Virtual Multiuser Environment for Adapted Physical Activity and Rehabilitation for Older Adults: Usability and Acceptance Evaluation

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Abstract **Physical activity and socialisation are vital keys in enhancing health and well-being of older adults. This paper presents a usability, accessibility, and user acceptance evaluation study of a virtual multiuser environment that allowed users to train and socialise with other older adults under the supervision of a physical trainer. Researchers used an open-ended questionnaire to interview six participants who resided at nursing home. The identified issues will be considered in the next refinement phase of the system. These issues included the instability of avatars´ movements, and the need to provide the environment with a mechanism for reachable human support and integrate gamification approaches to enhance users´ commitment. They also involved the need to align the avatars´ location and size with the expected roles in the training sessions, and the importance of finding an alternative solution to detect users´ soft voices and transmit them to the environment. Screen´s size, height, and distance with the users are three correlated factors that should be standardised and optimised according to users´ needs and systems´ calibration demands.**

Keywords-Active Ageing; Virtual Reality; Adapted Physical Activity; Rehabilitation; Usability.

I. INTRODUCTION

The global proportion of older adults (over the age of 60) is expected to double between 2017 and 2050 [1]. Aging is often linked with deteriorating health and physical abilities; However, it can be a positive experience, and is commonly referred to as "active ageing" or "successful ageing.". Promoting active aging in the community is crucial in this regard. Regular Physical Activity (PA) positively affects the main determinants of active ageing: good physical and mental health, opportunities for social interaction, the ability to cope with disease symptoms and functional limitations [2][3].

Many scholars and designers recognize the potential of Virtual Reality (VR) technology to enhance older adults´ wellbeing, quality of care, and socialisation while also supporting their independence [4]. For instance, VR games interfaces such as the Wii [5], Kinect-based systems [6]-[8], Rehaboo [9], and REHABILITY [10] have been utilised in improving physical function, balance, and fall prevention of older adults. Additionally, XRHealth [11], Eodyne [12], and Clynx [13] offer personalised VR-based rehabilitation sessions for older adults, each tailored to individual cases and remotely supervised by professionals. Other VR based solutions adapt the multiuser feature to enhance user engagement and motivate the olders adults to exercise, such as the Social Bike [14], and the social collaborative VR-based exergame for rehabilitation [15] and Maestro Game VR [16] for physical and cognitive treatment.

Incorporating older users early in the design process through participatory (PD) and co-design methods will enhance the usability and acceptability of digital products or systems. The active involvement of older adults enables designers and developers to create solutions, which meet the users' requirements and preferences as well as understand the context in which they will use the solution. VR2Care [17] is a digital ecosystem developed using participatory and co-design methods to promote the physical activity and socialisation of older adults through the use of interactive technologies. Four partners, bringing their existing products [10] [18]-[20], are engaged in an integration process aimed at providing older adults with virtual environments for playing exergames or exercising individually or in groups with a trainer across various virtual settings. Additionally, VR2Care offers clinicians, physiotherapists, physical trainers, and caregivers a telemonitoring and onboarding tool for crafting training and rehabilitation plans, whether for single or group sessions in a Multi-User Environment (MUE). This tool enables the monitoring of participants' performance and includes a companion application for session management, along with safety sensors to detect falls or obstacles. VR2Care follows a co-design approach by actively involving future end-users in the requirements development [21], testing, and evaluation phases.

This study presents a preliminary usability, accessibility, and user acceptance evaluation of one of the VR2Care components, the Multi-User Environment. The results of this study will be used to refine the MUE to meet users 'needs and expectations. The structure of this paper is as follows. Section II provides an overview of the VR2Care ecosystem. Section III outlines the methods employed in this study. Section IV presents the results and a discussion of the study. Finally, Section V addresses the study´s conclusions and future work.

