VRehabilitation: A Pilot Study of HMD-Based Guided Exercise & Rehabilitation in VR for Post-Shoulder-Surgery Patients at Home

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Figure 1: A screenshot from a virtual reality physiotherapy session in action. Notice, among other things, the virtual mirror and instructor in the exercise room.

Abstract

Shoulder rehabilitation is a critical component of recovery for post-shoulder-surgery patients. This study introduces a virtual reality application designed for shoulder rehabilitation commencing six weeks post-surgery, utilising virtual mirrors, instructor guidance, and real-time motion tracking. We have addressed challenges such as limited supervision and motivation during home rehabilitation. The application aims to bridge the gap between clinical supervision and at-home recovery by adhering to physiotherapy's best practices, providing an engaging, non-gamified platform. Expert evaluations were collected through interviews. Further data was collected through an experiment in an everyday environment with 8 subjects (4 male and 4 female) with prior experience in physiotherapy rehabilitation participated in this study. The average age for males was 26.0 years (± 6.83 SD), and for females was 38.75 years (± 14.83 SD). While outcomes are promising, with participants reporting high usability and engagement, issues like cybersickness and accessibility require further investigation. Although no severe cybersickness was reported, optimising motion design and visual feedback could further enhance user comfort. Additionally, feedback emphasised the need for more exercise variety and customisation to improve long-term usability.

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1 Introduction

Shoulder injuries are among the most common conditions that require post-surgical rehabilitation. Recovery typically involves repetitive exercises aimed at restoring function, reducing pain, and improving mobility [3]. The consistent performance of these exercises is an extremely important factor in achieving a smooth and successful recovery. However, adherence to these exercises, particularly during unsupervised at-home sessions, often proves challenging. Lack of motivation, improper technique, and insufficient feedback can negatively impact rehabilitation outcomes [2]. In-person sessions provide valuable guidance but are often limited by logistical constraints, such as availability, cost, and patient mobility. Therefore, a tool that can complement physiotherapy, limiting the need for unnecessary face-to-face appointments, will prove exceptionally useful.

Virtual Reality (VR) technology offers a promising solution to these challenges. Immersive VR environments can replicate the clinical setting, provide real-time feedback, and enhance patient engagement without requiring constant supervision. Despite the prevalence of gamified VR rehabilitation tools such as [1], a game-based application for elbow rehabilitation, this project deliberately avoids gamification. The purpose behind this is to maintain focus on the therapeutic value and for the participants to not unintentionally exceed their pain limit or make any potentially harmful movements yet remain engaged and immersed. Additionally, avoiding gamification ensures that the rehabilitation process prioritises slow, controlled movements over rapid, competitive behaviours often encouraged by games. Gamification may unintentionally distract users from maintaining proper form or adhering to their physiotherapist's prescribed range of motion, potentially leading to over-exertion or improper technique. Steering away from game mechanics, this application fosters a calm, guided experience that minimises unnecessary strain and emphasises recovery. Furthermore, it aligns with the non-competitive nature of physiotherapy, where the primary goal is safe and sustainable improvement rather than achieving high scores or completing challenges.

There is currently a massive market for gamified rehabilitation. In contrast, there remains a gap within the non-gamified aspect, even though it could be deemed a handy tool for enhancing and improving the future of rehabilitation. Immersion in virtual reality is often mistakenly linked to game elements. While it can be a valuable tool for creating immersive experiences, it is not the defining factor of VR immersion. It is not essential, especially in applications like our VR shoulder rehabilitation tool. The level of immersion depends on the intended user experience and the design choices that align with it. As discussed in [10], immersion can stem from system immersion (high-fidelity VR technology), narrative immersion (engagement with meaningful content), or challenge-based immersion (focused interaction with tasks). Our design promotes system immersion through precise motion tracking and visual feedback, as well as challenge-based immersion by encouraging users to focus on guided movements and tasks. This demonstrates that effective immersion can be achieved without gamification.

Figure 2: Screenshot of the virtual physiotherapist presenting an exercise from the user's POV.

As a pilot study, an HMD-based VR application was developed, featuring a virtual mirror for body tracking as seen in Figure 1, an instructor character for guidance and detailed motion feedback. The programme incorporates several innovative features to enhance the user's rehabilitation experience. The virtual mirror is a key component for real-time body tracking, allowing users to observe their movements accurately mirrored in the virtual environment.

