Com@Rehab: An Interactive and Personalised Rehabilitation Activity Based on Virtual Reality

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Keywords: Virtual Reality (VR), COVID-19, Motor Rehabilitation, Multidisciplinary, Virtual Reality Activity, Serious Games, Game Design, Health Communication.

Abstract: Background: This work presents Com@Rehab, a patient-centred activity for individuals needing a physical rehabilitation approach and with specific loss of functionality, designed for the context of severe post-covid19 complications. Within this scope, this paper focuses on the description of the activity in virtual reality (VR), its components, the game design approach, and the results of an initial prototype testing in the laboratory aimed at evaluating the experience of the Com@Rehab system. Methods: The VR activity was customised according to patients' clinical needs while replicating an activity of daily living. A prototype was tested by a group of 33 healthy individuals for a showering activity scenario. A questionnaire was developed within the scope of this project to test the efficiency of the technology that supports the VR activity, as well as to evaluate health literacy components. Results: Preliminary results showed that 94% of the participants recommended the experience, the performance of the various components of the system was successfully implemented, participants quickly adhered to the VR technology, and the user interface (UI) assistant functionality needs to be improved. Conclusion: The prototype test shows potential effectiveness in enhancing the rehabilitation experience and favourable usability, offering a promising path for advancing rehabilitative care. Further research is needed for validation in clinical settings. In addition, the Com@Rehab Communication Module improves human-human and human-machine communication while contributing to health literacy.

1 INTRODUCTION

Coronavirus disease 19, commonly known as COVID-19, outbroke into one of the most severe global health threats of all time, being considered a pandemic in March 2020 by the World Health Organization (WHO). The disease is characterised by several symptoms with a wide range of severity depending on factors related to the individual (Bhagat et al.,

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2022). In cases where the infection progresses, the developed symptoms may require urgent medical intervention and ICU admission in more severe cases. Once in the ICU, critically ill patients may require mechanical ventilation and be immobilised for long periods. Motor dysfunction is a common and serious complication of critical illness, which can be caused by critical illness polyneuropathy (CIP), critical illness myopathy (CIM), or a combination of both (Hermans and den Berghe, 2015). CIP is characterised by nerve damage that affects the muscles, particularly in the limbs, while CIM is a type of muscle weakness caused by inflammation and disruption of muscle fibres. It has been reported that approximately 26% to 65% of patients who receive mechanical ventilation may experience muscle weakness upon awakening in the ICU, and ICU-acquired weakness (ICUAW) has been diagnosed in up to 67% of patients who require long-term mechanical ventilation ($\geq$10 days) (Mirzakhani et al., 2013). Therefore, motor rehabilitation is crucial not only during the ICU stay but also after hospitalisation to facilitate the recovery of motor function, improve range of motion, restore coordination, and enable patients to regain their independence and resume a normal lifestyle. Furthermore, restoring motor function, specifically in the upper limbs, plays a pivotal role in determining an individual's prospects of leading an independent life, given that a significant portion of daily routine activities involves functional movements of the upper extremities.

Technological advancements have led to promising tools that offer a substitute or complement to conventional rehabilitation approaches (Viruega and Gaviria, 2022). The concept of employing serious games to enhance healthcare outcomes has garnered substantial interest and recognition within an expanding community of researchers, developers, and healthcare professionals (Damaševičius et al., 2023). Although the significance of technology has been steadily increasing over the years due to its integral role in transforming various aspects of society, ranging from communication to healthcare, there are still difficulties observed in patients' interaction with technology. Moreover, concerning the rehabilitation process, therapists need to develop simple, clear, motivating and effective communication with the patient to contribute positively to the recovery process.

Com@Rehab is a patient-centred activity based on virtual reality (VR), designed for individuals needing motor rehabilitation and with loss of function due to critical illness hospitalisation, with the final aim of bringing back independence in daily living activities. This system aims to create an effective, interactive, and humanised rehabilitation tool based on a VR activity and involving a Communication Module, therefore improving human-human and human-machine communication, to promote health communication in serious game technology and contributing to technological literacy.

This paper introduces Com@Rehab's concept and initial prototype of Com@Rehab, by providing a comprehensive overview of the VR activity, its constituent elements, design, and target user profile. Moreover, the paper highlights its adaptability and potential application across various age groups, pathologies, and rehabilitation settings. The paper presents the results of the prototype testing in the laboratory, which involved gathering feedback on the developed system from a group of healthy subjects who experimented with the activities for the initial prototype.

2 VR APPLICATIONS IN REHABILITATION

In academic literature, there is a prevailing notion regarding the potential of video games to captivate and stimulate individuals, thus potentially augmenting the retention and efficacy of their application in serious settings (Baghaei et al., 2022). This captivating aspect of games is particularly relevant in rehabilitation, where motivation plays a pivotal role, as it has been consistently linked to improved therapeutic outcomes (Vahlo and Hamari, 2019).

