Strengthening Social Contacts and Care for Older Adults Using Mixed Reality

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Abstract: This thesis develops and evaluates a mixed reality application for remote physiotherapy sessions targeting older adults. The application is designed to address social isolation and access barriers, and explore the benefits of incorporating mixed reality technology in healthcare and physiotherapy. Data was collected from 25 user tests, and participants provided feedback through post-scenario surveys. The preliminary results found that the mixed reality application may assist in combating social isolation, through improvement in access to physiotherapy services, and by delivering effective training exercises remotely. They also suggest that mixed reality tools may be as effective as traditional in-person methods for physiotherapy in balance and strength training. This thesis highlights the potential for increased social sustainability and improved health outcomes among older adults. Future research is needed to explore the long-term impact and effectiveness of mixed reality applications in physiotherapy and healthcare settings. This thesis contributes to the research on the usability of mixed reality applications, paving the way for more widespread use in healthcare for older adults.

Keywords: mixed reality; physiotherapy; social isolation; older adults

1. INTRODUCTION

The use of technology in healthcare has been rapidly expanding, with innovative applications aimed at improving patient care, accessibility, and outcomes. In particular, mixed reality technology has emerged as a promising tool in various applications, including healthcare and physiotherapy. Mixed reality is defined as a system in which components of a partially virtual world and partially physical world are overlaid onto each other, perceived simultaneously in an environment (Nevelsteen, 2017).

In developing mixed reality tools and applications for older adults, it is essential to consider the specific conditions of their home and care environments (Seifert and Schlomann, 2021). This thesis aims to address the needs of older adults receiving physiotherapy care. Involving qualified professionals in the development process can provide valuable insights into the care needs and challenges faced by potential patients (Seifert and Schlomann, 2021). By combining the virtual and physical worlds, mixed reality applications offer immersive and interactive experiences that can enhance traditional therapeutic approaches.

The prevalence of social isolation and limited access to healthcare services among older adults has become a growing concern. Many older individuals face challenges in attending in-person appointments due to mobility issues, transportation limitations, or geographical constraints (Fakoya et al., 2020). As a result, there is a need for innovative solutions that can overcome these barriers and provide effective physiotherapy interventions in a remote setting.

In response to this need, the proposed mixed reality application leverages an immersive virtual reality environment (VRE) and real-time interaction to deliver physiotherapy exercises remotely. By utilizing affordable hardware such as the Meta Quest 2 headset and widely available communication platforms like Microsoft Teams, the application aims to bridge the gap between physiotherapists and older adults, enabling interactive sessions regardless of physical location.

The implementation of the physiotherapy scenario involved collaboration with a physiotherapist who provided professional input on exercise selection and safety considerations. The exercises were designed to simulate real-world tasks and challenges encountered during traditional, in-

person physiotherapy appointments. Through a series of participant scenarios, the effectiveness and user experience of the mixed reality application were evaluated.

This short paper will provide a summary of my ongoing thesis work, including the development of the mixed reality application, data collection procedures, preliminary analysis of the results, and a discussion of their implications. The high-level goal of my thesis is to advance the field of remote physiotherapy and to enhance quality of care and quality of life of older adults by leveraging the potential of mixed reality technology.

2. BACKGROUND

With rapidly-developing societal and technological advances, the global population is growing, aging, and living longer (Fakoya et al., 2020). The United Nations defines an older adult to be an individual over the age of 60 (World Health Assembly, 69, 2016). The World Health Organization expects that the number of adults over the age of 60 will make up 18 percent of the global population by 2030 (World Health Assembly, 69, 2016).

While humans living longer is a celebratory feat, it does bring forth historically unforeseen problems (Rudnicka et al., 2020). Some problems associated with aging include an increased likelihood of living alone, death of loved ones, chronic sickness, and physiological decline (National Academies of Sciences, Engineering, and Medicine, 2020). Such problems pose an increased risk of social isolation in older adults. It can be difficult to visit others, whether it is for recreational, social, or essential purposes. The issue of social isolation poses increased risk to older adults for physiological and psychological issues, such as cognitive decline, feelings of loneliness, and conditions such as depression and dementia (Fakoya et al., 2020).

