediate interaction moment to include preparation time, device setup, and infrastructural constraints, often introducing friction before engagement could even begin. Participants described numerous situations in which interaction could not begin until organisational and bodily preconditions were in place. One participant noted that group-based sessions, while therapeutically valuable, were rarely feasible due to insufficient staffing: there were simply not enough ward staff available to move patients to a shared space. Another highlighted that CBT-based relaxation techniques (cognitive behavioural therapy) were difficult to implement because the hospital environment offered neither privacy nor appropriate space. Both accounts suggest that interaction in therapeutic VR is shaped well before the headset is placed on the patient.

3.2. Tension between control and presence

Interaction was organised through competing logics. A first logic emphasises control, task completion, and goal-oriented action – the dominant paradigm in many VR systems. A second logic, highlighted by participants, centres on presence, sensory immersion, and affective engagement: nature-based environments and calm atmospheres were valued not for enabling action, but for supporting relaxation and emotional connection. A third logic emerges at the level of infrastructure and mediation: physical constraints, technical contingencies, and institutional conditions shape the therapeutic session before it has even begun.

Participants drew a consistent distinction between task-oriented and experiential engagement. Several emphasised that VR activity without a clear therapeutic goal was perceived as ineffective: "VR activity is not effective if it has no goal." At the same time, the most meaningful therapeutic responses often arose not from task completion but from ambient, emotionally resonant experiences – a patient watching personal photographs in a virtual cottage, or moving through a forest environment that invited reflection on different life stages. In these cases, presence and emotional connection proved to be the primary therapeutic mechanisms, not interaction in the conventional sense of system control.

3.3. Autonomy as design-dependent

Autonomy emerged not as an individual capacity but as a condition that needed to be actively restored and scaffolded through design. One participant described working with oncology patients whose sense of control had been severely diminished by illness: the therapeutic goal was to identify and amplify whatever domains of control remained, even where control over the illness itself was no longer possible. Another participant described a VR task in which patients were placed in an unfamiliar environment and invited simply to decide whether they wanted to stay or leave, where this framing choice itself is a therapeutic intervention. A recurring theme was the importance of giving patients responsibility: caring for a virtual animal, tending to a plant, or making decisions within the virtual environment. These examples suggest that autonomy in therapeutic VR is less about interface control and more about the restoration of a sense of agency within a constrained clinical reality.

4. Critical interpretation

The findings highlight the limits of control-oriented interaction models in therapeutic VR. While HCI has traditionally prioritised efficiency and usability, these frameworks do not fully capture the embodied and relational nature of interaction in clinical contexts (Hornbæk & Oulasvirta, 2017). This limitation can also be understood through the concept of technoableism (Shew, 2020), which describes a broader cultural and design logic in which technologies are framed as empowering solutions for disability while simultaneously reproducing normative assumptions about desirable bodies, functioning, and participation. Ability-based design offers an important perspective by emphasising adaptation to users' situated capacities and recognising diversity in how interaction is achieved (Wobbrock et al., 2011). Disability studies extends this perspective by directing attention to the relational conditions through which exclusion emerges. Difficulties often arise through mismatches between bodies and systems organised around idealised assumptions about perception, movement, communication, and control (Garland-Thomson, 2011; Titchkosky, 2011). These can be further approached through perceiving access as a relational and political condition shaped through social, material, and institutional arrangements (Hamraie, 2017). In therapeutic VR for older adults in hospitalized care settings, access encompasses usability, opportunities for different forms of engagement, the possibility of non-performance, and recognition of embodied variability. This understanding aligns with broader European policy frameworks that position accessibility as a fundamental condition for equal participation and inclusion (AccessibleEU Consortium, 2024). A recurring theme across participants' accounts was the concept of ‘learned helplessness’, which is the progressive withdrawal of agency that occurs when patients repeatedly experience their actions as ineffective or irrelevant. This dynamic, well documented in gerontological and clinical contexts (Langer & Rodin, 1976; Bandura, 1977), was identified by participants as one of the central challenges that therapeutic VR might address, not through task performance, but through the restoration of meaningful choice and consequential action within the virtual environment. Therapeutic VR can therefore be understood as an interaction ecology in which participation emerges through the ongoing negotiation of situated embodiments, technological systems, therapeutic practices, and clinical infrastructures.

5. Design implications

The findings point to a need to rethink dominant interaction paradigms in therapeutic VR for older adults in geriatric and palliative care settings. Systems should support open-ended forms of engagement that allow participation at different paces and through different modes of interaction. Alternative input methods, including gaze-based selection, voice interaction, simplified one-button controls, therapist-assisted interaction, and passive immersive experiences, may better accommodate the diverse bodily, cognitive, and sensory conditions encountered in clinical practice. Reducing reliance on conventional hand-held controllers may broaden opportunities for participation across a wider range of users and care contexts. Design attention should therefore extend beyond the immersive experience itself and consider the wider therapeutic process in which VR is embedded. Preparation procedures, onboarding strategies, technical setup, therapist involvement, and opportunities for post-session reflection all influence the quality of participation and therapeutic engagement.

6. Conclusion

This paper examined how therapeutic interaction emerges in VR applications used with older adults in geriatric and palliative care settings. The study contributes to current discussions of therapeutic VR by drawing attention to the interdependent nature of participation. Clinical psychologists described therapeutic engagement as a process sustained through guidance, adaptation, interpretation, and negotiation between diverse embodied conditions, technological systems, and therapeutic goals. A further contribution lies in the methodological approach. By combining temporal process mapping with a multi-dimensional analysis of barriers and enabling conditions, the workshop framework made visible forms of therapeutic mediation, embodied adaptation, and infrastructural support that are often difficult to capture through conventional usability studies. Therapeutic VR is best understood as part of a wider ecology of care, in which more inclusive design and implementation depend on attention to the relationships among people, technologies, and clinical environments.