Due to the enticing and interactive attributes of games, coupled with the increased accessibility of affordable gaming devices, prior research has extensively investigated the multifaceted advantages associated with therapy utilizing game-based approaches (Shahmoradi et al., 2022) and virtual reality (Premkumar et al., 2021). The enticing and interactive attributes of games have led to numerous healthcare applications employing serious games from academic and industrial sources, encompassing diverse formats that align with various therapeutic methodologies (Abd-alrazaq et al., 2022). Such formats include exergames (Bassano et al., 2022), commercial games (Vita-Barrull et al., 2022), digital-based interventions (Baños et al., 2022), biofeedback (Lew et al., 2022), board games (Gauthier et al., 2019) and virtual reality (Oliveira et al., 2021; Hassandra et al., 2021; Gamito et al., 2015).

VR allows researchers to construct highly realistic environments while maintaining precise control over vital elements, such as visual and audio feedback and virtual characters. A crucial advantage of VR in rehabilitation lies in its potential to train patients using exercises that closely simulate the cognitive demands of real-life activities of daily living. This enables patients to engage in rehabilitation tasks that require cognitive processes, like how they perform within authentic real-life contexts (Hassandra et al., 2021).

Extensive evidence supports the efficacy of activities of daily living-focused therapy in enhancing patient performance in daily activities (Adams et al., 2018). According to Adams et al. (2018) the ecological validity of virtual world-based training for stroke rehabilitation remains to be thoroughly established. While the outcome measures employed in their study indicate improved motor function, further investigation is required to ascertain whether these gains effectively translate to enhanced performance in real-world tasks (Adams et al., 2018). A more recent study conducted by Oliveira et al. (2022) proposes that incorporating virtual reality-based exercises into everyday life activities could serve as a valuable cognitive rehabilitation approach, offering significant short-term improvements in cognition after a stroke (Oliveira et al., 2020). Moreover, for older adults, Liao et al. (2020) concluded that VR-based physical and cognitive training was superior in improving instrumental activities of daily living compared to conventional training (Liao et al., 2020).

Considering the focus of Com@Rehab as motor rehabilitation for the upper limb with VR, the literature indicates high activity and ongoing progress in this area of research. Aminov et al. (2018) conclude that VR shows advantages over conventional interventions, producing immediate and lasting improvements in motor function and cognitive abilities post-stroke (Aminov et al., 2018). Its efficacy applies to acute and chronic recovery stages, utilizing purpose-designed or commercially available systems. Baluz et al. (2022) developed a serious game called "Rehabilite Game" and evaluated its usability and user experience with physiotherapists and patients (Baluz et al., 2022). Additionally, the game was well-received by users, being perceived as user-friendly, attractive, and enjoyable. Notably, in the evaluation with patients, "Rehabilite Game" ranked among the top 10% of products with the most favourable outcomes. The study's findings revealed that the serious game elicited considerable excitement, fostering high levels of motivation (as indicated by the stimulation scale). According to Koutsiana et al. (2020), incorporating serious games can be an adjunctive approach to enhance motivation (Koutsiana et al., 2020).

These findings highlight the potential fruitful areas for future research in serious games and upper limb rehabilitation. Specifically, a promising path exists to explore serious games focused on remote rehabilitation, facilitating rehabilitation outside traditional clinical settings. Additionally, game difficulty adaptation based on the user's muscle strength and posture emerges as a key idea to explore, allowing for personalised and tailored interventions to enhance rehabilitation outcomes. These concepts resonate with the core idea of the Com@Rehab project, which emphasises the importance of advancing serious games in rehabilitation to promote effective and personalised therapy approaches.

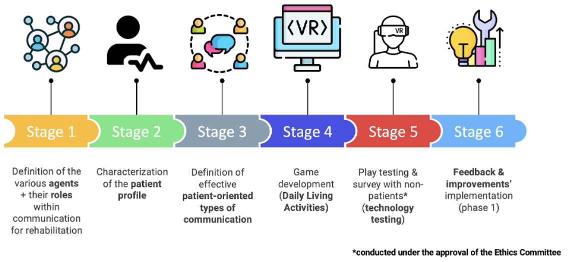

Figure 1: Simplified step-by-step methodology.

3 MATERIALS AND METHODS

The prototype presented in this paper arises from the need to adapt the Com@Rehab solution to post-COVID patients, from the observation of patients' difficulties in interacting with technology, and the efforts of therapists to develop motivational communication with them. The Com@Rehab is an innovative interactive rehabilitation technology system, which combines VR and a biosensor glove to rehabilitate patients in a hospital/home setting (Quaresma et al., 2018; Fonseca et al., 2019). As an innovating factor, a communicative support module for post-COVID patients, Com@Rehab, has been integrated into the existing solution. Com@Rehab thus encompasses an interactive rehabilitation methodology focused on humanised communication between rehabilitation professionals (therapists) and patients through a VR game. In this methodology, the patient plays a central role. The steps taken for the development of Com@Rehab, from requirements' identification and prototype testing, are depicted in Figure 1.

