# VR and AR for Reactive Stepping Exercises: A Comparative Feasibility and Acceptability Study in Elderly with Vestibular Dysfunction

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Figure 1: Conceptual illustration of balance and reactive stepping training for older adults, reflecting the design approach of our VR/AR rehabilitation experience (Generated with ChatGPT)

## Abstract

This study explores the comparative use of Virtual Reality (VR) and Augmented Reality (AR) technologies for reactive stepping rehabilitation in elderly individuals diagnosed with vestibular dysfunction. A programme was developed and tested in both VR and AR conditions on the Meta Quest 3 headset, designed in Unity, and in collaboration with Gentofte Hospital. The final experiment involved five female participants aged 65–78 years (mean age 71), all presenting varying degrees of balance impairment. The purpose was not to measure clinical outcomes directly, but rather to investigate user experience, perceived usability, acceptance, and preference through observation, semi-structured interviews, and repeated administration of the Simulator Sickness Questionnaire (SSQ). Participants generally found the AR condition more intuitive and less disorienting, with four out of five preferring it due to the visibility of their physical surroundings. The VR condition, while rated as more immersive and motivating, led to feelings of disorientation or nervousness in three participants, and one reported mild cybersickness. Observational data revealed more exaggerated stepping behaviours in VR, while stepping in AR appeared more confident and controlled. Physiotherapists highlighted VR's potential for immersive, therapist-guided training, while recommending AR for home-based use due to its lower sensory load and safer context. These findings suggest that both modalities have complementary roles. The VR condition for controlled, immersive clinical interventions, and the AR condition for intuitive, real-world practice. The study provides insights into XR usability among elderly users and contributes to the design and deployment of safe, adaptable rehabilitation tools.

**Index Terms:** Vestibular Dysfunction, Balance, STABLE, Physiotherapy, Rehabilitation, Virtual Reality (VR), Augmented Reality (AR), Meta Quest 3, Pass-Through, Reactive Stepping, Elderlys Acceptance, Cybersickness

## 1 Introduction

### 1.1 Vestibular Dysfunction and Rehabilitation Needs

Vestibular dysfunction is a widespread and often under-diagnosed condition that significantly affects the health and quality of life of elderly populations. Studies estimate that up to 35% of adults over 40 years of age experience some form of vestibular dysfunction, with the prevalence increasing substantially with age, affecting nearly 50% of individuals over 60 and up to 85% of those over 80 [12]. This progressive deterioration of the vestibular system, which plays a critical role in maintaining balance and spatial orientation,

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often results in symptoms such as vertigo, dizziness, unsteadiness, spatial disorientation and oscillopsia (the sensation that the visual field is moving) [1]. These symptoms contribute to a heightened risk of falls, which are a leading cause of injury, hospitalisation, loss of independence and mortality in older adults. According to the World Health Organisation, falls are the second leading cause of accidental deaths worldwide and over 30% of adults over 65 fall at least once per year, with 10% of those falls resulting in serious injuries such as fractures or traumatic brain injuries [26].

One of the most critical skills for fall prevention is reactive stepping, defined as the ability to take rapid, automatic and corrective steps when balance is suddenly lost. Unlike anticipatory postural adjustments, which involve planned movements, reactive stepping is an involuntary response triggered by unexpected perturbations, such as tripping over an obstacle or slipping on a wet surface. Reactive stepping is particularly important for elderly individuals, as age-related declines in sensory integration, neuromuscular control and cognitive-motor interaction reduce their ability to recover from such disturbances. Impairments in reactive stepping have been linked to a significantly higher risk of falls, making it a priority domain for intervention in vestibular rehabilitation [6].

Traditional vestibular rehabilitation protocols often focus on in-person physiotherapy sessions, where patients engage in structured exercises targeting balance, gaze stabilisation and postural control [5]. These sessions typically involve guided feedback from physiotherapists, who provide verbal, visual and tactile cues to help patients refine their movements and develop compensatory strategies [1], but these interventions can sometimes lack variety, controlled challenge progression or the ability to simulate complex or high-risk scenarios safely.