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Examining the Technology Experience Profile of Individuals with Disabilities from Sexual and Gender Diversity in Quebec, Canada

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Abstract

This study examined technology use among 30 people with disabilities identifying as LGBTQIA+ in Quebec, Canada. The sample demonstrated substantial diversity in gender identity, sexual orientation, and disability status. Participants showed moderate to high technology experience, with mean scores indicating competency to expert levels. Frequent use was reported for mobile phones, computers, email, and social media. Conversely, health-related technologies, such as blood pressure monitors, health management software, and medication reminder devices, were used less often. Findings suggest that people with disabilities identifying as LGBTQIA+ may prioritize technologies that support communication, connection, and socialization over those focused solely on health management.

1. Introduction

People with disabilities who identify as lesbian, gay, bisexual, transgender, queer/questioning, intersex, asexual, and other sexual orientations and gender identities (PD-LGBTQIA+) encounter multiple challenges to social participation stemming from the intersections of different systems of inequality. Technology can create safer spaces and offer different possibilities to increase social participation of this community. The literature on LGBTQIA+ populations has largely focused on how technology can foster identity development, relationships, and social supports (Berger et al., 2021). In contrast, research on disabled people has tended to center on assistive technologies designed to compensate for function loss and support interaction with others, such as hearing aids, canes, and screen readers (Crawford et al., 2023). Yet assistive technology is not limited to specialized devices; everyday technologies, including smartphones, can also function as important forms of assistance and access (Barbareschi et al., 2019). However, little is known about technology use among PD-LGBTQIA+. For some disabled people, even widely used technologies, such as smartphones, can be inaccessible because of cost (Scherer, 2005). Even LGBTQIA+ disabled individuals who have access to technology often hesitate to use it due stigma, including within LGBTQIA+ digital spaces (Crawford et al., 2023).

The objective of this study is to describe the familiarity with, and experiences of, PD-LGBTQIA+ with different technologies in Quebec, Canada. This knowledge is crucial to improve their social participation.

2. Methods

2.1. Participants

A total of thirty French-speaking PD-LGBTQIA+ (mean age = 38.7 years, SD = 13.6) took part in the study. As shown in Table 1, the sample was highly diverse regarding gender identity, sexual orientation, and disability status. Most participants were born female (73.4%), identified as a cisgender woman (28.6%) or as gender fluid or non-binary (31.4%). The most common sexual orientations were queer (21.5%), lesbian (19.6%) or pansexual (19.6%). Most participants were White (83.3%), had pursued higher education (70%), were single (66.7%), and were physically disabled (53.3%). Examples of physical disabilities include motor, visual, and hearing impairments, while mental disabilities included autism spectrum disorder, posttraumatic stress disorder, and adult attention deficit hyperactivity disorder.

Sex at birth, n (%)	
Female	22 (73.4)
Male	7 (23.3)
Prefer not to answer	1 (3.3)
Gender identity, n (%)	
Cisgender woman	10 (28.6)
Cisgender man	4 (11.4)
Transgender woman	1 (2.9)
Transgender man	3 (8.5)
Gender fluid or non-binary	11 (31.4)
Does not know	1 (2.9)
Other	5 (14.3)
Sexual orientation, n (%)	
Asexual or aromantic	3 (5.9)
Bisexual	8 (15.7)
Homosexual or Gay	4 (7.8)
Lesbian	10 (19.6)

Pansexual	10 (19.6)
Queer	11 (21.5)
Demisexual	3 (5.9)
Abrosexual	1 (2)
Two-spirit	1 (2)
Race/Ethnicity, n (%)	
Black	1 (3.3)
Middle Eastern	1 (3.3)
White	25 (83.3)
Other	3 (10)
Education, n (%)	
Secondary school diploma	6 (20)
Registered apprenticeship or trade certificate/diploma	1 (3.3)
College or other non-university certificate/diploma	9 (30)
Undergraduate degree or some university education	6 (20)
Postgraduate degree or professional designation (e.g., Master's, PhD, MD)	6 (20)
Special education school	2 (6.7)
Marital status, n (%)	
Married	1 (3.3)
Common law	7 (23.3)
Single	20 (66.7)
Divorced	2 (6.7)
Type of disability, n (%)	
Physical disability	16 (53.3)
Mental disability	6 (20)
Both physical and mental disabilities	8 (26.7)

Table 1: Participants' sociodemographic characteristics (N = 30).