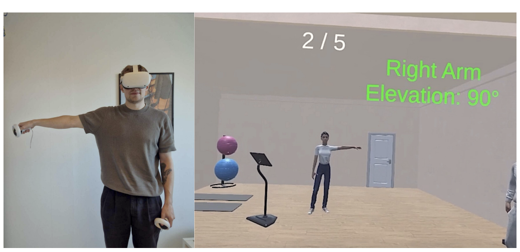

Figure 3: Side-by-side of user performing exercise and a screenshot of what they see in the application.

This feature helps users visualise their posture and alignment, ensuring they perform exercises correctly and confidently. Additionally, an instructor character provides clear and precise guidance by demonstrating the exercises step-by-step (see Figure 2), offering a virtual alternative to in-person physiotherapy instruction. The application delivers detailed motion feedback to further support the rehabilitation process, including visual, auditory, and haptic cues. These feedback mechanisms notify users when they achieve the correct range of motion or when the limit is exceeded, enabling them to refine their technique and avoid improper movements that could hinder their recovery.

2 State of The Art

Existing studies underscore the importance of early, structured and easily accessed rehabilitation. Research by Kibler et al. [8] highlights the role of kinetic chain exercises in promoting functional recovery, emphasising the need for a structured programme. Similarly, Eriksson et al. [4] demonstrated the effectiveness of telemedicine in shoulder rehabilitation, finding that consistent remote guidance can enhance outcomes. One of the explanations for the more successful results among the telemedicine group discussed in the article is the fact that they received a more extensive and frequent procedure. Figure 4 demonstrates the amount of sessions the test groups received during their experiment.

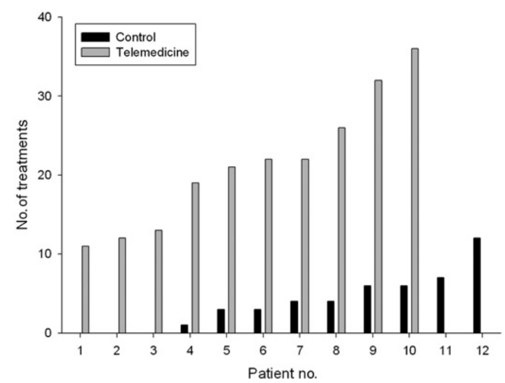

Figure 4: Number of physiotherapy sessions among the two test groups during the two months after discharge from hospital, taken from [4]

This highlights the importance of easily accessible rehabilitation, and building on these insights, the VR application integrates key principles of physiotherapy within an accessible digital framework.

2.1 Presence

Presence in VR refers to the sensation of "being there" within a virtual environment and is crucial for creating immersive and impactful experiences [10]. This phenomenon is characterised by two primary illusions: the illusion of place and the illusion of plausibility [14]. The illusion of place occurs when users feel transported to the virtual environment. In contrast, the illusion of plausibility relates to the realism and logical coherence of events within the VR world. These elements contribute to a heightened sense of presence and can assist in elevating user engagement, particularly in contexts like rehabilitation, where immersion is essential for effective outcomes [15].

One critical factor for achieving presence in VR is body ownership, which refers to the user's perception of their virtual avatar as an extension of their physical body. This is facilitated by real-time synchronisation between the user's movements and the avatar's representation in the VR environment [15]. For instance, when users look down, they should see a life-sized virtual body that accurately mirrors their movements. This real-time alignment fosters a sense of ownership and enhances the feeling of presence, making the VR experience more engaging and intuitive [15] [11]. Studies have shown that incorporating elements like a virtual mirror reflecting users' movements can further strengthen this connection. When users observe their avatars accurately replicating their actions, it increases body ownership. It ensures that they remain mindful of their physical boundaries, particularly useful in rehabilitation settings [6].

The design of the virtual environment also plays a pivotal role in establishing presence. Research suggests that users experience a stronger sense of presence when VR settings resemble familiar real-world environments [11]. For example, creating a virtual space replicating a physiotherapy gym can enhance the continuity between users' real-life experiences and the virtual world, reinforcing their sense of presence [16]. Additionally, multisensory stimuli, such as tactile feedback synchronised with visual and auditory cues, can amplify this effect [12]. Simple interventions like controller vibrations that match in-world interactions help bridge the gap between the physical and virtual realms, enhancing the user's overall immersion [15].

Achieving presence, however, must be balanced against the risk of inducing cybersickness, a common side effect of VR experiences. Cybersickness and presence have been shown to share an inverse relationship; high levels of cybersickness can diminish users' focus on the virtual environment, thereby reducing their sense of presence [7]. Conversely, an engaging and immersive VR environment that fosters a strong sense of presence can help users overlook mild symptoms of cybersickness. Factors such as reducing sensory conflicts, improving display quality, and ensuring intuitive user interactions are essential to optimising presence while minimising cybersickness [18].