Due to recent scientific and technological advances, individuals, researchers, and medical professionals can integrate advanced technologies such as mixed reality into daily life and healthcare to improve the overall well-being of older adults (Marston et al., 2021). While mixed reality is not a new concept, its contextualization and integration into the lives of older adults are still relatively unexplored (Marston et al., 2021). Existing literature predominantly focuses on the entertainment applications of mixed reality, with limited research conducted on its potential contributions to health and well-being in older adults (Hughes et al., 2017). Advancements and research in this area have the potential to minimize and optimize the issue of social isolation associated with aging (Hughes et al., 2017).

This short paper summarizes my thesis, which develops a system utilizing mixed reality tools in the context of physiotherapy for older adults with mobility issues. Existing remote communication solutions, such as telephone-based and video-based options, face various challenges and limitations in healthcare settings including usability, accessibility, security, and technological limitations (Harlington et al., 2022). Previous studies have highlighted the challenges associated with common remote communication approaches, including participant frustration with technology limitations, latency issues, and a preference for in-person communication (Schuster and Hunter, 2017).

3. METHODOLOGY

The methodology employed in this thesis is participatory design (PD), which involves the active participation of users in the design process of technological solutions (Danbjorg, Clemensen, and Rothmann, 2016). In this thesis, PD is used to involve users in the design of a mixed reality application for physiotherapy (Clemensen et al., 2017). By engaging users throughout the design process, PD ensures that the resulting technology meets their specific needs (Danbjorg, Clemensen, and Rothmann, 2016). This approach allows for the identification of problems and challenges and enables participants to contribute to the design and testing of the technology (Clemensen et al., 2017).

Participants for the user tests were recruited from the local community and Leeds Beckett University. A physiotherapist was consulted throughout the design process to ensure the safety and effectiveness of the exercises incorporated into the mixed reality application.

The mixed reality application allows for real-time interaction with virtual-world and real-world objects (the participants' hands). By using both Microsoft Teams and the Meta Quest 2 headset, the proposed system allows for an immersive experience. See Appendix A for the prerequisites of the proposed system. The Unity engine was chosen as the application development platform for its availability of documentation, the engine's flexibility, and its compatibility with the Meta Quest 2 headset. In particular, because it easily enabled the implementation of hand tracking and user interaction within the mixed reality application.

The integration of mixed reality technology in remote healthcare appointments is expected to enhance social sustainability, improve health outcomes, and address access barriers faced by older adults.

4. IMPLEMENTATION

4.1 Phase I: Physiotherapy Scenario Design

Throughout this thesis, a physiotherapist at Luleå University of Technology in the Division of Health, Medicine and Rehabilitation at the Department of Health, Education and Technology was consulted. The physiotherapist provided the following common and hypothetical interaction for which to base my design around: A meeting with an elderly person who has been assessed as having a high risk of falling and needs to follow an exercise program that focuses on muscle strength and balance training.

The physiotherapist provided a list of exercises that could potentially be implemented into the application to help improve the patient's muscle strength and balance. Using this list, one exercise from each type of training was selected for incorporation into the application: strength training, static balance training, and dynamic balance training. Based on these real-world tasks, exercises were designed and tailored to the

VRE that simulate everyday movements and challenges that the patient may face in a physiotherapist's office during a traditional, in-person appointment

The physiotherapist was consulted throughout the design process, providing feedback on the VRE-based exercises to ensure that they were effective and safe.

4.2 Phase II: Proposed System Physiotherapy Evaluation

Once the proposed system and application was developed, the physiotherapist supervising this thesis was briefed for a simulated patient evaluation. The researcher took on the role of a patient and launched the application, and shared the output to a Microsoft Teams meeting with the physiotherapist. The physiotherapist could see the body positioning of the researcher as she moved through each of the exercises. At same time, the researcher-patient's point-of-view in the VRE was projected into the Teams meeting. This demonstration was deemed suitable, and the researcher was encouraged to move on to the next phase of testing.

See Appendix B for an overview of the proposed interaction of an implementation of the application in a remote appointment scenario.

4.3 Phase III: Participant Scenarios

Potential participants were verbally screened to gauge suitability for this thesis. The requirements were such that they were an adult over age eighteen, and did not have any known mobility issues for safety purposes of running the scenario. The scenario involved participants using the application to complete three exercises: Strength Training, Static Balance Training, and Dynamic Balance Training. The total time for each task was recorded, and the number of successful cubes moved during the balance training tasks were counted. After completing the scenario, participants completed a feedback survey, which includes questions about their user experience and general feedback.