2.2. Measures

The Technology Experience Profile (TEP) is a self-reported questionnaire of 36 questions addressing individuals' familiarity and experience with different technologies over the past 12 months (Barg-Walkow et al., 2014). For each technology, participants were asked to rate on a five-point scale how much they have used the technology in the past year (1 = not sure what it is, 2 = not used, 3 = used once, 4 = used occasionally, 5 = used frequently). The technologies are separated into six categories: a) Communication technology, b) Computer technology, c) Everyday technology, d) Health technology, e) Recreational technology, and f) Transportation technology. A version in French was used in this study. The total possible score ranges from 36 to 180. Individuals' scores correspond to different levels of technology experience as follows: a) « Novice technology experience » with a score of 36 to 54, b) « Novice to beginner » with a score of 55 to 71, c) « Advanced beginner » with scores from 72 to 90, d) 'Advanced beginner to competent » with a score of 91 to 107, e) « Competent » with scores between 108 and 126, f) « Competent to expert » with a score of 127 to 143, and g) « Expert » with scores over 144. These categories complement those suggested previously (Hongyang, 2020). Also, the TEP revealed very good reliability through internal consistency (Cronbach's alpha $\alpha > .8$), inter-rater reliability (Cohen's Kappa $\geq .80$), and test-retest reliability showing stable scores over the study period (Cronbach, 1951; Harris & Rogers, 2023). Evidence of good content validity comes from experts in gerontechnology and user feedback involved in the formulation of the items (Harris & Rogers, 2023). A factor analysis proved the construct validity of the TEP, showing that the items grouped coherently with the subscales of each dimension (Harris & Rogers, 2023). Concurrent validity with the Technology in Caring Questionnaire showed strong and positive correlations ($r = .578$, $p < .001$) and good criterion validity (Kiselica et al., 2024).

2.3. Procedure

The current study was approved by the Research and Ethics Board of the CCSMTL. Participants were recruited through community services and networks serving disabled people and individuals of diverse sexual orientations and gender identities, using posters, emails, and radio announcements. To be eligible, participants had to be non-heterosexual, be at least 18 years old, report having a diagnosis of a permanent physical or mental disability, and be able to provide consent. Interviews were conducted by members of the research team in person or via Zoom. When needed, a translator was invited to support individuals with hearing or communication disabilities. Participants completed the TEP based on their previous experiences with different technologies and received CAD$50 in compensation for their participation.

3. Results

The mean total score suggests that the cohort falls between the competent and expert levels in terms of technology use ($M = 136.5$, $SD = 13.6$). Indeed, most participants scored between 144 and 162 ($n = 12$, 40%). As higher scores indicate more frequent use of technology, these results may suggest that participants in our sample were relatively proficient (Hongyang, 2020). Table 2 presents the descriptive statistics of the sample's technology experience. An average of 3.8 ($SD = 0.4$) on the scale indicates that most of them are occasional technology users. Descriptive analysis revealed that the lowest level of technology use included health technologies ($M = 3.0$, $SD = 0.7$), transportation technologies ($M = 3.4$, $SD = 0.7$), and recreational technologies ($M = 3.7$, $SD = 0.6$). The highest levels of technology were in areas of computer technologies ($M = 4.5$, $SD = 0.4$), followed by communication technologies ($M = 4.2$, $SD = 0.4$), and everyday technologies ($M = 3.9$, $SD = 0.4$). Mobile phones ($M = 4.8$, $SD = 0.6$), computers ($M = 4.8$, $SD = 0.6$), email ($M = 5.0$, $SD = 0.0$), and social media ($M = 4.9$, $SD = 0.3$) were used frequently. In contrast, technologies such as blood pressure monitors ($M = 2.8$, $SD = 1.1$), health management software (e.g., for diet and exercise) ($M = 3.0$, $SD = 1.4$), and medication reminder devices ($M = 3.0$, $SD = 1.3$) were used less often, with mean ratings corresponding approximately to "used once."

TEP Domains	Mean (SD)	Min	Max
TEP Total Score	3.8 (0.4)	2.9	4.4
Communication technology	4.2 (0.5)	2.8	5
Computer technology	4.5 (0.4)	3.5	5
Everyday technology	3.9 (0.4)	3.2	4.5
Health technology	3.0 (0.7)	2	4.7
Recreational technology	3.7 (0.6)	2.3	4.5
Transportation technology	3.4 (0.7)	2.3	4.7

Table 2: Participants' mean scores for the Technology Experience Profile categories (N = 30).

4. Discussion

We have described familiarity with, and experiences of, different technologies among a group of 30 PD-LGBTQIA+ in Quebec, Canada. In this sample, the lowest level of technology use were reported for health, transportation, and recreational technologies, whereas the highest levels were found for computer, communication, and everyday technologies. These findings are notable given that the sample primarily consisted of individuals with physical disabilities (53.3%), for whom health-related technologies might be expected to play a more prominent role. This is not surprising, as Barbareschi et al. (2019) suggest that communication and computer technologies can function as assistive technologies for disabled people. Other studies have also shown that technology plays a role in sexuality and in the pursuit of romantic relationships (Crawford and Hamidi, 2025; Patel et al., 2025). These findings suggest that PD-LGBTQIA+ may prioritize technologies that facilitate social connection over those designed for health-related purposes. This preference could be leveraged to promote social participation, particularly within LGBTQIA+ spaces, by using technology to foster inclusion, engagement, and community building. However, as this was not directly measured in the study, this interpretation should be treated with caution. Lower use of health-related technologies may also reflect lack of access, cost, lack of perceived need, accessibility barriers, stigma, or differences in disability type and health status. LGBTQIA+ individuals with disabilities can experience higher rates of poverty and underemployment, which prevents them from purchasing many health technologies, such as specialized Apps, telemedicine hardware, and wearable monitors. Those technologies are prohibitively expensive and may not be covered by insurance. Accessibility barriers can also be a potential explanation. Digital tools and health platforms are frequently designed without considering the needs of users with sensory or cognitive disabilities, including lack of screen-reader compatibility, complex navigation, or insufficient accommodations. Many LGBTQIA+ people with disabilities may not feel the need to use health technologies. Given that frequently health technologies are often developed with a "one-size-fits-all" approach that ignores intersectional identities., these tools are rarely tailored for LGBTQIA+ people with disabilities. Finally, the specific type of disability and overall health status may have an influence in technology experience. For instance, individuals with chronic fatigue or mobility challenges may rely heavily on telemedicine, while others may find certain technologies incompatible with their physical or mental health conditions.