Emerging digital technologies, such as Virtual Reality (VR) and Augmented Reality (AR), offer innovative ways to address these challenges. VR provides fully immersive environments that simulate real-world scenarios or controlled therapeutic settings, enabling patients to engage in task-specific training under safe and supervised conditions [5]. The immersive nature of VR can promote body ownership, enhance engagement and provide precise, multimodal feedback through visual, auditory and haptic cues [1]. Meanwhile, AR overlays digital elements onto the physical world, allowing patients to practice tasks within a familiar environment, promoting ecological validity and potentially enhancing skill transfer to real-life situations [2]. Both modalities offer promising avenues for advancing the balance rehabilitation experience in new and challenging ways. However, despite their potential, the comparative strengths, limitations and clinical relevance of VR and AR, particularly in the context of rehabilitation for vestibular patients, remain under-explored in existing literature.

This paper builds upon the work conducted in our project in collaboration with Gentofte Hospital, where we developed and tested both VR and AR conditions for reactive stepping training. The programme consisted of two versions; VR and AR. The VR condition featured a lake, surrounded by nature and trees and on the lake lily-pads appeared from the water (Figure 2, Right). The AR environment did not contain the lake or trees, just the lily-pads (Figure 2, Left). In both programmes there were virtual shoes, that would align with the user's feet placement. The user's task in the programme is to register the location of the lily pad, step onto it and once the step is completed, a new lily pad appears, prompting the user to repeat the exercise in a continuous sequence. An animated frog jumps from lily pad to lily pad, indicating the target location for the user. This design took inspiration from reactive stepping exercises observed during physiotherapy sessions. The frog not only provides visual guidance but also enhances immersion by adding liveliness and movement to the scene. It is deliberately coloured bright red to stand out against the green lily pads, ensuring it is easily seen. The frog's jumping motion is animated using a custom rig and Unity's animation curve to simulate a smooth arc, helping older adults intuitively follow its path.

Figure 2: Left: AR task in progress - Right: VR task in progress

In addition, a "ghost feet" system is implemented to demonstrate the correct foot movement to the first lily pad (Figure 3). This system displays transparent shoes as visual markers for where the user should step, reinforcing the reactive stepping task and reducing uncertainty.

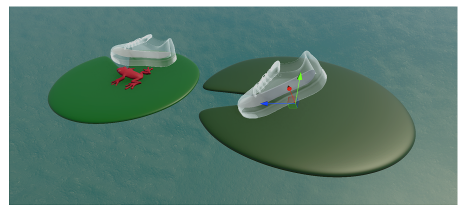

Figure 3: The ghost feet and frog meant to guide the user to take the first step in the application

By integrating theoretical frameworks such as the STABLE model (Specific Training According to BaLance Evaluation) [6], the Virtuality Continuum and principles of user-centred design for elderly populations, we aim to critically assess and compare how these technologies can support vestibular rehabilitation. Through empirical data collection, user feedback and physiotherapist insights, we seek to contribute to the growing body of research on Extended Reality (XR) applications in healthcare and provide evidence-based recommendations for their integration into clinical practice.

### 1.2 Aims and Research Area

The primary aim of this study is to investigate the comparative effectiveness, feasibility and clinical relevance of VR and AR as tools for reactive stepping rehabilitation in elderly patients with vestibular dysfunction. Specifically, we seek to understand how these technologies differ in terms of user experience, engagement, safety and potential for skill transfer.

The secondary aim is to explore elderly's and physiotherapists' acceptance of VR / AR, how they perceive the usability, challenges and benefits of each modality and how these perspectives can inform the design of future XR-based rehabilitation tools.