The experiments were conducted on a voluntary basis, and participants were briefed on the study's purpose and methods beforehand. Ethical considerations such as obtaining informed consent and maintaining confidentiality was carefully observed during the experiments. Any photos taken and utilized in this paper were used with the consent of the involved participants.

The implemented physiotherapy scenario consists of three tasks, each designed to target a different aspect of the participant's physiological health: strength training, static balance training, and dynamic balance training. The following table is a description of exercises to be completed by each participant while running the scenario:

Table 1. Descriptions of the exercise tasks in the implemented scenario

No.	Exercise Name	Exercise Description
1	Strength Training	The participant is required to complete ten air squats.
2	Static Balance Training	The participant is required to shift the body weight from side to side while picking up a cube from a table, moving the cube to the opposite hand, and placing it on the opposite end of the table. Finally, the participant will then repeat the motion and return the cube to the original side. The participant will repeat this task for a total of three cubes, and then repeat the motion to return all cubes to the original side.
3	Dynamic Balance Training	The participant is required to walk to a table, pick up a cube, and walk to the opposite table while carrying the cube, and place it down on the other table. The participant will repeat this task for a total of three cubes.

There is an elapsed timer that measures time to complete each and all tasks, which is controlled by each participant so they may start and end each task in their own time.

4.3.1 User Testing

25 participants were identified and assessed between April and May 2023. After obtaining informed consent from the participants, each session began with a brief introduction and explanation of the physiotherapy scenario, as well as an overview of the tasks that the participant would be required to complete. Participants were then given time to ask any questions they had before beginning the session.

Next, a safe area in the physical environment was identified by the researcher, and a Guardian boundary was set up on the Quest 2 headset. Then, the researcher summarized the controls required to operate the scenario, including teleportation, button selection, and grabbing. The research demonstrated the required hand gestures prior to moving forward. Finally, the researcher directed the participant to put on the headset, adjusted for comfort, and assisted with any additional questions or concerns prior to startup. The VRE at application startup is depicted in Figure 1.

Figure 1. VRE application on startup.

Once the level of comfort was found to be suitable, the researcher instructed the participant to familiarize themself with the environment, and to practice teleporting around the environment. Once the participant verbalized that they were comfortable with the controls, the researcher instructed the participant to begin with the strength training task.

Each participant was enabled to move through each of the three exercises in their own time. Depictions of some of the participants' and their point-of-views while completing the exercises can be found in Appendix B.

Qualitative notes were taken by the researcher throughout the scenario and evaluation process, with each participant's performance observed and notes were taken on their movements, reactions, and verbal feedback. The researcher also monitored the participant's progress on each task and recorded the time elapsed and number of cubes moved successfully for each relevant exercise. Once all three tasks were completed, the participants were instructed to remove their headsets, and then they were given a survey on Google Forms to complete.

5. PRELIMINARY RESULTS

The survey data collected from participants was analyzed using a variety of methods. Google Colab was used to allow for a more in-depth analysis of the data. In this section, images from the notebook are included. The data from the Google Sheet was first loaded into a Pandas dataframe to preprocess the data, which involved renaming, cleaning, encoding, visualizing, and transforming the data.

Qualitative data was collected through video and audio recordings, photos, and verbal and written feedback from participants both individually and in focus groups. The data will be organized and coded into categories based on common themes and patterns that emerge. The data will provide additional valuable insights and contribute to the overall findings of this thesis.

5.1 Participant Demographics Summary

Participants were between the ages of 18 and 65. Of the 25 total participants, 10 identified as female and 15 identified as male. Figure 2 shows the representations of the distribution of the genders of the participants.

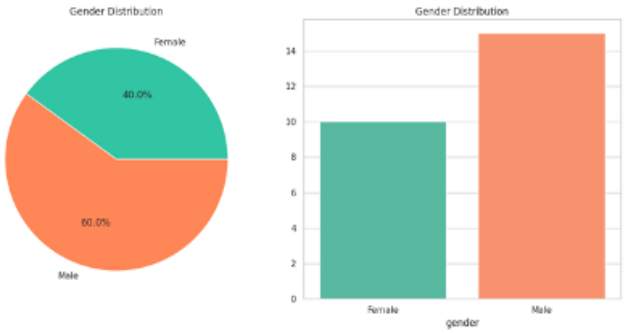

Figure 2. Gender Distribution of Participants.