5. Conclusion

This study aimed to describe the technology experiences of PD-LGBTQIA+. We found that health technologies were often reported as being used only occasionally, whereas computer and communication technologies were used more frequently. These findings carry important implications. On the one hand, they highlight the importance of technology in the lives of PD-LGBTQIA+, particularly as a means of facilitating social participation through connections with online communities. On the other hand, they also point to how technology can act as a barrier to social participation, including through stigma surrounding its use. However, the present study has several limitations: a small sample size, a mostly White and highly educated sample, and a focus on a limited geographical area, which restricts generalizability. These findings are therefore exploratory and descriptive. Considering the sample characteristics, the findings must be considered as exploratory and descriptive, rather than as evidence of broader patterns.

Future research should examine differences in technology use across disability groups within PD-LGBTQIA+ populations and consider the influence of living environments, such as urban and rural settings. To enhance social participation through technology, it is important to involve PD-LGBTQIA+ in the co-design of new technologies and better understand their perceptions and lived experiences of technology use. This could be achieved by following the notion of "radical accessibility" in co-design, which embraces intersectional experiences and creates a space that aims to provide safety, allowing participants to define the terms of their own participation and needs (Drysdale et al., 2026). Overall, technology represents both a challenge and an opportunity, making its inclusive development crucial to supporting social participation among PD-LGBTQIA+.

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11

EDUCATION & PEDAGOGY

Student-Developed Podcasts as an Accessible Pedagogical Model for Teaching Rehabilitation Technologies

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Abstract

Emerging technologies such as virtual reality (VR), augmented reality (AR), and artificial intelligence (AI) are transforming rehabilitation, yet integrating these rapidly evolving topics into undergraduate curricula remains challenging. This paper presents a Universal Design for Learning (UDL)-informed pedagogical model that uses student developed podcasts to support learning about rehabilitation technologies in an undergraduate motor control and learning course. Students critically evaluate evidence related to a selected rehabilitation technology, synthesize findings regarding its application in rehabilitation practice, and communicate those findings to a broad audience through an interview-style podcast and transcript. The assignment promotes science communication, critical appraisal, and knowledge translation by requiring students to translate complex scientific concepts into accessible language for broad, non-specialist audiences. As a multi-modal assessment strategy, the model provides alternative pathways for demonstrating knowledge while supporting competencies relevant to evidence-based rehabilitation practice. The approach offers a practical and transferable framework for integrating emerging technologies into rehabilitation and health sciences curricula.

1. Introduction

Emerging technologies including virtual reality (VR), augmented reality (AR), and artificial intelligence (AI) are increasingly used in rehabilitation and assistive technology applications. Integrating these rapidly evolving technologies into undergraduate curricula requires instructional approaches that support critical evaluation of evidence and effective communication of complex concepts. Podcasting is particularly well suited to these topics because it requires students to synthesize research, translate technical information for non-specialist audiences, and communicate practical implications. Unlike traditional assignments that primarily prepare students to communicate with instructors or other professionals, podcast development emphasizes science communication and knowledge translation for broader community audiences. These communication skills support scientific literacy and align with critical appraisal and knowledge translation competencies central to evidence-based rehabilitation practice (Kaur, 2022; Almendingen et al., 2021).

2. Pedagogical approach

The aim of the podcast assignment is for students to critically evaluate evidence related to a selected rehabilitation technology, synthesize findings from the research literature regarding its applications in rehabilitation practice, and communicate those findings through an accessible podcast for a broader audience. Podcasting is particularly well suited to rehabilitation technologies because it requires students to synthesize evolving evidence, evaluate clinical applications, and translate complex scientific concepts into language accessible to patients, families, and community audiences.

The pedagogical model for this podcast assignment is grounded in Universal Design for Learning (UDL), which emphasizes proactive instructional design that provides multiple means of engagement, representation, and action and expression (CAST, 2024). Engagement was supported through student-selected rehabilitation technology topics, self-selected groups, peer discussion, and iterative instructor feedback, allowing students to connect learning to their interests while participating in collaborative inquiry. Representation was fostered through engagement with peer-reviewed literature, research summaries, class discussion, and podcast transcripts, providing multiple formats for accessing and organizing information. Action and expression were addressed through the creation of an interview-style podcast and transcript, enabling students to demonstrate understanding through multimodal communication rather than traditional writing-intensive assessments. Together, these components support critical evaluation of evidence, science communication, and knowledge translation skills relevant to evidence-based rehabilitation practice.

Shifting assessment from writing-intensive assignments to multimodal production may reduce barriers for students with chronic pain or fatigue associated with prolonged writing tasks. Flexible pacing and location independence support participation through mobility accommodations and preferred work environments. As an inclusive design strategy, podcast production also provides alternative ways for students to demonstrate knowledge (Kushwaha & Kushwaha, 2025).

3. Assignment design

Students worked in self-selected groups to investigate a rehabilitation technology topic of interest, such as VR, AR, or AI applications in rehabilitation. The assignment consisted of five stages: (1) topic development, including class presentation, peer and instructor feedback; (2) research development through the identification and synthesis of six peer-reviewed articles; (3) creation of a 12-minute interview-style podcast and accompanying transcript intended for a broad audience; (4) instructor review and feedback on the podcast and transcript; and (5) group discussion.