## 2 Theoretical Framework

This section presents the theoretical foundations underpinning our comparative study of VR and AR in vestibular rehabilitation, focusing on reactive stepping. We draw on established rehabilitation models, human-computer interaction theory, XR design principles and literature on ageing populations and technology use.

### 2.1 The STABLE Framework in Vestibular Rehabilitation

Vestibular rehabilitation is a specialised area within physiotherapy aimed at improving balance, gaze stability and postural control. The STABLE model offers a structured framework for addressing the multidimensional aspects of balance rehabilitation. Developed through clinical research and expert consensus [6], the STABLE model identifies six key domains essential for comprehensive balance training: Stability limits, sensory orientation, cognitive-motor interaction, turning, power and reactive stepping.

Among these, reactive stepping is of particular interest for fall prevention, as it directly addresses the body's ability to respond rapidly and appropriately to unexpected imbalances. Unlike anticipatory postural adjustments, where individuals prepare for a movement in advance, reactive stepping is an involuntary, automatic response triggered by external disturbances. For example, when a person trips over an uneven surface, their ability to execute a quick step can mean the difference between recovering balance or experiencing a fall.

Evidence suggests that age-related declines in sensory processing (particularly from the vestibular system), muscle strength, reaction time and cognitive-motor integration impair reactive stepping ability in elderly populations [12][8]. Consequently, training interventions must not only target physical components such as strength and agility but also simulate realistic real-world balance challenges. Traditional physiotherapy attempts to address this through manual perturbations or controlled exercises, but these methods have limitations. They may lack variety, realism and intensity control, and they are often restricted to the clinical setting [1].

XR technologies, VR and AR, offer novel ways to put STABLE principles into practice, enabling controlled, repeatable balance challenges (VR) and contextualised practice in real environments (AR). For our research, the STABLE framework guided the design of training tasks, emphasising the need for dynamic, responsive environments that challenge postural control without introducing safety risks.

### 2.2 The Virtuality Continuum and XR Technologies

The Virtuality Continuum (Figure 4), introduced by Milgram and Kishino (1994), conceptualises XR technologies as existing on a spectrum between the completely real and the fully virtual [15]. At one end lies the Real Environment (RE), the world we navigate every day. At the opposite end lies Virtual Reality (VR), computer-generated environment. Between these extremes lies Augmented Reality (AR), where digital content is overlaid onto the physical environment, enhancing but not replacing reality [21].

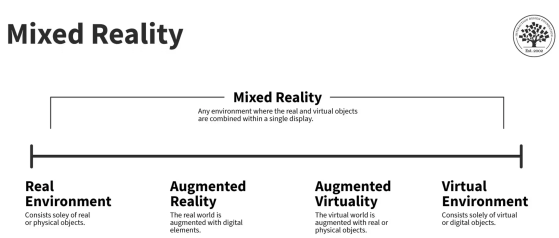


Figure 4: An illustration of the Virtuality Continuum spectrum, which ranges from fully real environments to fully virtual ones, including Augmented Reality (AR) and Augmented Virtuality (AV) as stages in between [7]

This continuum provides a theoretical lens for comparing VR and AR in rehabilitation contexts.

VR, by immersing users in a fully synthetic world, allows precise control over stimuli, enabling the presentation of tailored, repeatable and often exaggerated perturbations that would be impractical or unsafe in the real world. This control is particularly valuable for simulating hazardous scenarios (e.g., stepping on unstable surfaces, navigating obstacles) without physical risk [19]. However, VR's strength in immersion can also be a weakness. Users are disconnected from their real surroundings, which may hinder the transfer of trained skills to daily life [23].

In contrast, AR preserves the real-world context, allowing patients to practice tasks in familiar settings, such as their own living room [2]. This ecological validity supports the transfer of skills to real-world environments, which is crucial for functional independence. However, AR systems often offer less precise control over stimuli, as the environment's unpredictability can limit the types of perturbations introduced. AR's reliance on tracking real-world features also introduces technical challenges, such as spatial mapping inaccuracies or limited field of view [1].