3.1 Com@Rehab Description

This section describes the Com@Rehab prototype that was developed following the steps described before. The defined requirements for the VR activity were, firstly, to be intuitive and quick to learn, especially since the main target users are older adults, as well as physicians or therapists who professionally,

Figure 2: Com@Rehab bathroom with the virtual character.

may not be used to working with technology. Secondly, to perform a serious and interactive patient-centred rehabilitation using different forms of communication, always with a motivating purpose. A therapist should also accompany the VR activity and report the patient's progress. A game scenario was developed to meet these requirements, where the innovation lies in the contributions of Linguistics to structure the interactive component and increase communication effectiveness during the VR activity.

3.1.1 VR Activity

The activity is a single-player VR experience developed using Unity for the Oculus Quest 2 headset. The selection of this headset and Oculus Quest controllers was driven by its portability, affordability, and ease of setup. In this activity, the player assumes control of a virtual character navigating a VR bathroom to carry out various self-care activities. The design and implementation of the bathroom aim to create a relaxed and immersive environment and Figure 2). The game is designed to be played in a stationary position, either sitting or standing, without incorporating any player locomotion. This intentional design choice aims to minimise the risk of cybersickness. The activity is presented in a video: https://youtu.be/x6WXhHrAjlk.

The activity was designed for persons with age above 65 years, post-ICU hospitalisation with overall decreased strength, i.e., muscle weakness and reduced range of motion, with no signs of ataxia, sensory deficits, or cognitive and/or perceptive impairments. Based on the International Classification of Functioning, Disability and Health (ICF) (Organization., 2001), it was determined that target patients have a “Moderate Problem”.

The ICF's Activities and Participation domain guided the selection of suitable rehabilitation activities for the platform. Self-care activities were chosen, given their emphasis on taking care of oneself and personal health, as they are crucial for maintaining self-esteem and one's image (Organization., 2001). Com@Rehab focuses on the subchapter of washing oneself, where the patient is led, step by step, to reproduce the appropriate movements for autonomously washing a specific body area. The VR activity and the game design were structured in varying difficulty levels, and progression to the next level depended on the preceding level's successful completion.

For the therapist:

- Communication within the therapist's menu is facilitated through both written and verbal means. Before starting the activity, the therapist, player, or caregiver is provided with the option to customise various parameters, such as selecting the desired level (1, 2, 3, or 4), determining the number of repetitions for each body part (ranging from 0 to 2), and setting the tolerance level for the range of motion. Upon completion of the activity, the therapist gains access to the ”Final Quantitative Result,” comprising crucial information, including the duration of each task and a graphical representation depicting the patient's progress over time.

For the player:

- At the beginning of each session, the player is presented with two options: (i) proceed directly to the shower by pressing a prompt button or (ii) explore the bathroom to familiarise themselves with the virtual scenario.

The prototype comprises a calibration stage (adaptation of the environment towards the player's physique, as arm length and height) and the first difficulty level. This level includes washing the belly and forearm, with voice instructions using clear and easily understandable language for the patient (Figure 3). The tasks' activities are available in the videos: https://youtu.be/93eIX7spTOU and https://youtu.be/NoPlR3UsvhQ.

Throughout the application, most interactions are conducted via directional gaze tracking, allowing participants to make choices by merely looking at their preferred options. During the rehabilitation exercise tasks, direct input from the participant's upper limbs is necessary to execute the exercises.

Colour bubbles are strategically positioned on the relevant joints to provide visual guidance for the player's task execution. Upon the gesture's successful and precise completion, the bubbles transform from yellow to green (Figure 3).

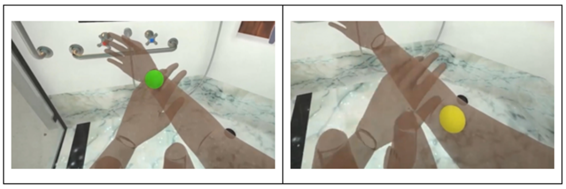

Figure 3: Guided Joint Colour Transformation.

3.1.2 Communication Module

Com@Rehab's communication module was designed according to the principles underpinning health literacy, namely "an individual's knowledge, skills, motivation and ability to identify, understand, evaluate and use health information when making decisions in the contexts of health care, disease prevention and health promotion to maintain or improve quality of life over the life course" (Sørensen et al., 2012). Health literacy is currently a key concept in patient education, disease management, and health promotion. Thus, the communication module developed within the scope of this project and of the VR game aimed to foster the patients' abilities to obtain, assimilate and transmit information, to suitably execute and progress in their rehabilitation exercises. While contributing to increasing their personal involvement and motivation in what concerns their rehabilitation process, such an approach also promotes the patients' adherence to technology as a therapeutic medium.

Each stakeholder involved in the communication module plays a critical role in the effectiveness of the proposed solution from a therapeutic standpoint. Given his/her degree of involvement, the patient is simultaneously the receiver (via written and voice instructions, as well as visual elements) and the sender of the information (reacting to the decision-making stages that allow him/her to progress in the game or providing feedback about his/her motivation status). The therapist, on the other hand, plays two roles as far as the game communication is concerned. As a sender, inside the VR game, his/her voice is recorded to guide the patient on how to suitably perform the rehabilitation movements and also to provide encouragement. Outside the game, the therapist is a receiver of information transmitted by the patient, both orally and via his/her body. In addition, the therapist supervises and assesses the correction of the various movements, thereby taking on an active role inside and outside the game. This methodology, focused on humanising communication, an approach centred on the interactions between the various stakeholders, supports the development of positive relationships between patients, therapists and caregivers (Gordon et al., 2019) and is, therefore, a relevant empowering tool towards self-care and at the service of health, technological and digital literacy.