Assessment emphasized evidence synthesis, critical evaluation of rehabilitation applications, communication of findings to non-specialist audiences, and participation in collaborative discussion. This staged design provided multiple opportunities for feedback, reflection, and knowledge translation while supporting the development of evidence-based practice skills. Example podcast topics included VR for stroke rehabilitation, AR for gait training for Parkinson's disease, and AI-enabled robotic gait therapy for stroke.

4. Pedagogical outcomes and implications

The podcast assignment supports the development of critical appraisal, science communication, and knowledge translation skills relevant to evidence-based rehabilitation practice. By requiring students to identify, synthesize, and communicate research findings related to emerging rehabilitation technologies, the assignment encourages critical evaluation of evidence rather than passive acquisition of technical knowledge. Communicating findings to non-specialist audiences further promotes scientific literacy and provides opportunities for students to translate complex concepts into accessible language for patients, families, and community members. This approach is consistent with emerging evidence that student-created podcasts can enhance subject understanding, engagement, and peer connections while promoting active participation in the learning process (Hernandez-Lopez & Mendoza-Jimenez, 2025). As emerging technologies continue to shape rehabilitation practice, instructional approaches that integrate evidence appraisal, science communication, and knowledge translation may help prepare students to critically evaluate new technologies and communicate their implications across diverse audiences. The model may also be transferable to other rehabilitation and health sciences courses exploring rapidly evolving areas of practice.

5. Conclusion

Student-developed podcasts may provide an accessible and scalable pedagogical model for integrating rehabilitation technologies into undergraduate education. By engaging students in evidence synthesis, critical evaluation of rehabilitation applications, and communication for broad audiences, the assignment supports science literacy, knowledge translation, and competencies relevant to evidence-based rehabilitation practice. This approach offers a practical and transferable framework for rehabilitation and health sciences curricula.

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Teacher Perspectives on Social Virtual Reality for Remote School Participation: An Exploratory Study

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Abstract

Students experiencing emotionally based school non-attendance often lose not only instructional access but also regular social contact with school. This extended abstract reports an exploratory teacher study of a social virtual reality classroom for remote school participation. Three teachers tested the prototype and joined a facilitated focus group. Reflexive thematic analysis identified three design requirements: low-pressure participation, embodied social presence, and strong teacher orchestration within hybrid workflows. Teachers also noted possible relevance for later re-engagement with school routines, but that remains a hypothesis for future work.

1. Introduction

Emotionally based school non-attendance is associated with anxiety, contextual pressures, and diverse learning needs, and often leads to a progressive loss of contact with both teaching and peer relationships (Leduc et al. 2024). In this paper, we use the term emotionally based school non-attendance to foreground participation difficulty rather than intentional refusal. For these students, the practical problem is rarely access to curriculum alone. It is participation: joining class, feeling able to remain there, and reconnecting with teachers and peers without immediately facing the full demands of physical attendance.

Conventional remote learning tools preserve access to instruction, but they often reduce classroom interaction to a narrow set of visual and verbal cues. Prior work on telepresence and immersive education suggests that richer forms of mediated presence may support connection, but also introduce new demands around orchestration, usability, and teacher workload (Fletcher et al. 2023, Di Natale et al. 2020, Glawogger et al. 2025). Social virtual reality is relevant here because embodied avatars, spatial audio, and shared manipulable objects can create a stronger sense of being together in the same learning space (Riva et al. 2019, Hutson 2022).

The present work examines *ReEngage VR Classroom*, a prototype virtual classroom for synchronous remote participation. The goal is not to claim educational effectiveness from a small qualitative study. Instead, the goal is to identify how teachers understand the value, limits, and design requirements of social virtual reality for remote school participation in contexts of attendance difficulty.

2. Background and research questions

Prior studies show that immersive virtual reality can improve engagement and motivation in education, but the evidence also points to recurring constraints: onboarding effort, discomfort, content-production overhead, and the need to align immersive activities with existing pedagogy rather than replace it (Di Natale et al. 2020). Teacher-oriented platforms such as TeachInVR and VRTeaching demonstrate that classroom-focused virtual environments can support slide presentation, spatial organisation, and shared interaction, while also revealing practical challenges such as mental demand and the need for careful lesson orchestration (Schier et al. 2022, Glawogger et al. 2025).

This is especially important for students whose school participation is already fragile. Research on school anxiety indicates that virtual environments can provide controlled, lower-pressure encounters with school-relatedsituations, but the educational use case remains distinct from therapeutic exposure: teachers need environments that support social connection, pacing, and everyday classroom management rather than stand-alone treatment sessions (Beele et al. 2024). Our design rationale therefore combined three ideas from prior work: social presence through embodied interaction (Riva et al. 2019, Hutson 2022), low-friction reuse of familiar teaching materials (Schier et al. 2022, Glawogger et al. 2025), and a complementary role for immersive learning within broader school workflows (Di Natale et al. 2020).

The study addressed two research questions: how do teachers perceive the pedagogical value of social virtual reality for remote participation by students experiencing emotionally based school non-attendance, and what design requirements do they identify for making such environments workable in practice?

3. Prototype and study

The prototype was a multiplayer virtual classroom that combined networked avatars, spatial voice communication, and a small set of shared classroom artefacts. These included slide presentation, a timer, and manipulable objects that could be used for explanation, pacing, and informal interaction. The prototype was intentionally framed as a bridge technology: a place for discussion, orientation, and social contact, not a complete replacement for desktop-based schoolwork.

Three teachers from Nymarkskolen, a public school in Slagelse, Denmark, tested the system and then participated in a facilitated focus group. The sample was small, but the study aim was also narrow. Following the logic of information power in qualitative sampling, we treated the focus group as an early requirement-elicitation exercise with domain experts rather than a basis for generalisable claims (Malterud et al. 2016). The session therefore prioritised practitioner insight over breadth. Before the discussion, participants completed a short exploratory demonstration of the virtual classroom together, allowing them to experience its core features and interactions firsthand.