The median age range of all participants is between the ages of 25-30. The median age range for both female and male participants is 25-30 as well. In the case of age range, the distribution is skewed right, as there are more younger adults than older adults in the sample. Using the median age provides a better representation of the typical age in the dataset. Figure 3 shows distribution of the age ranges of the participants by gender.

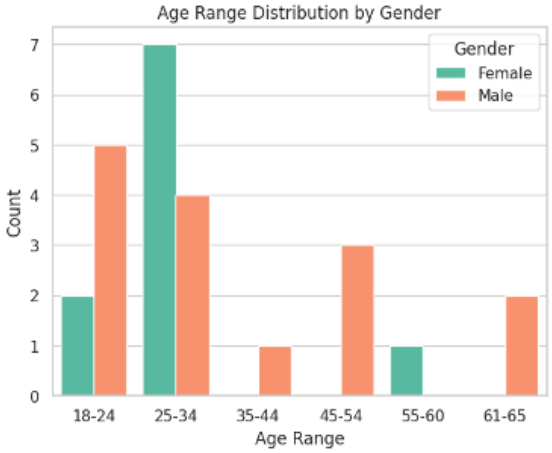

Figure 3. Age range distribution of all participants by gender.

5.2 Exercise Performance Summary

The median time to complete the Strength Training exercise for all participants is 29 seconds. The median time to complete the Static Balance Training exercise for all participants is 51 seconds. The median time to complete the Dynamic Balance Training Exercise for all participants is 30 seconds. The median total time to complete all exercises for all participants is 113 seconds.

The median scores across all participants for balance training exercises are 3 Static Balance cubes successfully moved from left to right, 2 Static Balance cubes successfully moved from right to left, and 3 Dynamic Balance cubes successfully moved.

5.3 Correlation Analysis Summary

A correlation analysis was conducted to identify variables that exhibited moderate or high levels of correlation with other variables, using a threshold of absolute correlation greater than 0.3. The correlation analysis revealed several variables that exhibited moderate to high levels of correlation. It is important to note that correlation does not imply causation. However, some notable correlations were observed, and their implications will be discussed in the subsequent discussion section.

5.4 Qualitative Results Summary

The survey results also yielded qualitative feedback from participants, which can be summarized as follows:

- **Positives**: Participants expressed positive feedback, highlighting the immersive nature of the VRE, the convenience of doing physiotherapy at home, and incentivization by the gamified elements of the exercises.
- **Negatives**: Some participants also mentioned certain drawbacks, including discomfort from wearing the headset, challenges in adapting to the virtual environment initially, and a desire for more variety in the exercises.
- **Improvements**: Participants provided suggestions for improving the experience, such as enhancing realism, improving the responsiveness of controls, and incorporating more visual and auditory feedback within the VRE.

6. DISCUSSION

The results of the user tests indicated the potential of the mixed reality application in addressing social isolation, improving access to physiotherapy services, and delivering effective training exercises remotely. Participants' feedback and survey responses provided valuable insights into the usability, comfort, and overall user experience of the mixed reality application. The findings suggest that mixed reality technology can be an effective alternative to traditional in-person physiotherapy sessions.

The following sections will delve into the specific findings in detail.

6.1 Participant Demographics Implications

The demographic summary of the user tests revealed that the participant pool consisted of 25 individuals, with only 3 participants aged 60 or above. While this limits the generalizability of the findings to the broader population of older adults, it highlights the importance of specifically studying this age group in the context of mixed reality applications for exercise. Future studies should aim to recruit a larger sample of older adults to better understand their experiences and outcomes in using mixed reality for balance and strength training.

Furthermore, female participants in the user tests on average performed better in terms of completing the exercises quicker. This finding is also aligned with the survey results of the female participants in the survey providing higher ratings for the instructions for the application. However, it is also important to note that speed is just one measure of success, and successful physiotherapy is more about improvement in strength and balance over a prolonged period of time.