The communication framework was developed by a multidisciplinary team composed of linguists and rehabilitation experts. Firstly, the team identified the components of verbal and non-verbal communication which should integrate Com@Rehab's communication module. The next step involved work on linguistic description, namely regarding language use, as well as the role of verbal and non-verbal language within the scope of the proposed game. Sentence construction rules were also applied to develop clear and precise instructions, following plain language principles (Action and (PLAIN), 2011).

Afterwards, the different types of communication underpinning the game development stage were outlined and subdivided into two: game-patient communication and patient-therapist-game interaction. On the one hand, the game-patient communication includes verbal communication, with voice-based and written instructions/messages containing domain-specific terms and expressions adapted to patient/caregiver understanding. Non-verbal elements have also been included and play a key role: for example within the scope of VR, an animation of a 2D User Interface (UI) assistant performing the intended activities is used, and hence mimics them, in case the player needs help to perform the activity; there are also sound effects, such as clapping, to congratulate the patient for the successful completion of a given task; the game contains visual indications of temperature and dirt when, for instance, a body part is being washed, which provides information on how long the patient might still take to complete that task; finally, emojis have also been incorporated to allow the patient to describe his/her emotions at different stages of the game. He et al. have recently argued in favour of the use of emojis in healthcare communication, highlighting some of its advantages, namely the "universal appeal" of such a visual medium, as well as the ability to make information accessible to more and more people within the healthcare ecosystem (He et al., 2023).

The patient-therapist-game interaction exists in two forms: firstly, by showing motivational patient-oriented communication, which can be conveyed through written or visual means; for instance, the patient can interact with the game by selecting the body part he/she would like to wash which, in this case, will retrieve from the database a set of tasks pre-defined by the therapist according to that patient's stage in the rehabilitation process, while the second form comprises therapist voice instructions for each rehabilitation exercise.

The final result consisted of introducing three levels of patient communication, which integrated the communication module and are complementary in their objectives: (1) to increase the patient's general knowledge (functional literacy); (2) to develop the patient's understanding (communicative literacy); and (3) to boost patient motivation through his/her active involvement (motivational literacy).

The UI was designed concerning the user's characteristics and the narratives of the procedure and comprised two different screens. The main screen that shows the principal information is positioned on the level of a seated person, and the secondary screen shows auxiliary information below, usually the task's status. The system's communication modalities with the patient are audio and visual (usually text) to ask questions and give instructions and feedback for the exercises.

The first challenge in the user interface and interaction was the clarity of the message, meaning the readability. A sans-serif font was used, and size and leading were considered to improve the readability in older adults (Beier and Oderkerk, 2021). The communication modalities from the user to the system are eye gaze to select the answers and act on some objects and movements using the controllers.

In the questions to the user, the options appear beside the main screen. The selection is made with the eye gaze; the selection status is communicated to the user with a colour that fills the selected button. Other actions, such as opening the shower faucet, have visual feedback. In both cases, this visual feedback is associated with time so that the user knows that he can interact with that object, and if he fixes the eye gaze, he can select it.

To support the exercise executions, the interaction principles of feedback and mapping were used (Norman, 2013). Mapping indicates the points where the movement should pass, and feedback during the exercise shows the number of concluded repetitions.

The virtual environment in terms of space and colours was also designed with the impacts of ageing in sensory modalities, especially auditory, visual, and movement control (Fisk et al., 2018).

As mentioned before, the virtual assistant was created to assist in exemplifying the exercises. It is positioned on the right, at the same visual level as the screens (Figure 4). The system is prepared to count the times the patient looked at the animated character. This count could indicate how many times the patient needed assistance (https://youtu.be/p2ayJN2vwAA).

Figure 4: VR activity scenario with the animated character.

3.2 Prototype Testing

The main goal of prototype testing was to evaluate the experience of the Com@Rehab system and the usability of one of its activities. The study sought to collect valuable user feedback on challenges encountered during VR interaction and suggestions for enhancing the overall experience. A usability test was conducted with a group of 33 individuals who did not have any associated pathologies, to assess the technological aspects of the activity. All participants signed an informed consent including the objectives and description of the study, as well as the statement of GDPR compliance.

3.2.1 VR Game Activity

The VR activity involved two different tasks, namely washing the belly and washing the forearm. These tasks constituted the first level of the VR activity, each with a maximum duration of 10 minutes. User interaction was simplified by selecting activity options through gaze direction. To facilitate task completion, yellow balls were strategically placed in the regions to be washed, guiding the necessary path. However, for washing the belly, an initial calibration step was required to determine the desired location for washing. All activities were repeated three times to support the rehabilitation process. If users faced difficulties performing the movements, a 2D animated character demonstrating the required actions was available on the right-hand side of the VR environment. User choices and the number of times they sought help from the character were recorded in the database for further analysis. Upon completing both activities, the VR session was concluded.