II. VR2Care

VR2Care aims to create age-friendly virtual environments fostering the use of interactive technologies for the promotion of physical activity and social interaction. The practice of physical activity and training is performed in a realistic multiuser virtual reality environment, where users are represented with real human forms (avatars), with animations synchronised with natural movements (embodiment) and multimodal interactions combining voice, gestures, and body movement. The environment allows professionals to monitor and guide physical activity based on the specific requirements of each intervention. It accommodates a variety of activities, ranging from functional training to rehabilitation. Therefore, the VR2Care platform offers a unique setting for physical activity, training, and rehabilitation. It features intelligent interfaces within both single and multiuser environments, blending VR technologies for supervised exercise with natural interaction techniques. Additionally, it fosters socialization through physical activity within a metaverse context. The VR2Care concept surfaced from a need identified by the home care market in which state-of-the-art technology could be applied. The project aims to leverage VR multiuser technology from the lab to the market, piloting the prototypes with the involvement of professionals and primary end-users. The core of the VR2Care digital ecosystem is developed by technological partners with their own products, which are being adapted and integrated to meet the identified requirements for pilot scenarios. This vision leverages for a system-of-systems approach [22] a set of independent, useful systems integrated into larger systems that deliver unique capabilities [23] where individual components are regarded as systems with independent operationality, complemented by additional properties and features from the assemblage of components [24]. Figure 1 represents VR2Care architecture.

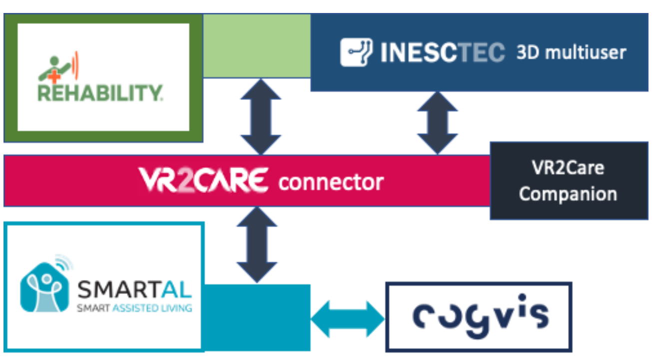

Figure 1. VR2Care architecture

VR2Care high-level functional architecture is composed by the following main modules:

1. Telemonitoring (SmartAL) [18], that allows caregivers and patients to define, manage and execute daily monitoring plans and gather gaming information to be processed in the gamification add-on.
2. The AI Motion Capture and Metrics (Cogvis) [20], that is able to detect poses, motion and falls while keeping the privacy of the patient.
3. The VR Environment, which is responsible for the natural interaction and multiuser embodiment, common to both the REHABILITY (single end-user) [10] and 3D Multiuser services (MUE) [19].

III. Methods

This research will focus on evaluating the usability, accessibility, and user acceptance of the VR2Care MUE. Six older adults reside at nursing home care called Venerável Ordemde Terceira de Sao Francisco do Porto (OSF) in Portugal involved in the evaluation. Each older adult had a training session (10-15 minutes) using MUE under the supervision of the physical trainer in the nursing home. After each session, the researchers asked the participants to respond to an open-ended questionnaire, which was developed following Nielsen's model [25] to assess usability based on the five attributes: learnability, efficiency, memorability, error recovery, and satisfaction. Accessibility questions were included in the questionnaire to assess three factors: perceivability, operability, and understandability following the World Wide Web Consortium (W3C) [26] principles. The developed questionnaire also takes into account the Technology Acceptance Model (TAM) [27] to evaluate user acceptance, specifically focusing on Perceived Usefulness and Perceived Ease-of-Use aspects. Additionally, researchers made some notes from the field.

A. Participants

The participants were recruited from a nursing home (OSF), which was one of four pilot sites of VR2Care project. Table 1 shows the characteristics of the participants.

TABLE I. Participants´ characteristics

Characteristics	Number of participants
Weekly exercise	Once (*N*=2)
	Three times (*N*=1)
	None (*N*=3)
Experience in using electronic devices	Television and remote control (*N*=6)
	Smartphones (*N*=5)
	Laptop (*N*=3)
Education	Higher education (*N*=3)
	Primary education (*N*=3)
Profession	Farmer (*N*=1)
	Educational assistance (*N*=2)
	Architect (*N*=1)
	School teacher (*N*=2)
Type of disabilities (if any)	Vision: neutral with glasses (*N*=6)
	Hearing: difficult (*N*=1), neutral (*N*=2), easy (*N*=3)
	Motor: difficult (*N*=4), easy (N=2)
	Memory: very difficult (*N*=2), difficult (*N* =2), neutral (*N*=1), easy (*N*=1)