3 Methodology and Design

3.1 Implementation Process

The VR application was implemented using Unity (LTS version 2022.3.48f1) and was designed for the Meta Quest 2. The Meta Quest 2 was chosen, as it was the only available option to the research team. Unity's High-Definition Render Pipeline (HDRP) was used to enhance graphical realism, while Blender was employed to create the immersive environment.

The development process incorporated physiotherapist input to refine exercise selection and interaction design, ensuring alignment with clinical rehabilitation goals. Usability testing guided improvements to enhance user interaction and overall system effectiveness.

The system features haptic and auditory feedback to reinforce correct exercise execution. Real-time performance was optimised using Unity's physics engine and GPU-accelerated rendering to maintain smooth interactions.

3.2 Design Process

Our analysis identified 25 functional and 13 non-functional design requirements for the application. The virtual environment emulates a physiotherapy clinic, incorporating familiar elements to enhance user comfort and reduce cognitive load. Careful attention was paid to the design elements to ensure they align with realistic physiotherapy components while maintaining user engagement.

Key features include a virtual mirror [5] for body ownership [13], an instructor character for exercise demonstrations and visual indicators to confirm correct arm movements. The application supports dynamic feedback through haptic and auditory cues. For example, controllers vibrate when exceeding prescribed motion limits, while audio prompts reinforce correct movements. The design integrates Gestalt principles [17] to maintain simplicity and coherence, ensuring ease of use. Visual clarity was prioritised to prevent confusion and support precise movement tracking, with bright yet soothing colours used for the interface.

The virtual mirror's design was guided by Gonzalez-Franco's findings on body ownership, emphasising the importance of real-time reflections for user engagement [5]. These theoretical foundations were combined with practical considerations to create a balanced and effective application.

The first version focused on establishing the core design, including prototypes of the interface and functionality. Usability testing at this stage revealed initial design and interaction issues. In response, the second version incorporated refinements to both the interface and functionality, addressing feedback to improve the overall user experience. Additional usability tests in this phase confirmed the effectiveness of these updates and highlighted further areas for improvement. The final version prioritised enhancing user interaction and refining the overall experience to make it more intuitive. Comprehensive testing confirmed that the design met both functional requirements and user needs.

The application integrated principles of information, interaction, and presentation design. Information design ensures clarity and improves user comprehension of the application's interface and functionality. Interaction design focuses on intuitive navigation and user engagement, employing multimodal feedback (visual, auditory, and haptic) to guide users and provide real-time support. The presentation design emphasises realism and familiarity with the VR environment, promoting user comfort and immersion. Features like a virtual mirror for real-time feedback and a realistic-looking avatar enhance the sense of body ownership and connection to the virtual space.

Throughout the development, usability testing was crucial in refining design elements. This user-centred approach ensured that the application evolved into a polished, therapeutic tool aligned with physiotherapy best practices, designed to support effective at-home rehabilitation for shoulder surgery patients. The current prototype can be seen in Figure 2 and 3.

3.3 Evaluation

3.3.1 Experiment Design

The evaluation of the VR system employed semi-structured interviews, a questionnaire, and an expert interview to gather comprehensive feedback on its usability, effectiveness, and potential for improvement (5). Each method contributed unique insights into the system's strengths and areas for refinement. All tests were conducted using the Meta Quest 2 head-mounted display, and all application versions were developed in Unity (LTS version 2022.3.48f1).

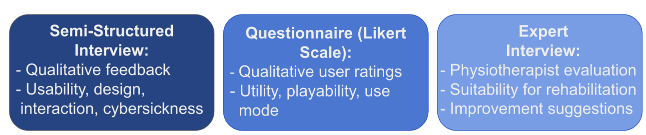

Figure 5: Simple block diagram of the evaluation phases and what they address.

Prior to conducting the final test, a pilot test was conducted for both the interview and the questionnaire to identify and refine unclear or imprecise questions. This process improved clarity and precision, ensuring the reliability of the final test.

The interview consisted of 8 participants: 4 males between the ages of 19-32 and 4 females between the ages of 23-58. The choice of test participants was influenced by the availability and accessibility of individuals who could engage with the VR system within the constraints of the study timeline. As a result, the participant group did not consist of the intended target group (shoulder surgery patients 6 weeks post-surgery) but included individuals with prior physiotherapy experience.