3.2.2 Instruments to Evaluate Communication in the VR Activity

To test the communication interaction in the VR activity, we developed a questionnaire in European Portuguese, based on previous work by (Ishikawa et al., 2008; Ousseine et al., 2018; Bandura, 2005). We partially adopted Nutbeam's (2000) theoretical model of health literacy, namely concerning two of the three literacy levels he proposes: functional literacy (transmission of factual information) and interactive literacy (Nutbeam, 2000), also known as communicative literacy (Ishikawa et al., 2008) (opportunities to develop skills in a supportive environment). These advanced competencies allow us not only to extract information and meaning from different communication sources but also to apply new information to various situations and circumstances. The third level put forward by (Nutbeam, 2000), critical literacy (i.e. advanced competencies that enable someone to critically analyse information and use it to perform several actions), has not been taken into account, since it was not considered pertinent in this context.

Within the scope of this project, we believed it would be relevant to explore a component of interactive/communicative literacy which Nutbeam calls motivational literacy and defines as the "improved capacity to act independently on knowledge, improved motivation, and self-confidence (Nutbeam, 2000). Motivational literacy in healthcare implies literacy not only in what concerns basic healthcare knowledge but also in understanding the psychological aspects underlying motivation and behaviour change.

As a whole, these three literacy components (functional, communicative and motivational) constitute the backbone of the questionnaire developed for the project. They play a crucial role in determining whether the individuals are involved in health promotion behaviours or less healthy habits or attitudes.

The questionnaire was applied and divided into three groups of questions to evaluate different aspects of the VR experience. The first group focused on functional literacy, gauging elements' clarity, such as the adequacy of time for reading instructions and ease of using gaze for option selection. The second group delved into communicative literacy, assessing comprehension of words, voice instructions, and nonverbal communication effects. The third group centred around motivational literacy, exploring participants' motivation levels concerning various aspects of the VR activity. Each group comprised 6-8 questions, and participants rated their responses on a Likert scale ranging from 1 (totally disagree) to 5 (totally agree). Once the questionnaire was finished, the test was concluded, with a total duration of approximately 30 minutes.

We used Cronbach's Alpha coefficient as a statistical measure to evaluate the internal consistency of the questionnaire, based on the answers from the participants in the prototype testing.

Figure 5: Flowchart of the experimental setup.

Data Collection and Privacy: To ensure participant privacy, each individual was assigned a unique code for the questionnaires, interviews, and game metrics. The data collected were associated with the respective participant's code and stored in a database accessible only to the investigators responsible for the Com@Rehab project. Upon study completion, all identifiable information would be securely destroyed.

3.3 Experimental Protocol

The experimental protocol followed a series of steps demonstrated in Figure 5.

At the beginning of the experience, participants were asked to complete a sociodemographic questionnaire to enquire about age, genre, nationality, and experience with video games and VR, among others.

Following that, and before starting the experiment, the VR glasses were placed on the participant, who was in a seated position, and the handling of the controllers was explained After completing the game activity, the participant removed the VR glasses, and a questionnaire about the game experience and its usability was conducted. In this type of activity, considering that the participant only had to perform movements of the upper limbs and head, the risk of cybersickness was very low. However, in case it occurs or if the participant felt any discomfort, he/she had the possibility to abandon the experience at any time.

4 RESULTS

The prototype testing stage aimed to assess the VR technology integrated with a communication module in motor rehabilitation. As referred to earlier, we collected sociodemographic data from participants, including age, education level, and previous experience with VR technology. Additionally, we evaluated participants' functional, communicational, and motivational literacy understanding upon completion of the activity. In this results section, we present a detailed analysis of these outcomes to shed light on the future improvements of the project.

4.1 Sociodemographic Questionnaire

The sociodemographic questionnaire was completed by 33 participants, with an average age of 36 years

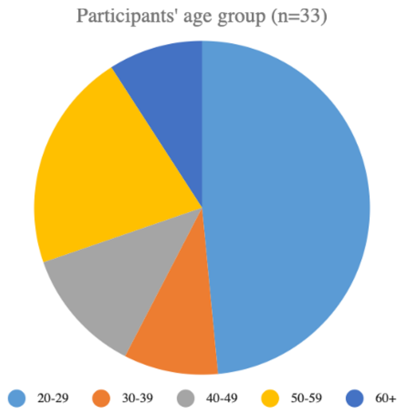

Figure 6: Graph showing the distribution of the 33 participants according to their age, with the 20-29 age group constituting the largest proportion (48%).