The focus group concentrated on four topics: where virtual participation might be useful for students with emotionally based school non-attendance, which classroom interactions felt educationally meaningful, which risks or barriers teachers anticipated, and what teacher controls would be required for real use. The discussion was recorded and transcribed using a locally deployed instance of WhisperX (Bain et al. 2023), an open-source automatic speech recognition toolkit. The transcript was subsequently reviewed and corrected by the first author before being coded using reflexive thematic analysis (Braun & Clarke 2006); single-coder analysis is a recognised limitation, but it is consistent with the exploratory, requirement-elicitation framing of the study rather than a claim to theoretical saturation. The analysis looked for recurring patterns in how participants described participation, social connection, classroom management, and integration with existing school practice.

Figure 1: Screenshot of the VR Classroom prototype showing student avatars and interactive objects used to support synchronous remote classroom participation.

4. Findings

Teachers consistently described the virtual classroom as a low-pressure way of reconnecting students with school participation. Because the student could join from home while still entering a shared school-like space, teachers saw the prototype as a practical middle ground between absence and full physical attendance. This was considered especially relevant for students who may want contact with school but struggle with the sensory, social, or emotional demands of being physically present for an entire day. This suggests that the environment should support easy entry, temporary withdrawal, and re-entry without making the student feel that they had failed the session.

The second theme concerned embodied social presence. Participants repeatedly contrasted the prototype with videoconferencing tools, arguing that shared space, avatar embodiment, and object-based interaction would make it easier to establish rapport and maintain attention. The value was not realism for its own sake. Rather, teachers cared about readable cues: who is present, who is speaking, where attention is directed, and how informal interaction can help rebuild trust. This aligns with previous arguments that embodiment in social virtual reality may reduce some of the pressure of face-to-face interaction while preserving a sense of togetherness (Hutson 2022, Riva et al. 2019).

At the same time, teachers were explicit that social presence alone would not make the system educationally usable. A third theme was the need for strong teacher orchestration. Participants wanted to preserve playfulness because it could lower barriers and support relationship building, but they also wanted clear mechanisms for pacing activities and reducing overstimulation. In practice, this meant asking for functions such as muting, limiting movement, controlling object availability, and transitioning cleanly between open interaction and focused instruction. Teachers also emphasised that virtual reality would work best when part of a hybrid workflow. They imagined using the headset for welcome routines, discussion, and social reconnection, then shifting students back to familiar desktop tools for writing, complex notation, and longer individual tasks.

5. Discussion and conclusion

Addressing the first research question, teachers perceived the pedagogical value of social virtual reality primarily as a complementary participation layer rather than a replacement classroom. Compared with videoconferencing and telepresence approaches, they saw it as offering a stronger sense of shared space and relationship building, but considered that benefit worthwhile only if the environment remains manageable, low-pressure, and tightly connected to ordinary school routines (Fletcher et al. 2023, Glawogger et al. 2025). Addressing the second, the design requirements teachers identified are: support low-commitment entry and exit, prioritise readable embodied cues over visual complexity, give teachers direct control over pace and stimulation, and design for hybrid use rather than full virtual substitution.

These findings should be interpreted within the limits of an exploratory study with three teachers from one school. They do not show student outcomes, sustained adoption, or long-term educational benefit. They do, however, offer a clearly delimited contribution: an empirically grounded account of what teachers require from a social virtual classroom if it is to support remote participation for students experiencing emotionally based school non-attendance. Whether this kind of mediated participation later contributes to return-to-school processes remains for future longitudinal study.

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REPLICA: Development and Evaluation of an Immersive First-Person Simulation Platform for Psychiatric Education

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Abstract

Understanding the subjective experience of psychiatric disorders is challenging in clinical education. This study presents REPLICA, a virtual reality application simulating psychiatric symptoms from a first-person perspective. The system was evaluated across two student cohorts using an early prototype and an optimized version. Participants completed measures of usability (SUS), presence (IPQ), and simulator sickness (SSQ). Usability significantly improved in the optimized version, while presence remained stable. Cybersickness decreased, though not significantly. Qualitative responses confirmed that participants recognized key symptoms of the simulated disorders. These findings indicate that system improvements enhanced usability without reducing immersion, supporting VR as an effective tool for experiential psychiatric education.

1. Introduction

Understanding psychiatric disorders requires not only knowledge of symptoms but also insight into patients' subjective experiences, which are often difficult to convey through traditional teaching methods. The phenomenological approach emphasizes this first-person perspective, focusing on how individuals experience and interpret their condition (Jaspers, 1968), and is essential for fostering empathy and effective clinical care (Chandra et al., 2018). Immersive technologies such as virtual reality (VR) offer new possibilities for experiential learning by simulating psychiatric symptoms from a first-person perspective. Previous research has demonstrated that VR simulations, particularly of hallucinations, can enhance understanding and empathy (Ando et al., 2011; Marques et al., 2022), although they may also produce unintended effects if not carefully designed (Kalyanaraman et al., 2010). More recent studies highlight the importance of emotional engagement and narrative structure in improving learning outcomes (Hadjipanayi & Michael-Grigoriou, 2022; Lem et al., 2024).

To address limitations of existing applications, which are often restricted to single disorders, this study introduces REPLICA, a modular VR system designed to simulate a range of psychiatric conditions. Building on principles of perspective-taking (Davis et al., 1996) and prior development work (Sharma, 2023), REPLICA enables users to engage with simulated symptoms across multiple conditions from a first-person perspective. This study evaluates its usability, immersive qualities, and experiential impact in psychiatric education.