6.2 Exercise Performance Implications

The analysis of exercise scores and times provided insights into the performance of participants in the mixed reality exercise program. The findings demonstrated variations in performance times across different exercises, indicating that some of the tasks were more challenging than others. The most difficult exercise across all participants was the Static Balance Training exercise, because many participants had difficulty in picking up the cube and transferring it to the opposite hand successfully. Understanding these differences between tasks is necessary for tailoring mixed reality physiotherapy programs to meet the specific needs and abilities of older adults.

The shorter median time for the Strength Training exercise compared to the Static and Dynamic Balance Training exercises suggests that the participants may find strength exercises relatively more familiar and accessible. Incorporating strength exercises that target specific muscle groups into mixed reality applications may provide older adults with a sense of familiarity and enhance their engagement and confidence in using the technology.

6.3 Correlation Analysis Implications

The correlation analysis revealed several significant correlations between exercise performance and other variables. These findings have direct implications for the design and implementation of mixed reality applications for older adults.

For instance, the strong positive correlation between Dynamic Balance time and Static Balance time suggests that older adults who perform well in one balance-related exercise tend to perform well in others. This finding emphasizes the transferability of balance skills in the mixed reality context. By incorporating multiple balance exercises that target different aspects of balance control and stability, mixed reality applications may effectively improve overall balance in older adults.

The correlations between exercise times and variables such as clarity of instruction, feeling of security, and demographic factors also have practical implications for the design of mixed reality applications. For example, those who took longer to complete the exercises may have experienced difficulties with understanding or following the instructions for the exercises.

6.4 Future Directions

The preliminary results of this provide valuable insights for the development and implementation of mixed reality applications for physiotherapy in older adults. As the thesis is fine-tuned, I will uncover the details of the insights, practical applications, and considerations:

- **Tailoring Physiotherapy Programs:** The variations in exercise performance times highlight the need to tailor mixed reality exercise programs to the specific abilities and needs of users. By providing a range of exercises with different difficulty levels, the application may be better suited to an individual's preferences and performance, allowing for an appropriate challenge.
- **Addressing Psychological Factors**: The correlation between exercise times and feelings of comfort and security in the VRE emphasizes the importance of creating an immersive and secure environment within it.
- **Enhancing Instructions and Feedback**: The negative correlations between exercise times and the participant perception of clarity of instructions highlight the significance of clear and concise instructions in mixed reality applications. Providing dynamic visual and auditory feedback, along with demonstrations, may aid in participant understanding and execution of the exercises.
- **Inclusivity and Representation**: As this research was limited to a small number of adult participants over the age of 60, future research should aim to include a more diverse and representative sample of older adults. This would better meet the unique needs and preferences of this population, ensuring that mixed reality applications are inclusive and accessible to a wide range of people.

Further research with larger and more diverse samples should be undertaken to expand these findings, to allow for the development of effective mixed reality interventions for older adults' overall health.

6.5 Ethical Considerations

This thesis examines the use of a mixed reality application as a system of supporting medical practitioners and patients, as opposed to using it to replace traditional care. Additionally, the broader use of mixed reality tools should not exacerbate existing inequities or biases within healthcare. Healthcare professionals and mixed reality developers must guarantee that the technology is accessible for diverse populations of patients.

6.6 Societal Implications

The preliminary results show that the application and participant scenarios were well-received, immersive, and engaging, indicating that mixed reality may be a promising tool for enhancing the life and care of older adults. The use of mixed reality in physiotherapy may also have broader implications for healthcare. However, it is important to note that additional research is needed to determine the long-term effects of mixed reality-enhanced physiotherapy and how it can be effectively implemented in clinical settings.

By creating immersive environments and scenarios, mixed reality technologies can provide a sense of co-presence and interaction that older adults may not have access to otherwise. In particular, the use of remote physiotherapy sessions using mixed reality and Microsoft Teams can promote social sustainability by improving access to healthcare services and addressing social isolation among older adults. By allowing older adults to participate in physiotherapy sessions from the comfort of their own homes, mixed reality technologies can remove physical and geographic barriers to care and provide a sense of social interaction that may have otherwise been lacking. This not only promotes social sustainability, but it can also improve physiological and psychological health outcomes.