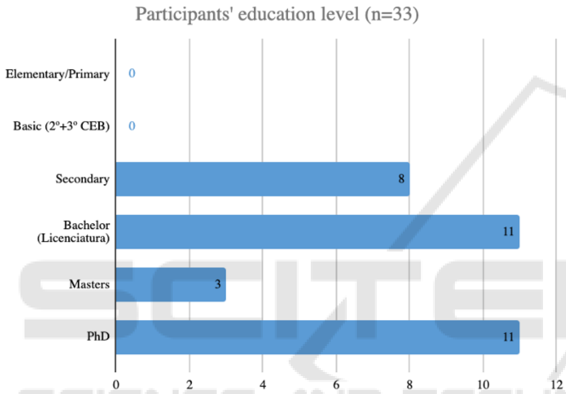

Figure 7: Graph showing the distribution of the 33 participants according to their education level.

(standard deviation (SD) = 15.9) and an age range of 21 to 71 years. A pie chart that depicts the participant's distribution by age is shown in Figure 6. The participants' education level is represented in Figure 7, where it can be seen that the majority of participants (approximately 76%) had completed at least some college education, while 24% had a high school diploma or equivalent, and 33% had a PhD.

Regarding previous experience with VR technology, as can be seen in Figure 8, 76% of participants reported having used VR devices before, of which 27% used them occasionally or regularly.

We also conducted statistical analyses on their prior experience with VR based on age (Figure 9) and educational level (Figure 10). The results revealed a significant difference in the level of VR experience across different age groups, with older patients reporting less prior experience with VR than younger patients. However, there was no significant correlation between educational level and prior experience with VR. These findings can inform the development

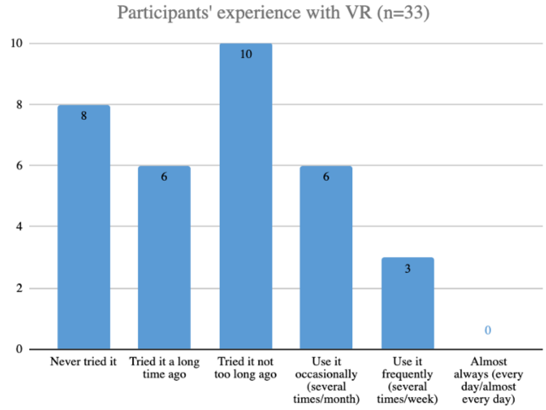

Figure 8: Graph showing the results for the question "Experience with VR" by age group.

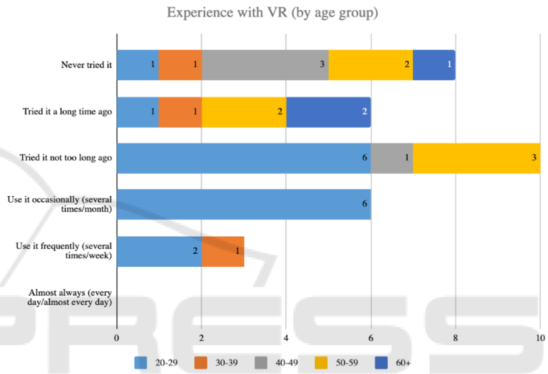

Figure 9: Graph showing the results for the question "Experience with VR" by age group.

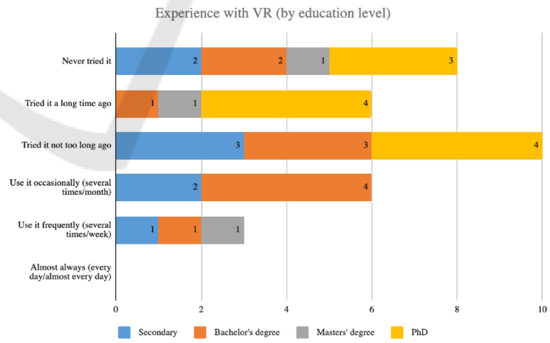

Figure 10: Graph showing the results for the question "Experience with VR" by education level.

of future VR-based rehabilitation programs that consider the varying levels of prior experience with VR among different patient populations, focusing on the needs of older patients who may require additional support in using VR technology.

These findings suggest that our sample is relatively diverse in terms of age, education level, and familiarity with VR technology, which will be important to consider in our subsequent analyses.

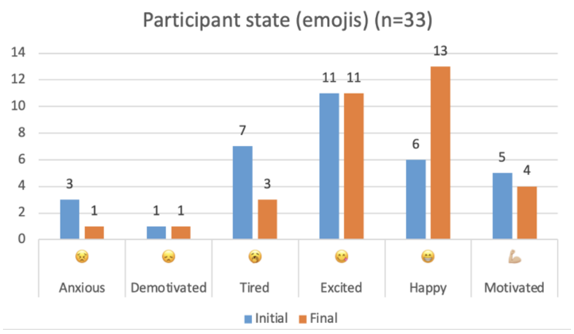

Figure 11: Graph showing the initial and final state of the participants according to their emotions: anxious, demotivated, tired, excited, happy, and motivated, respectively.