Older adults with severe cognitive or physical impairments were excluded from the study, in order to not burden vulnerable older adults and to ensure active participation. One caregiver and physical trainer from OSF participated in organizing the evaluation. The study involved a sample size of six participants. We opted for a small sample of participants because this study is a preliminary usability and acceptance study of the MUE. With this sample size, we obtained deeper qualitative insights that will be considered in the iterative design journey we followed in the VR2Care project. A subsequent evaluation study will involve a larger sample size of 60 participants for validation.

The six participants of this study (*N*=4 female, *N*=2 male), were with an average age of 84.17 (*SD*=5.78) years. Three of them did not exercise in a gym at all, but they walked 2-4 kilometres outside every day. The other three participants performed their exercises at the nursing home gym with a trainer. Participants reported different reasons for the difficulty of committing to regular exercises in the gym: previous injuries such as pelvic, spine injuries, and knee (*N*=2), social anxiety and shyness about training in front of people at the gym (*N*=1). Two of the participants had never heard of or used VR technology, while the other four participants heard about VR technology from TV. A few (*N*=2) thought that VR was something related to Artificial Intelligence (AI), and two others (*N*=2) had tried VR exergames.

B. *Ethics*

Ethics approval was obtained from the INESC TEC ethics committee. The researchers sought advice from the committee before conducting the evaluation with older adult participants. Moreover, each participant was requested to carefully read and sign the consent form to participate in the study. The form provided clear information to patients, emphasizing that their involvement in the research was entirely voluntary. It assured them that they could withdraw from the process at any point without facing consequences or needing to provide a reason. Patients would not be penalised or have their motives questioned; they simply needed to contact the researchers to withdraw.

C. *Evaluation Setup*

The VR2Care hardware package allowed end users to access the VR Environment (REHABILITY and MUE). It consists of a processing and communication unit (homekit) connected to a depth camera and a TV display, which enable the user to experience VR without requiring a specialised immersion device such as VR glasses. This approach ensured that the use of VR is not restricted by the audience or the cost of additional equipment. The VR environment was not displayed on a VR headset, but rather on a standard TV screen. This provided enough dimensions for user immersion. Users (the older adults and the trainer) interact with the environment through body movements, gestures, and voice, which simulates natural human interactions. Figure 2 shows an example of the VR2Care MUE setup that was deployed in the TV room at the nursing home.

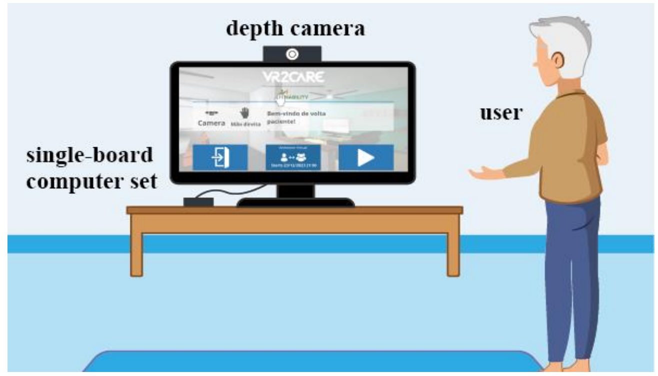

Figure 2. VR2Care MUE setup in the TV room at the nursing home.

The setup included a depth camera that is connected to a single-board computer, which was connected to the television. Utilising this computer, the VR2Care system enabled users to intuitively engage with the VR2Care MUE. Once the patient/trainer initiates the system, a calibration screen will be displayed (Figure 3). The camera then scans the user's body to align it to the avatar to represent their movements in the MUE. The user will need to use their hands and body to interact with the system to complete the calibration process and login to the MUE.

Figure 3. MUE – Calibration screen.