6.7 Limitations

While this thesis provides useful insights, it is important to acknowledge its potential limitations:

- **Sample Size and Generalizability**: This thesis had a relatively small sample size, which may limit the generalizability of the findings. Moreover, only three out of 25 participants fit the criteria of an "older adult." Therefore, the findings may not fully represent the experiences and perspectives of that specific age group.
  Another limitation is that this application was only tested on one type of headset, the Meta Quest 2, which may limit the generalizability of the findings to other mixed reality systems.
- **Lack of Control Group**: Without a control group or comparative baseline, it may be challenging to attribute the observed differences between participants directly to the mixed reality application itself.
- **Research Duration**: This thesis might have been limited in terms of time constraints or duration, which could impact the depth of data collected. A more comprehensive research study would involve multiple scenarios and repeated interactions over a longer period of time to assess the long-term effects of mixed reality technology on participants' physical and psychological health.
- **External Factors**: External factors, such as technical issues with the mixed reality application or unexpected interruptions during the user tests, could have influenced the participants' experiences or performance, introducing confounding variables.
  For example, a few of the participants were affected by environmental constraints, such that they were limited by their immediate physical environment which affected and hindered the effectiveness of the VRE, and slowed down the completion of some of the exercise tasks. Another example is one participant could not complete the Dynamic Balance Training exercise due to the

battery of the Meta Quest 2 dying during the testing session.

7. CONCLUSIONS

In this thesis, a mixed reality application for remote physiotherapy sessions targeting older adults was developed and evaluated. It aims to address social isolation, access barriers, and the potential benefits of incorporating mixed reality technology in healthcare and physiotherapy. The application was designed to simulate real-world tasks and challenges faced during traditional, in-person physiotherapy appointments.

The data collection process was conducted in 25 participant scenarios. At the end of each scenario, participants completed a survey and provided feedback on their experience with the mixed reality application. A preliminary evaluation of the collected data has been completed to analyze the application, and initial limitations encountered were identified.

Although a more thorough analysis will be carried out, the preliminary results suggest that the incorporation of mixed reality technology in remote physiotherapy appointments is expected to increase social sustainability for older adults, leading to improved physiological and psychological health outcomes, a greater sense of community and social inclusion, and greater equity.

The preliminary analysis of the results in this thesis suggest that the mixed reality application improves access to physiotherapy services, and can deliver remote training exercises effectively. The results of the participant scenarios and feedback surveys provided valuable insights into the usability, comfort, and overall user experience of the application. Additional analysis of the results will be carried out. The incorporation of mixed reality technology in remote health and physiotherapy appointments shows potential for increased social sustainability, and improved physiological and psychological health outcomes.

In summary, this thesis demonstrates the potential of mixed reality technology in remote physiotherapy sessions for older adults. Through the incorporation of an immersive VRE and real-time interaction, the application aims to improve access, engagement, and outcomes in physiotherapy in older adults. Further research and development in this field could lead to more widespread adoption of mixed reality applications in healthcare and contribute to the overall well-being of older adults.

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Appendix A. EQUIPMENT AND PHYSICAL PREREQUISITES FOR THE PROPOSED SYSTEM.

Table 2. System prerequisites

Prerequisite	Rationale
Computer, Tablet, or Smartphone device	To run Microsoft teams and to share the Quest 2 screen to device
Microsoft Teams	To enable communication between the physiotherapist and the patient
Meta Quest 2 headset	To load and run the mixed reality application for the physiotherapy scenario
Internet Connection	A wireless or ethernet connection is required to connect the computer/tablet/smartphone device and the Quest 2 to the internet
Clear space in immediate physical environment to complete the tasks	On startup, the Quest 2 requires the establishment of a virtual boundary in the user's physical environment, called a Guardian. This is required for the user's safety.