The Virtuality Continuum highlights that no single modality is inherently superior, rather, each has distinct affordances and limitations. For vestibular rehabilitation, where both controlled skill acquisition (e.g., practising stepping strategies in a safe space) and task generalisation (e.g., applying skills in daily life) are important, understanding this continuum is critical for designing effective interventions.

### 2.3 Presence, Cybersickness and Ageing Populations

A central consideration in XR design is presence, the psychological state of "being there" in the virtual or augmented environment. Presence enhances engagement, promotes embodiment (the sense of owning and controlling a virtual body) and may facilitate motor learning by aligning visual, proprioceptive and vestibular inputs [22][20][16]. In VR, high presence is typically achieved through immersive visuals, spatial audio, natural interaction metaphors (e.g., hand tracking) and minimal latency. AR generally induces lower presence, as the real world remains the primary reference frame and digital overlays may feel less integrated into the user's perception of their environment [2].

While presence is often viewed as desirable, it carries trade-offs, particularly the risk of cybersickness, a motion-sickness-like syndrome caused by sensory conflicts (e.g., visual motion without corresponding vestibular or proprioceptive feedback). Cybersickness symptoms include dizziness, nausea, disorientation and visual fatigue, which can limit session duration and user adherence [9][11][14]. Notably, studies suggest that older adults may experience lower cybersickness than younger users, potentially due to age-related declines in the sensitivity of the vestibular system and reduced responsiveness of the autonomic nervous system [3][25]. This finding is encouraging for the application of XR in elderly populations, though it must be tempered by awareness that individual susceptibility varies and factors such as task complexity, system design (e.g., frame rate, latency) and user familiarity all influence symptom onset [18][17].

For reactive stepping tasks, the risk of cybersickness is particularly relevant, as dynamic movements can exacerbate visual-vestibular conflicts. Therefore, XR system design must prioritise minimising visual-vestibular mismatches, ensuring smooth motion rendering, maintaining stable frame rates and providing appropriate visual anchors (e.g., ground planes, horizon lines) [24][13]. Additionally, given the reduced reaction times and potential balance deficits in elderly users, safety considerations must guide every aspect of XR intervention design. This includes establishing clear physical boundaries, enabling real-time supervision (especially in VR) and offering gradual progression in task difficulty [12][8].

In summary, the interplay between presence, embodiment and cybersickness forms a critical consideration for XR design in vestibular rehabilitation. Balancing immersion with safety and user comfort is essential for creating systems that are both engaging and clinically effective.

## 3 Methodology and Design

This section outlines the methodological approach used to investigate the comparative effectiveness of VR and AR for reactive stepping rehabilitation in elderly patients with vestibular dysfunction. It details the implementation process, system design, user testing and evaluation methods. The approach followed an adaptive, iterative model, combining insights from physiotherapists, elderly users and theoretical frameworks such as STABLE and the Virtuality Continuum.

### 3.1 Implementation Process

The VR and AR prototypes were developed through an adaptive process that combined agile development principles with ongoing feedback from physiotherapists and user testing. The implementation spanned roughly 15 weeks and centred around several core components.

The initial design was informed by the STABLE framework and discussions with physiotherapists, focusing on exercises that supported balance and reactive stepping in elderly users with vestibular dysfunction. The goal was to create a system that felt intuitive and accessible, while directly targeting relevant skills.

The VR environment presented a calm lake scene with floating lily pads as stepping targets. Visual elements were deliberately kept simple to avoid overwhelming users and 3D assets were created in Blender. Natural ambient sounds, such as water ripples and frog calls, added to the sense of immersion without overstimulation.