2. Methods

2.1. Study sample

The sample consisted of 157 university students from health-related disciplines (e.g., medicine, psychology, allied health) at different stages of training. Participants engaged with the REPLICA system as part of educational activities focused on psychiatry. Two cohorts reflected different stages of system development: an earlier group using the initial prototype from April 2023 to September 2024 and a later group using an optimized version with hand gestures and expanded simulation features from October 2024. All participants completed the simulations individually in immersive VR, followed by quantitative and qualitative evaluation.

Characteristic	Total Sample (N = 157)	April 2023 – Sep 2024 (n = 82)	Oct 2024 – April 2026 (n = 75)
Age (years) M (SD)	23.36 (2.51)	23.64 (2.66)	22.99 (2.42)
Range	18–40	19–40	18–36
Gender (n)			
Female	92	50	42
Male	65	32	33
Female/Male ratio	1.42	1.56	1.27

Table 1: Descriptive Characteristics of Study Participants by Study Cohorts (Periods).

2.2. REPLICA software & Apparatus

REPLICA is a modular virtual reality (VR) application designed for psychiatric education through immersive first-person simulation of mental health symptoms within realistic everyday environments. Using a head-mounted display (Meta Quest 2), users experience perceptual, cognitive, and emotional alterations from the perspective of a patient, enabling direct engagement with the subjective aspects of mental disorders. Technically, REPLICA is developed in the Unity engine and is based on a modular architecture, where individual symptoms can be independently configured and combined into presets representing specific disorders (e.g., mania, depression, and psychosis). Across system development, several key modifications were implemented to the original prototype. The virtual environment was scaled down from a large multi-floor house to a compact apartment, allowing better focus on individual rooms, easier navigation, and improved performance. User interaction was also refined: while the early prototype relied on handheld VR controllers for navigation (Sharma, 2023), the optimized version employs intuitive hand gesture-based control. In addition, auditory components were enhanced – moving from purely AI-generated voices to voice-to-voice AI synthesis, enabling more emotionally expressive inner speech and auditory hallucination-like experiences. Simulations combine task-based activities with symptom-driven alterations to illustrate how mental disorders affect daily functioning. Visual effects include changes in contrast and brightness, vignetting, distortions of shapes and space, and the appearance of hallucination-like elements (e.g., silhouettes, particles), which dynamically modify the perceived environment.

2.3. Measures

Usability, presence, and simulator-related discomfort were assessed using three standardized self-report instruments administered after the VR experience. The System Usability Scale (SUS) measured perceived usability, yielding a total score from 0 to 100. The Igroup Presence Questionnaire (IPQ) assessed immersion across general presence, spatial presence, involvement, and realism (mean score range -3 to +3). The Simulator Sickness Questionnaire (SSQ) evaluated cybersickness symptoms, including nausea, oculomotor discomfort, and disorientation (scale 0–3). In addition, participants provided open-ended responses describing experienced symptoms for each simulated condition (mania, depression, psychosis). These qualitative data were analyzed to capture perceived symptomatology and subjective experience of the simulations.

2.4. Statistical and qualitative analysis

Participants were divided into two cohorts based on system version: an early cohort (April 2023 – September 2024) and an optimized cohort (October 2024 – April 2026). For each measure (SUS, IPQ, SSQ), descriptive statistics (mean, standard deviation) were computed. Between-group differences were analyzed using independent samples t-tests. Statistical significance was evaluated at $p < .05$. In addition, to explore participants' subjective experiences, open-ended responses were analyzed using a qualitative frequency-based approach using ChatGPT 5.3. Representative symptom-related terms were extracted, standardized, and grouped into three categories corresponding to the simulated conditions: manic state, depression, and psychotic disorder. The relative frequency of each term was visually represented using proportional bubble sizes in a comparative diagram.

3. Results

3.1. Cohort differences for SUS, IPQ and SSQ

The System Usability Scale (SUS) scores indicated a significant improvement in perceived usability between system versions (see Fig.1). Students evaluating the optimized REPLICA system (October 2024–2026; $n = 75$, $M = 77.00$, $SD = 12.60$) reported significantly higher SUS scores than students evaluating the early system (January 2023–September 2024; $n = 82$, $M = 70.18$, $SD = 15.61$), $t(152.69) = 3.02$, $p = .003$, $d = 0.48$. According to established SUS benchmarks, the early version falls within the "Good" usability range, while the optimized version reaches high "Good" and approaches "Excellent" usability. Importantly, both cohorts exceeded the industry average threshold (68), indicating overall acceptable usability, with the optimized system demonstrating a clear shift toward higher and consistent usability. Analysis of the presence measure by IPQ revealed no significant differences between cohorts across all subscales (all $p > .05$). Descriptively, the optimized cohort reported higher general and spatial presence than the early cohort (general presence: $M = 0.90$, $SD = 1.25$ vs. $M = 0.29$, $SD = 1.59$; spatial presence: $M = 0.82$, $SD = 0.83$ vs. $M = 0.54$, $SD = 0.84$), while involvement and experienced realism were comparable. Overall presence remained stable across system versions (IPQ total: $M = 0.36$, $SD = 0.56$ vs. $M = 0.34$, $SD = 0.53$). SSQ cybersickness scores were lower in the optimized system cohort ($M = 0.47$, $SD = 0.34$, $n = 44$) than in the early cohort ($M = 0.63$, $SD = 0.50$, $n = 26$), although this difference was not statistically significant, $t(42.3) = 1.50$, $p = .141$. This pattern suggests a trend toward improved user comfort in the optimized system. Together with the improved usability scores and stable levels of presence, these findings indicate that the system refinements enhanced the overall user experience without compromising immersion.