They were given the tasks of setting up the exercise in the menu and then performing exercises 1 (abduction) and 2 (external rotation). The experiment was conducted in a typical everyday setting to simulate real-world applications. When the participants finished the tasks, a semi-structured interview was conducted, which consisted of 11 questions divided into categories inspired by previous research: usability, design, interaction, and cybersickness.

Thereafter, the participants completed a questionnaire that followed a 5-point Likert scale and consisted of 14 questions divided into 3 categories: utility, playability, and use mode. The questionnaire was inspired by [9] and tailored to the context of our application.

The expert interview was held with a physiotherapist with a Bachelor's degree in physiotherapy and 3 years of experience in the private practice. The expert semi-structured interview was conducted after the final development and population testing. The physiotherapist first tested the VR application and was then asked if they felt the application would benefit patients undergoing shoulder rehabilitation. They were also asked if they would consider using or recommending it and if they had any overall feedback as an expert.

3.3.2 Experiment Results

The semi-structured interviews provided qualitative insights by exploring participant experiences during testing. This format allowed for open-ended feedback on usability, design, and interaction. Participants generally expressed satisfaction with the system, highlighting the clarity of the user interface and the overall functionality. The experiments were performed in a home-based setting, allowing everyday distractions to occur.

However, the potential for possible bias was noted, as participants knew members of the research team on a personal level, potentially leading to overly positive responses. Efforts were made to encourage candid feedback to ensure the data's reliability.

A structured questionnaire was presented after the interview, collecting quantitative data. Participants rated the system highly for its usability and engagement. Notably, 87.5% of respondents found the system engaging and easy to use, while all participants (100%) appreciated its real-world applicability and expressed willingness to use it for at-home rehabilitation. However, feedback on exercise adequacy was mixed, with 50% agreeing that the exercises were sufficient and 37.5% remaining neutral. The participants also highlighted the need for more variety in exercise and further refinement of some visual elements.

Lastly, a separate expert interview with a physiotherapist added a professional perspective, emphasising the system's potential for clinical use, particularly during the early stages of post-surgery rehabilitation. The physiotherapist appreciated features such as real-time visual feedback and the non-gamified approach, which they believed would keep patients focused on their recovery. Suggestions for improvement included incorporating goal-oriented progress tracking, expanding the range of exercises to include passive range-of-motion movements, and enabling greater customisation. The expert also recommended adding data analysis features to help physiotherapists monitor patient progress more effectively.

These evaluation methods provided a well-rounded initial understanding of the system's strengths, including its usability, clinical relevance, and engaging design. The feedback also highlighted areas for improvement, such as exercise variety, customisation, and progress tracking, offering clear directions for future development.

4 Discussion

Users found the application engaging and effective in providing real-time feedback, which is crucial for home-based rehabilitation. The results highlighted the potential of VR in enhancing physiotherapy practices.

However, several limitations were noted. The participant pool had to be adjusted from shoulder surgery patients 6 weeks post-surgery to patients who had been through any physiotherapy rehabilitation process, which affected the applicability of the results. This deviation from the target group means that while the findings provide insights into the usability and general effectiveness of the VR system, they do not perfectly mirror the real clinical needs of shoulder surgery patients. It was deemed sufficient as their familiarity with home exercises and motivation to train closely aligned with the characteristics required for the study. The small, homogenous group of participants, who had little to no prior VR experience or only limited exposure, restricted the generalisability of the findings.

No participants reported experiencing severe symptoms of cybersickness following the play-through. Locomotion is widely recognised as a substantial factor contributing to the onset of cybersickness. The limited requirement for users to move around within the virtual environment likely contributed to the reduction in cybersickness, as indicated by findings from previous usability testing.

The study's mixed-method approach was effective but could be improved with more extensive primary data, such as interviews or focus groups, during the early design stages. Design refinements, including greater customisation and enhanced accessibility for VR novices, were also suggested. Additionally, more focus on scalability, cost, and long-term application in public healthcare settings would have strengthened the findings.

An unexpected insight was VR's ability to foster greater self-awareness among participants. Rather than solely replicating the role of a physiotherapist, the immersive feedback encouraged users to assess and correct their movements in real-time, promoting a more active role in their recovery. This highlights VR's potential to complement external supervision and increase patient empowerment, a finding that could redefine its role in physiotherapy.