After completing the calibration process, the user will encounter the welcome screen and proceed to choose the MUE (Ambiente virtual in Figure 4). If patients join the training session earlier than the trainer, their avatars will be placed into a virtual waiting room, where they can communicate with each other using the voice channel. Once the trainer joins, patients will see their avatars in addition to the trainer's avatar (positioned in the upper left corner of the screen in Figure 5) in a training environment. The trainer will guide them to exercise. Patients and trainer can talk to each other during the session. But the trainer can talk to a specific patient using private voice channel.

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Figure 4. MUE – Welcome Screen. Translation "Portuguese"–English: "Camera"–camera; "Mão direita"–Right hand; "Bem-vindo de volta paciente"–Welcome back patient; "Ambiente Virtual"–Virtual Environment".

Figure 5. MUE – trainer (upper left corner) and patients.

Training session is terminated by the trainer once the planned exercises are completed.

D. *Protocol*

The same protocol was applied with each participant, where an introduction about VR2Care project were presented to the participant, followed by a request to read and sign the consent form. Then, two researchers conducted the pre-evaluation interview to gather participant´s demographic information and data pertaining to their physical activity and overall experience with electronic devices and VR technology. After that, a caregiver accompanied the participant to the TV room where the MUE setup was deployed. When needed, researchers assisted the participant during the calibration process to login to the training session. A third researcher joined the training session in the role of a patient (third avatar) to receive the training alongside the participant and to interact by voice with the patient in the MUE. Finally, the trainer initiated a 10-minute training session by performing three different upper-limb exercises: 1) shoulder flexion, 2) elbow flexion, and 3) stretching out. Following the sessions, each participant was interviewed by two researchers to answer the open-ended questionnaire.

IV. Results and Discussion

A. *Semi-structured Interviews*

The questionnaire focused on evaluating the MUE regarding three aspects: usability, accessibility, and user acceptance. Participants' responses to the open-ended questions were analysed using thematic analysis [28]. This section includes sentences quoted from the transcribed participant interviews.

1) ***Usability****:* five factors were measured to evaluate the usability of the MUE:

a) Efficiency: 5/6 participants found it easy to use the MUE to accomplish the exercises. Only one participant reported a little difficulty in using the MUE, due to the latency between the synchronisation of the user's actual body movements and his presented virtual avatar´s movements [*"P1: A bit difficult because I could not do the exercise exactly, the avatar was not showing my movements immediately"*].

b) Satisfaction: 4/6 participants were satisfied exercising using the MUE and think that it could help them to regularly exercise and socialise with other older adults during their stay at the nursing home. One participant was satisfied using the MUE for regular exercising if it is pre scheduled, but she did not think the MUE could help her to socialise with the others, because she liked to interact with people in reality ["*P4: Yes I am satisfied, but I prefer to exercise only if the session is previously scheduled, because I like to finish my daily tasks and go for walks in the city, I do not think this technology can help me talk to people because I prefer to talk to people in reality!*"]. Another participant was not satisfied, nor sure if the MUE could help him to regularly exercise and socialise with others because he experienced a latency in synchronising his body´s movements and his avatar´s movements in MUE, and also because he lacked understanding of how this technology works [*"P1: I am not satisfied because the avatar was not moving with me during the exercise, so I am not sure if this technology can help me to regularly exercise or interact with new people! I don't know much about this technology or how it works!"*].

c) Learnability: all participants easily learned how to interact with the MUE to exercise.

d) Memorability: one participant (P2) said they could use the MUE for the second time by themselves without any help. Another three participants think they could use the system but preferred to have someone to help just in case they needed it. Two of them (P3 and P5) have motor and memory difficulties. The other two participants insisted that they needed help to use the MUE for the next time ["*P1: it is not easy for me, I still need help!*"]. It is important to mention that this participant (P1) had short-term memory difficulties. ["*P4: I think I need someone to help me with it"*]. This participant (P4) had little experience with electronic devices, limited to TV and remote-control use.

e) Errors: 4/6 participants reported that they didn´t expierence any situation during the training session, which made them confused. On the other hand, one participant (P3) experienced confusion only at the beginning of the session during the system calibration process. The system did not provide any voice or text feedback after each calibration attempt, where users depended on the researcher to guide them every time a calibration failed ["*P3: I felt confused at the beginning of the session. It is a new thing! but later everything became clear for me*"]. The last participant (P1) indicated the latency in synchronising his body´s movements with his avatar´s movements as the only situation where he felt confused during the training session.