Development took place in Unity using the XR Interaction Toolkit. The Meta Quest 3 was selected for its stand-alone functionality and pass through capabilities, which enabled the experience to be adapted for both VR and AR. In VR, the user was fully immersed in the lake scene, while in AR, the lily pads were anchored to the floor of the user's own environment using the Quest's pass through API. Spatial anchors and collision detection ensured safe placement and reliable interaction.

To ensure safety, each session included clear physical boundaries, active supervision and time limits tailored to the needs and comfort of elderly participants.

### 3.2 Design Process

The design process was user-centred, guided by principles of accessibility, simplicity and clinical relevance. It aimed to create a system that was both engaging and practical for elderly users with vestibular dysfunction, drawing on adaptive feedback from participants and physiotherapists throughout the development.

From an early stage, 5 men and 4 women were directly involved in initial testing of elderly's acceptance of Meta Quest 3 headset. They tried an extremely minimalistic VR prototype and an existing VR game from the Quest store, providing valuable feedback. Physiotherapists were engaged throughout the development process to ensure that the game's exercises aligned with best practices in vestibular rehabilitation, focusing on safety, task relevance and the specific needs of elderly users.

The visual design focused on creating a calm, uncluttered environment. In VR, the scene featured a tranquil lake with floating lily pads as stepping targets, rendered in soft colours. An animated frog acted as a visual guide, jumping from one lily pad to the next to indicate the correct target and support user engagement (Figure 5). In AR, the design used simple, high-contrast overlays to ensure the stepping prompts were clearly visible and safe to use within real-world spaces.

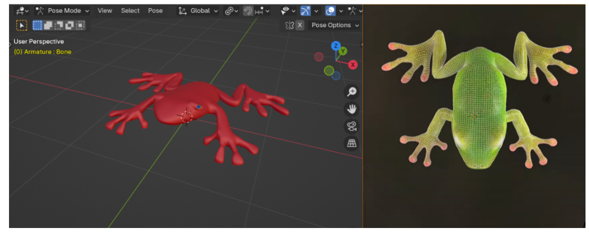

Figure 5: Left: Model of the frog created in blender. Right: The top-down image used as reference([4])

The interaction design encouraged multi-directional stepping, with lily pad targets appearing dynamically in randomised positions to promote reactive movement. Users were required to identify the correct target and step onto it, reinforcing balance control through repeated, responsive actions. Visual and auditory feedback confirmed successful interactions, while different coloured lily pads indicated varying levels of difficulty during task selection (Figure 6).

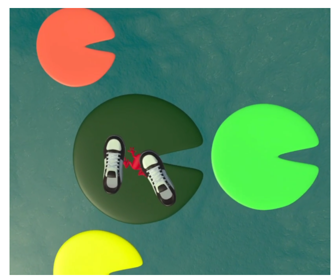

Figure 6: Three colored lily pads appear, each lilypad will start a route Green: Easy - Yellow: Medium - Red: Hard

Once a route is selected, lily pads appear sequentially and the player must step on the next before the currently stepped on disappears. The duration before disappearance is adjusted by difficulty, encouraging faster and more deliberate steps on harder levels. The player's goal is to complete the route and return to the start pad. The frog stays one pad ahead, indicating the next step in the sequence.

This collaborative, iterative approach was central to the development of a system designed to be both technically robust and practically useful in supporting balance training for older adults.

### 3.3 Experiment and Results

The evaluation phase used a mixed-methods approach, combining quantitative measures (e.g., usability scores and cybersickness incidence) with qualitative insights (e.g., user comfort, perceived realism and physiotherapist feedback) to gain a comprehensive understanding of system performance.

#### 3.3.1 Experiment Design

User testing involved five elderly participants aged 65–78 years (mean age 71) all diagnosed with vestibular dysfunction, each with varying degrees of balance impairment but no severe cognitive deficits. The participant pool only consisted of females, not due to any gender inclusion or exclusion, simply due to what was available at the time. Participants were recruited via the Gentofte Hospital physiotherapy network. Informed consent was obtained and sessions were supervised for safety.