5 Conclusion

Our findings suggest that our application offers a potential solution for bridging the gap between clinical physiotherapy and at-home exercises. The system may improve exercise clarity and adherence by integrating virtual mirrors, instructor guidance, and multimodal feedback mechanisms. The combination of visual, auditory, and haptic feedback appears to support users in performing exercises correctly, addressing common challenges like maintaining motivation and ensuring proper technique.

The system's simplicity and emphasis on usability throughout its implementation demonstrated its effectiveness among older participants and those with limited technological proficiency. Notably, these participants quickly adapted to managing orientation and navigation within the virtual environment.

The results suggest that this VR application has the potential to complement traditional physiotherapy, offering a scalable and effective solution for remote rehabilitation. However, the short-term nature of the experiment limits the ability to assess long-term adherence and therapeutic outcomes. The current approach provided foundational data for refinement and future iterations. With positive feedback from physiotherapists, this approach holds significant promise within the non-gamified field of shoulder rehabilitation, presenting a valuable, accessible, and engaging alternative for patients while ensuring continued therapeutic effectiveness. Serving as a solid foundation, this platform paves the way for future enhancements, including refined user experiences, integration of advanced therapeutic modalities, and expansion to other rehabilitation areas.

6 Limitations

The study was cross-sectional rather than longitudinal, focusing on short-term performance and immediate feedback due to the pilot nature of the study, time constraints and resource availability. While this approach provided valuable preliminary insights and minimised participant burden, it limits the ability to assess long-term adherence, therapeutic progress, and sustained patient motivation. We, therefore, acknowledge that longitudinal studies would have provided more profound insights into these factors.

Availability constraints within the study timeline influenced participant selection. This resulted in a group with prior physiotherapy experience rather than the intended post-shoulder-surgery patients at six weeks of recovery. Although this allowed for relevant feedback on exercise techniques, it may limit generalizability, as the absence of participants in active recovery could affect the assessment of clinical factors like pain management, restricted mobility, and range of motion. Future studies will aim to recruit from the target clinical group to better align with rehabilitation objectives and validate therapeutic effectiveness.

While Meta Quest 2 is accessible and cost-effective, its tracking precision is limited, particularly for dynamic shoulder movements, due to its inside-out tracking system. Occlusion issues can affect real-time feedback reliability, and the lack of external sensors reduces tracking fidelity for fine motor assessments.

7 Future Works

Future work should focus on enhancing the VR system's technical capabilities, practical applications, and user experience to increase its effectiveness and accessibility. One important area would be upgrading aspects within the system to improve the user's experience and the communication between patients and physiotherapists. This would include upgrading the tracking systems, especially for dynamic movements crucial to shoulder rehabilitation, and exploring alternative VR platforms or hybrid systems with external sensors. Integrating telemedicine is another key area for development. Enabling real-time remote monitoring by physiotherapists will allow immediate feedback, enhance accountability, and bridge the gap between clinical and home-based rehabilitation. In terms of data collection and visualisation, adding new metrics such as exercise adherence, range of motion, and movement accuracy could improve the development of more effective treatment plans.

Additionally, making adjustments and further developing the exercises within the application would be highly beneficial. Expanding the amount of exercises included in the system is necessary. Introducing more diverse movements and advanced options will cater to different rehabilitation needs, accommodate user limitations, and provide greater personalisation based on user preferences. Personalised customisation should also be a focus, enabling adaptive difficulty levels, real-time performance adjustments and tailored exercise recommendations to create a more individualised rehabilitation experience. Incorporating task-oriented interactions that simulate real-world activities, such as reaching for objects, enhances users' functionality and motivation.

Future iterations of the system should explore using the Meta Quest 3, leveraging its enhanced processing power, improved tracking accuracy and increased field of view. The Quest 3's depth sensors and higher-resolution pass-through could enable better spatial awareness and more precise movement tracking, addressing some of the limitations of the Quest 2. Additionally, its improved body-tracking capabilities could allow for more natural interactions, reducing reliance on controllers for specific rehabilitation exercises. These advancements could contribute to a more immersive and compelling rehabilitation experience, particularly for complex shoulder movements requiring high tracking fidelity.

Additionally, ergonomic strain from prolonged headset use may be problematic for post-surgery patients. Future work should explore hybrid tracking solutions to improve accuracy and usability in rehabilitation settings.

Lastly, expanding the scope of research is crucial. This includes broadening participant demographics to encompass individuals with diverse physical abilities, ages and varying levels of familiarity with VR and conducting longitudinal studies to evaluate the long-term rehabilitation outcomes through this system.

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