4.2 Participant State

The graph represented in Figure 11 displays the number of selected emojis representing various emotions before and after the rehabilitation activities. The x-axis represents different emotions, ranging from negative (anxiety, demotivation, tiredness) to positive (excitement, happiness, and motivation). The y-axis represents the number of times each emotion was selected. The aggregate scores show that two-thirds of the participants (66.7%) initially selected emojis connected with positive emotions, whereas the remaining third (33.3%) self-perceived their initial emotions as negative. The graph also shows a noticeable shift in the distribution of emotions after the rehabilitation activity, with an increase in positive emotions (from 22 to 28 participants overall) and a more significant decrease (of about 55%) in negative ones (from 11 to 5 overall). This suggests that the rehabilitation process had a positive impact on the patients' emotional well-being.

4.3 Functional Literacy

The functional literacy part of the questionnaire was composed of 8 questions related to the game functionalities, more specifically, if the types of communication used were adequate and helpful. Through Figure 12, it is possible to conclude that there were two questions whose response was not as positive as expected, namely regarding the choice of options through the gaze (question 5) and the use of the animated character or UI assistant as an animation to mimic the intended movements and therefore clarify and help accomplish the tasks (question 8), both questions related to the technological aspect of the activity. Considering the divergence among respondents regarding the use of the animated character, it is imperative to enhance its purpose and provide a clearer understanding of its intended function, thereby addressing an exist-

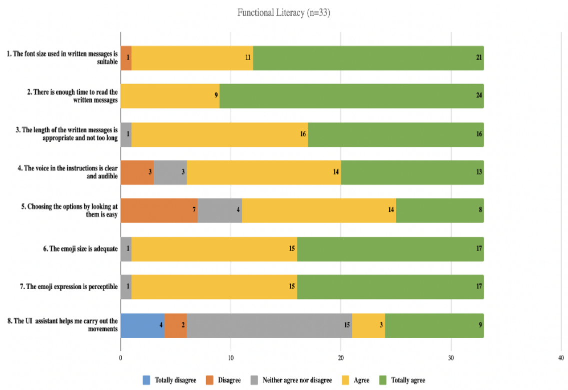

Figure 12: Graph showing the results for each question regarding functional literacy.

ing gap in the game. Respondents generally provided positive feedback to the remaining questions, indicating that the literacy techniques were proficiently implemented in the functional aspect of the game.

4.4 Communicative Literacy

The communicative aspect of the questionnaire included seven questions related to the user's understanding of voice instructions, written messages, emojis, UI assistant, and visual and sound effects used in the game, whose response statistics are shown in Figure 13. Question 5, which addressed the presence of the UI assistant, received the least amount of "totally agree" responses and the most amount of "totally disagree" responses, indicating the need for further investigation. Additionally, question 6, which asked about the use of coloured balls as visual effects to represent the path required to complete a task, received some contradictory responses as well. However, the remaining questions were successful, with participants providing positive feedback regarding their understanding of the various communication methods used in the game. Comparing the communicative aspect questionnaire with the other two literacy questionnaires (i.e., functional literacy questionnaire and motivational literacy questionnaire), it was found that the former had the most successful responses.

4.5 Motivational Literacy

The motivational literacy questionnaire, which consisted of 6 questions regarding the motivation of participants when playing the game and their responses to verbal and non-verbal communication, received the least amount of "totally agree" responses out of the three literacy questionnaires. As represented in Figure 14, the most positive response was the "neither agree nor disagree" option, indicating a lack of strong

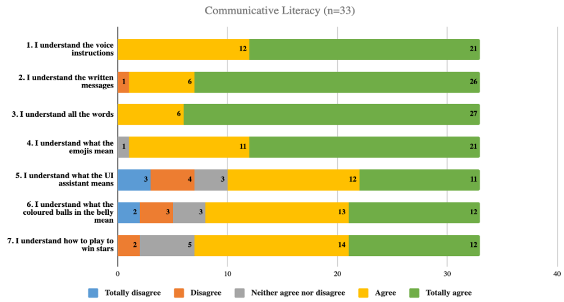

Figure 13: Graph showing the results for each question regarding communicative literacy.

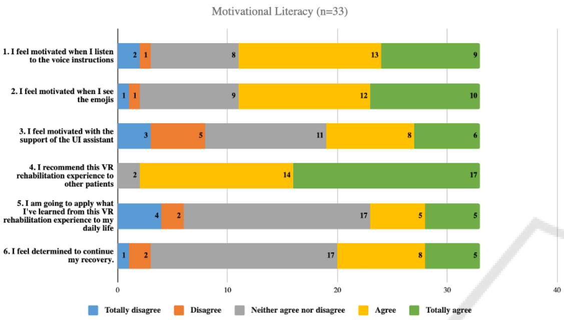

Figure 14: Graph showing the results for each question regarding motivational literacy.

agreement. However, it should be noted that the usability tests were completed by healthy participants who did not require the motor rehabilitation process, and therefore, the less positive responses to questions 5 and 6 should not be interpreted as negative feedback.

4.6 Internal Consistency

The Cronbach's Alpha analysis conducted in this study provided a valuable measure of the reliability of the questionnaire that we applied for the evaluation of three components of literacy. From the answers of the 33 subjects, the coefficients and confidence intervals (95%) obtained were: 0.98 [0.961, 0.996], 0.91 [0.775, 0.981] and 0.90 0.739, 0.984], for the functional, communicative, and motivational literacy questionnaires, respectively. These results suggest high internal consistency for the three components of our questionnaire.