Each participant took part in two sessions; one using the VR system and one using the AR system. Each session lasted 4-5 minutes, including onboarding, task familiarisation, a 2-minute active

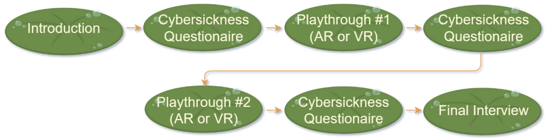


Figure 7: Diagram visualising the experiment setup and order

stepping phase and a cooldown period, which was when the cybersickness questionnaire was conducted. The participant completed the Simulator Sickness Questionnaire (SSQ) three times: once before beginning any AR or VR tasks (to establish a baseline), once between the two demonstrations, and a final time after completing both conditions. A semi-structured interview was conducted following the final SSQ. The order in which participants experienced the AR and VR conditions was randomised to minimise order effects. See Figure 7 for a visualisation of the experiment setup.

#### 3.3.2 Data Collection

The Simulator Sickness Questionnaire (SSQ) [10] was administered pre-, mid- and post-session to monitor symptoms such as dizziness and nausea. Semi-structured interviews explored participants' perceptions of usability, user-experience, cybersickness and preference. Observational data captured by researchers focused on task completion, hesitation, error correction and adaptive behaviours.

#### 3.3.3 Experiment Results

Out of the five elderly participants tested, four found the AR condition to be more intuitive and easier to use. This perception was primarily attributed to the ability to see and orient themselves within the real environment, which reduced uncertainty and contributed to a sense of safety and control. The VR condition, on the other hand, was described as immersive and engaging, but three participants also reported mild disorientation, dizziness, or a sense of nervousness during or after the experience.

Cybersickness symptoms were minimal overall. However, one participant in the VR condition explicitly reported feelings of dizziness, which were not present during the AR condition. Across the full sample, approximately two-thirds of the 60 questionnaire items (12 items × 5 participants) recorded the same value across all three testing rounds, indicating limited variation in cybersickness symptoms. This suggests that the XR experiences were generally well tolerated, though the small sample limits broader generalisation.

Behaviourally, participants in the VR condition exhibited more exaggerated postural adjustments, which was noted through observations. These included wider stances, delayed steps and occasional hesitation, likely due to reduced peripheral awareness in the fully immersive environment. In contrast, participants in the AR condition displayed more confident stepping patterns and an increase in speed, likely because they remained aware of their physical surroundings and potential real-world obstacles.

When it came to task performance, three out of five participants completed the stepping tasks faster in the AR condition than in VR. This could be attributed to the greater familiarity and lower cognitive load associated with AR, as users did not need to adapt to a fully virtual environment. Nonetheless, some participants expressed greater motivation and presence during the VR experience, suggesting that it may have greater potential for immersive, therapist-led training scenarios, while AR may be more suitable for home-based exercises.

These results, though based on a small and specific sample, provide early insights into the usability, comfort and behavioural responses associated with XR-based rehabilitation. They underscore the importance of tailoring modality choice to individual needs and training contexts.

Physiotherapists viewed the VR condition as a promising tool for delivering controlled, immersive training scenarios that would be difficult or unsafe to replicate in real-life clinical environments, particularly those involving dynamic visual cues and reduced environmental predictability. They appreciated the potential for using VR in structured, therapist-guided sessions to safely challenge balance and visual-vestibular coordination. In contrast, they highlighted the AR condition as more suitable for home-based rehabilitation, due to its lower sensory load and ability to maintain awareness of the physical surroundings. The experts also emphasised the importance of task customisability, specifically suggesting greater variation in step distances and the option to adjust response times. They viewed these features as essential for tailoring the experience to individual patients, and for enabling progressive difficulty scaling as part of a broader, adaptable rehabilitation programme.