Appendix B. SYSTEM INTERACTION ACTIVITY DIAGRAM

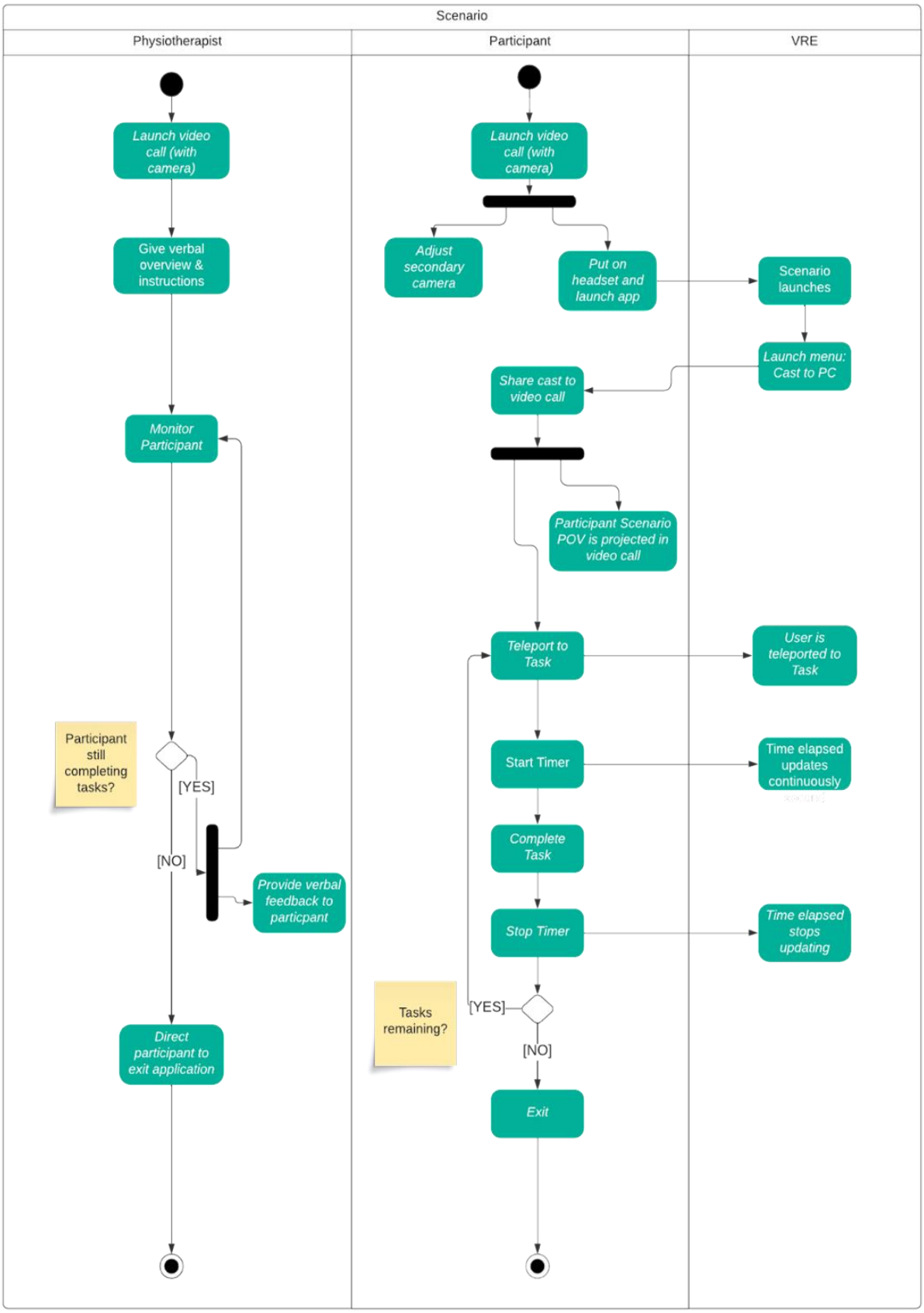

Figure 1. Activity diagram of the proposed interaction between physiotherapist, patient participant, and virtual reality environment: presenting interactions between each activity with arrows illustrating the flow of communication between start and exit points.

Appendix C. IMAGES OF PARTICIPANTS COMPLETING THE EXERCISES

Figure 1. A participant completing the Strength Training exercise; point-of-view while starting the timer at the Strength Training exercise (left), pictured doing air squats (right).