5 DISCUSSION

Overall, our results suggest that integrating VR technology and a communication module holds promise for improving patient-centred rehabilitation in individuals with motor impairments.

The results of the prototype testing activity were vital in determining whether users could understand voice commands, written messages, emojis, UI assistants, and visual and sound effects when using rehabilitative technology. Overall, the user feedback depicted several positive aspects: participants generally adhered to the equipment and overall technology, with no identifiable side effects (VR-related nausea) or doubts, while also successfully interacting with the game itself and the created scenario. In what concerns the motivational literacy component, there was a clear trend towards more positive emotional states from the participants at the end of the activity. Furthermore, 94% of the participants recommend the experience. However, the data also provided some crucial insights concerning potential improvements in future iterations: clearer and more audible voice instructions, with no (or less) background noise, should be integrated. Participants partially questioned the pertinence of such voice-based input as a motivational component. In addition to improving the UI assistant's functionality, participants specifically mentioned the need to make game option selection easier for the end user. Contradictory answers were also provided when colourful balls were used as visual effects to symbolise the necessary task path.

Results indicated a decrease in tiredness and motivation, which seems contradictory to the positive results related to experience and usability. The decrease in tiredness might result from our iterative design process, which optimized interactions to minimize user fatigue. As for motivation, it could have diminished as participants were aware that the prototype testing phase had concluded, reducing the novelty and excitement associated with evaluation. It's important to note that these findings are based on participant responses, and while we can speculate on the reasons, we don't have exact insights into individual choices. Future tests should include methods to evaluate the user choices in the experimental design to obtain a clearer explanation for the results.

This study was primarily qualitative, aiming to validate the technology in a laboratory environment using healthy individuals. Future research will test the VR activity with a group of patients. To further validate the patient experience, various patient groups with distinct pathologies and functionality levels will be included. Quantitative measures will be integrated into the prototype tests; such metrics will be derived from comprehensive in-game data collection, including but not limited to parameters such as elapsed time, initial exercise choice, exercise duration, error frequency, and repetition of completed exercises.

These results underline the importance of improv-

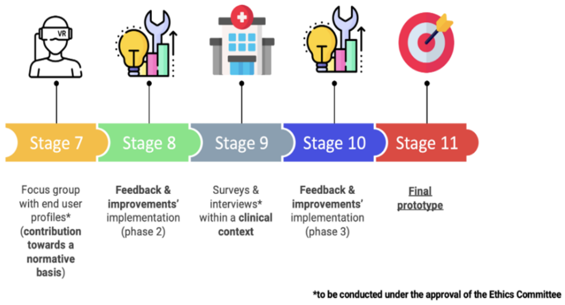

Figure 15: Simplified step-by-step methodology ahead.

ing and optimising the technology's communication components to improve user experience and comprehension. In the health sector, communication gaps between patients and healthcare providers can hamper patient-centred care and shared decision-making. Health literacy aims to foster clear and assertive communication, thereby ensuring that the various options in healthcare provision are understandable, pertinent, and applicable. Technology is indeed becoming increasingly crucial in healthcare communication, but clarity, understandability and empathy cannot be understated in this regard.

To maximise the communication components of patient rehabilitation technology, it is essential to go deeper into the issues found, address the participants' concerns, and explore creative solutions. Finding new ways to improve healthcare communication through innovative solutions and new dialogue interfaces, such as the ones provided by VR, is a current and quite promising challenge. Com@Rehab intends to transform therapeutic intervention by promoting more humanised communication, in an environment in which the interaction, though conducted through VR, aims to be as close as possible to human-related settings that are familiar to the patients. Ultimately, by contributing to the enhancement of patient motivation and subsequent therapeutic adherence, this approach helps to support more effective and improved results in patient rehabilitation. One of the strengths of the project lies in the interdisciplinarity and complementarity of the theoretical and methodological approaches underlying the different scientific areas involved.

After conducting an in-depth analysis of the laboratory and usability test results, we will proceed with optimising the initial level of activity. Once this is accomplished, the project will advance to subsequent phases, focusing on the development of the remaining levels and conducting validation with the target population (Figure 15).

6 CONCLUSIONS

In conclusion, this study introduces Com@Rehab, an innovative patient-centred activity tailored for individuals requiring targeted physical rehabilitation interventions. The paper outlines one VR-based activity, encompassing its essential components, game design, and the outcomes of a prototype test. The results of the prototype test showcased the potential effectiveness of the Com@Rehab system and its favourable usability in enhancing the rehabilitation experience. By emphasizing patient-centricity and leveraging the capabilities of virtual reality, Com@Rehab presents a promising path for advancing rehabilitation practices and addressing the diverse needs of individuals with functional limitations. Since these are preliminary results, further research and evaluation are crucial to refine and validate the system's efficacy in clinical settings, ultimately contributing to advancing patient-centred rehabilitative care.

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