These findings informed iterative refinements to the system, including adjustments to task difficulty thresholds, larger and more variating distance between lily pads, improved visual cues in AR and enhanced onboarding procedures for VR to mitigate disorientation.

## 4 Discussion

This section critically examines the study's findings in the context of existing literature, clinical practices and the broader goals of vestibular rehabilitation. By comparing VR and AR for reactive stepping training, we aim to provide nuanced insights into their respective strengths, limitations and integration potential within clinical rehabilitation programmes for elderly patients with vestibular dysfunction.

### 4.1 Clinical Implications

Our findings underscore that Virtual Reality (VR) and Augmented Reality (AR) offer distinct yet potentially complementary roles in supporting balance training for elderly users. The study evaluated five elderly participants' experiences with both AR and VR conditions of a custom-developed balance training prototype, created in Unity for the Meta Quest 3. The goal was not to measure clinical outcomes directly, but to gain insight into usability, perceived engagement and physical comfort through qualitative interviews, observation and standardised questionnaires, including the Simulator Sickness Questionnaire (SSQ).

Four out of five participants found the AR condition to be more intuitive and less overwhelming, which they attributed to being able to see their physical surroundings throughout the experience. In contrast, the VR condition was described by most participants as more immersive and engaging, but also led to feelings of disorientation or nervousness in three out of five participants, with one participant reporting symptoms of cybersickness during VR use. These perceptions were supported by behavioural observations, where participants tended to display more exaggerated postural adjustments in VR compared to more confident and faster movement in AR. These findings support existing research suggesting that AR may offer a smoother and more accessible introduction to XR for older adults, while VR holds greater promise for delivering fully immersive and dynamic training scenarios in supervised clinical settings.

Feedback from the physiotherapists, while gathered informally, provided valuable context for interpreting the system's potential clinical relevance. Their comments supported the idea that XR technologies could effectively complement traditional balance training. This aligns with participant feedback, where many expressed enjoyment and curiosity, despite initial unfamiliarity with the technology. However, physiotherapists also pointed out limitations in the current implementation, most notably the lack of variation in step patterns and distances. They suggested that the uniform stepping task, particularly on the easier difficulty route, might limit the programme's effectiveness in challenging users across multiple motor domains. Introducing variation in step length, direction and timing was proposed as a way to better simulate real-world balance scenarios and support more robust training outcomes.

Another important point raised was the differing use cases for VR and AR. While VR was seen as well-suited for supervised clinical environments, where immersive tasks could be carefully monitored and adapted, the physiotherapists recommended AR as a more accessible option for home-based training. The AR version's ability to maintain visual contact with the real world was considered safer and more intuitive for independent use, particularly for users new to XR.

These insights reinforce the importance of aligning XR content with established vestibular rehabilitation principles. The system must remain safe and adaptable, particularly for elderly users, while also delivering enough variation and challenge to support long-term therapeutic value. Future iterations of the programme would benefit from integrating these expert suggestions into the task design and tailoring the experience to specific clinical contexts.

In summary, while this study did not evaluate clinical outcomes such as fall risk reduction, the findings suggest that AR may offer a more accessible and intuitive solution for home-based training, while VR could support more immersive, clinic-based interventions for balance enhancement.

### 4.2 Cybersickness and Ageing

The study observed minimal reports of cybersickness among elderly participants, with only one participant noting slight dizziness after using the VR system. This is consistent with existing literature, which suggests that older adults may experience fewer cybersickness symptoms due to age-related changes in vestibular function. Nevertheless, the small sample size and short exposure times limit the generalisability of this finding.

However, it is important to note that while baseline susceptibility to cybersickness may be lower in older adults, other factors, such as pre-existing vestibular deficits, medication use, or postural instability, can still interact with XR use in complex ways. For instance, one participant in our study reported increased caution and reduced step amplitude in VR, potentially reflecting a subconscious fear of falling or disorientation. This observation reinforces the need for gradual onboarding, careful progression of task complexity and supervised training during initial sessions, particularly in VR. In contrast, AR's lower sensory conflict and visual anchoring within the real environment inherently mitigates cybersickness risk, making it a safer choice for unsupervised, home-based training.