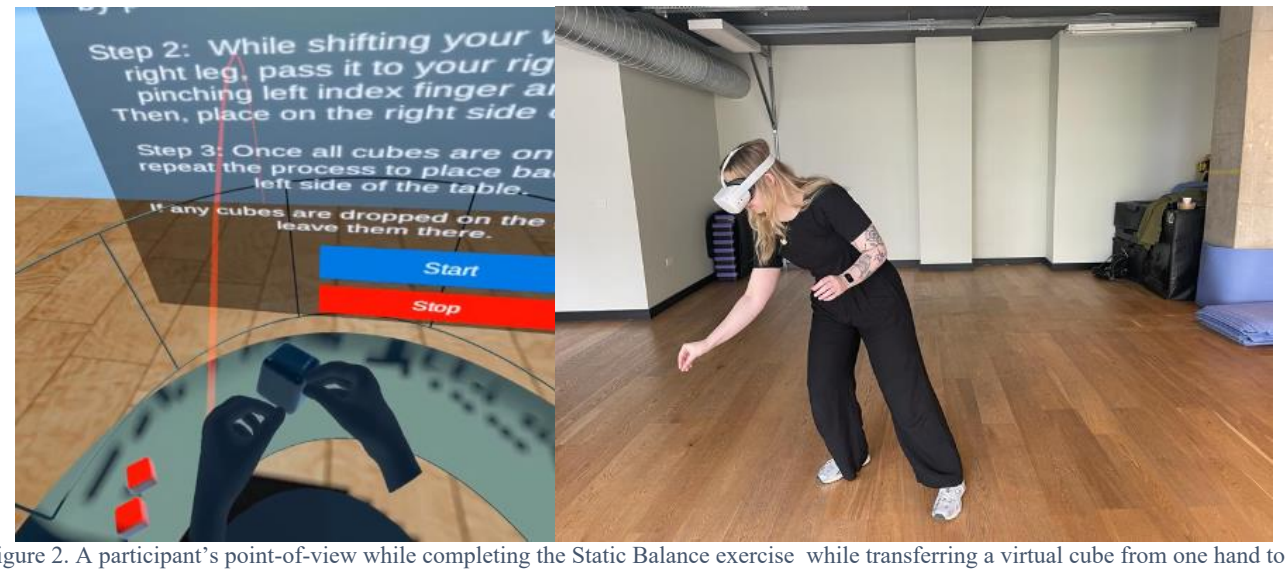

Figure 2. A participant's point-of-view while completing the Static Balance exercise while transferring a virtual cube from one hand to the other in the VRE (left), and pictured shifting body weight in order to pick up a virtual cube in the VRE (right).

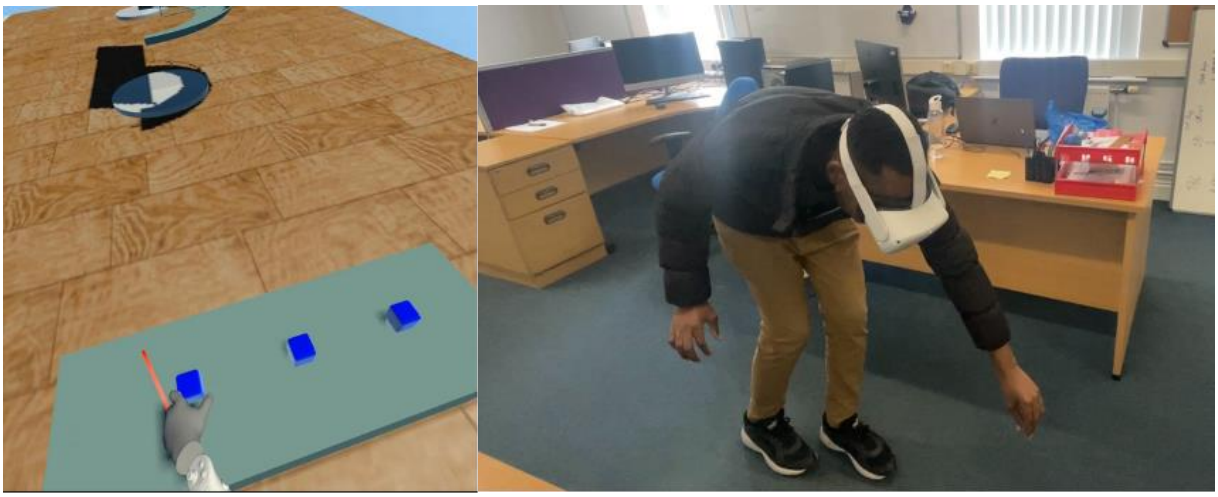

Figure 3. A participant's point-of-view while completing the Dynamic Balance exercise while picking up a virtual cube in the VRE (left), and pictured placing a virtual cube on a virtual surface in the VRE (right).