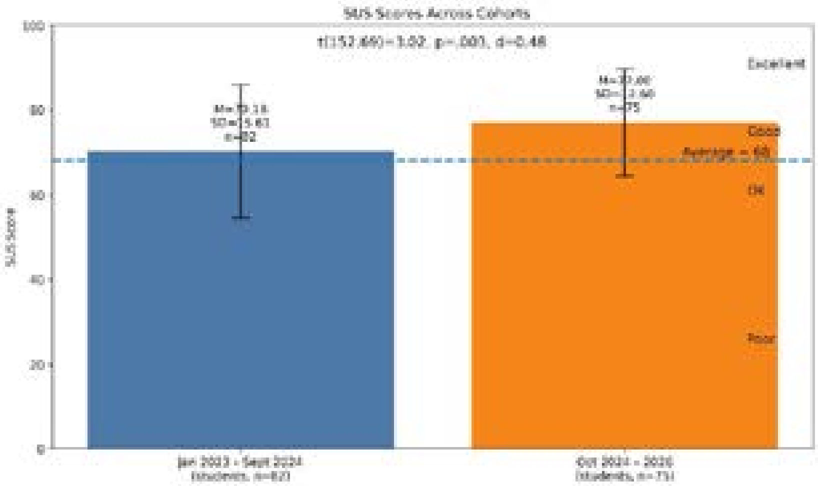

Figure 1: Comparison of SUS scores between student cohorts using the early and optimized versions of the REPLICA system. Error bars represent SD. Right side indicates SUS acceptability ranges and adjective ratings, a dashed line marking the industry average.

3.2. Qualitative Text Analysis of Reported Symptoms Across Simulated Disorders/States

Manic State was characterized by high activation and cognitive acceleration, with dominant features including excitability, increased energy, euphoria, and racing thoughts. Additional symptoms (e.g., impulsivity, irritability, reduced sleep) reflect heightened arousal and reduced behavioral control. **Depression** was defined by low energy and negative affect, with sadness, fatigue, and hopelessness most prominent. Other features (e.g., apathy, isolation, worthlessness) indicate emotional withdrawal and reduced motivation. **Psychotic Disorder** was marked by perceptual disturbances and impaired reality testing, primarily hallucinations and delusions, accompanied by fear, paranoia, and disorganized thinking. In summary, distinct patterns emerged across conditions: mania (high activation), depression (low energy and affect), and psychosis (perceptual distortion). The bubble visualization highlights dominant and condition-specific symptom clusters (see Fig. 2).

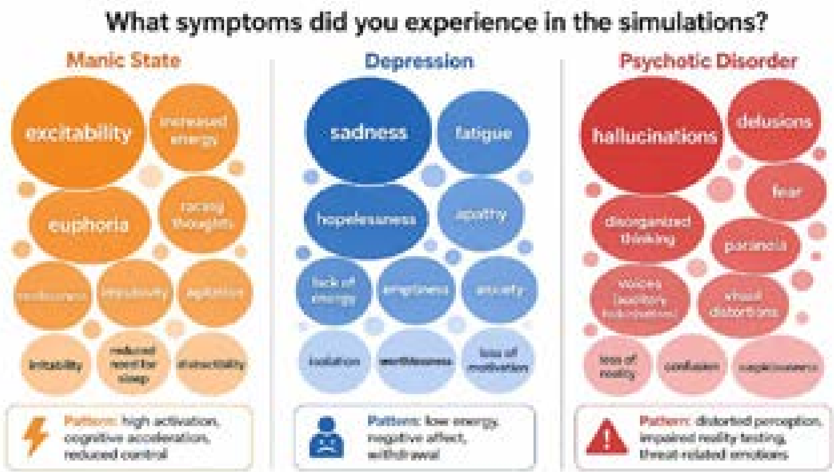

Figure 2: Visualization of the mostly reported symptoms, bubble size representing frequency.

4. Discussion

The comparison of cohorts testing the early prototype and the later optimized version of REPLICA indicates a clear improvement in usability, with the optimized version achieving higher SUS scores. This suggests that iterative refinements – particularly in interaction design and system structure – enhanced overall user experience. In contrast, presence (IPQ) remained stable across cohorts, indicating that the level of immersion was already sufficiently high in the early version, but could be potentially increased by implementation of more interactive tasks. For cybersickness (SSQ), the optimized cohort showed lower scores, indicating improved user comfort; however, this difference did not reach statistical significance. Together, these findings suggest that system development primarily enhanced usability while preserving immersion and contributing to a more comfortable user experience. These findings reinforce the value of iterative development and usability-driven design, particularly in immersive VR systems where interaction complexity can otherwise hinder learning outcomes.

The findings of the qualitative text analyses demonstrate that participants clearly differentiated between simulated mental states, with each condition producing a distinct experiential pattern. Mania was characterized by intensity and activation, with concentrated dominant features. Depression showed a diffuse, multidimensional structure, reflecting the complexity of depressive experience. Psychosis was defined by perceptual distortion and threat-related cognition, with a few highly salient symptoms. Importantly, the patterns align with clinical descriptions, suggesting that the VR simulations successfully conveyed core phenomenological aspects of each disorder. Based on these results REPLICA provides a flexible and scalable platform for experiential, phenomenologically oriented learning in psychiatric education.

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