### 4.3 Limitations

While the findings of this study are promising, several limitations must be acknowledged. Firstly, the small participant pool (n=5) limits the generalisability of results. Although qualitative insights from elderly users and physiotherapists offer valuable perspectives, a larger, more diverse sample, including individuals with varying levels of vestibular impairment, mobility status and technology familiarity, would strengthen the robustness of conclusions.

Secondly, the informal nature of physiotherapist interviews, while useful for formative feedback, lacks the systematic rigour of structured qualitative methodologies such as thematic analysis. Future research should incorporate formalised interview protocols, multiple coders for qualitative data and triangulation with quantitative measures (e.g., balance assessments, step accuracy metrics) to ensure methodological rigour.

Thirdly, the study's focus on short-term usability and engagement leaves open questions about long-term adherence, retention of skills and real-world functional outcomes. While participants expressed enthusiasm for XR training, sustained engagement over weeks or months, particularly in home settings, remains to be tested. Future longitudinal studies should evaluate retention effects, real-world fall incidence and the impact of XR interventions on quality of life metrics.

Lastly, technical limitations such as hardware constraints (e.g., AR field of view, VR headset weight), tracking accuracy and the learning curve associated with XR devices must be addressed to ensure accessibility for elderly users, many of whom may have limited prior exposure to digital technologies.

## 5 Conclusion

This short paper reflects on the findings from our project, where we explored elderly users' acceptance of Virtual Reality (VR) and Augmented Reality (AR) technologies for balance training using the Meta Quest 3.

Our results indicate that both VR and AR offer valuable, yet distinct, possibilities for balance training, depending on the context of use. AR was generally perceived as more intuitive by elderly users, as it integrates digital prompts into their familiar, real-world surroundings, making it suitable for home-based rehabilitation. The simplicity of AR and its lower potential for disorientation appeared to support greater user comfort and engagement in everyday environments.

Conversely, VR provides opportunities for immersive, focused training scenarios that are not possible in the real world. The fully synthetic environments of VR allow for the creation of controlled, repeatable tasks, such as dynamic stepping challenges or immersive visual cues, that could be useful for simulating specific balance scenarios. Importantly, physiotherapists in our study highlighted that VR's ability to introduce visual challenges, such as sudden obstacles or moving targets, could be particularly valuable for addressing specific aspects of balance control that are difficult to replicate safely in a real-world setting. However with VR there is a need for careful onboarding, supervision and gradual exposure when introducing this technology to elderly users.

In summary, the choice between VR and AR is not a matter of which technology is better overall, but rather which is better suited to the specific rehabilitation context. AR holds promise for at-home practice and task generalisation, while VR offers unique opportunities for controlled, immersive training within supervised clinical or research settings. Future research should continue to explore how these modalities can complement each other in balance rehabilitation, ensuring that technology remains a tool to support, not replace, the therapeutic process.

## 6 Future Work

This study highlights several directions for future research. Longitudinal studies are needed to evaluate the long-term effects of XR interventions on balance, fall risk and independence. Future systems should explore adaptive features, such as a difficulty adaptation and personalised feedback, to accommodate diverse user needs and capabilities.

Integrating XR into clinical practice requires research into deployment strategies, clinician training and cost-effectiveness. Expanding XR content to cover other areas of vestibular rehabilitation such as gaze stabilisation, cognitive-motor tasks and dual-task training could offer more comprehensive therapeutic solutions.

Finally, future work should ensure XR design remains accessible to a wide range of users by considering ergonomics, clear visual targets and simplified interaction options. These efforts can help ensure that XR technologies evolve into effective, safe and engaging tools for elderly users in balance rehabilitation.

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