2) ***Accessibility:*** the following aspects were considered in the questionnaire to evaluate the accessibility of the MUE:

a) Perceivability: all participants could easily recognize all three avatars in the MUE (trainer´s avatar, older adult´s avatar, researcher´s avatar), and only one participant (P6) could not remember the researcher´s avatar, although she has no memory difficulty. It was noticed that during the training, this participant was distracted for a while because she was following her avatar, thinking that it was the trainer's avatar; hence, she repeated the same exercises over and over until one of the researchers in the TV room guided her to follow the trainer´s avatar movements. In addition, all the participants were able to easily recognize the "Enter" and "Exit" buttons on calibration screen.

For the environment´s design, 2/6 participants did not pay attention to the environment´s background or design, because they were focusing on the avatars to do the exercises. ["*P1: I did not pay attention to the environment´s design, because I was focusing on the trainer´s avatar and my avatar to do the exercises*"], ["*P4: I was focusing on the avatars, not on the environment!*"]. 3/6 participants stated that the environment´s background and design were good, but they preferred to see different environments in the future, like beach or forest background. One participant liked the environment´s background and design and would not change anything.

b) Operability: all participants indicated that using their hands and body motions to interact with the MUE was easy. Similarly, they agreed that it was easy to hear the trainer´s and the researcher´s voices and talk to them.

c) Understandability: 4/6 participants stated that they did not pay attention to the texts in the MUE (users´/avatars´ names), but focused on avatars while exercising. Two participants found the texts in the MUE easy to read. 5/6 participants reported that the navigation between the three screens (calibration screen, welcome screen, and the MUE environment) was logical and simple and they understood what they had to do on each screen. One participant (P1) thought that having the calibration screen in Portuguese would help him navigate to the next step of the interaction more effectively.

When asked if they could compare group training at a real gym to group training at the MUE, both of which were supervised by a physical trainer, all participants demonstrated an understanding of the differences between the two options. 4/6 of them preferred to have training in both the real gym and the MUE. ["P2: *both! I can train at home using this technology in private and go to a real gym to interact with people naturally*"], ["*P5: I can do both, but I'd like to have someone to help me when I need it*"]. Two participants (P4, P1) stated that they still preferred to exercise in a real gym. P4 was the lady with little experience in using electronic devices, and she liked to go daily on a walk in the city to interact with people. P1 thought that he could not use the MUE properly for exercising because the avatar was not showing his real body movements immediately. The participant was referring to the latency in synchronising his body´s movements with his avatar´s movements.

d) User acceptance: in terms of percived usefullness and ease-of-use, 5/6 participants found the MUE easy to use, and they would not change anything about the environment, except P6, who would like to see more players (trainees) in the MUE in the future, to talk and exercise with them. P2 expressed her concerns about the possibility of using AI to supervise her training session in the MUE. P3 explained that training attendance and commitment depended on his emotional state at the time right before the training, and not just on the technology itself.

One participant (P1) was not sure about the percieved usefulness and ease-of-use of the MUE, due to the latency in synchronising his body´s movements with his avatar´s movements, in addition to the Portuguese language issue on the calibration screen.

B. Researchers observations/ Field notes

Researchers made written observations during the evaluation. First, avatar´s size and location on the screen was vital in guiding the attention of the participant to recognize the different avatars in the MUE. Participants tended to think that the biggest avatar in the centre of the screen was the trainer until the researcher intervened and assisted them to locate the real trainer avatar, which was in the upper left corner of the MUE screen. Second, it was noticed that the researcher who joined the training session virtually could not hear the voices of 4/6 participants during the training session because their voices were soft and weak due to the voice agism of some participants. Third, the proper size of the screen was important for the vision for the participants. Researchers noticed one of the participants was trying to bend his body forward to get a better view of the screen, while another participant asked for help to get closer to the screen to see better. Fourth, the proper height of the screen helps users perform the exercises with correct postures. The screen was a too high for the participants causing them to raise their heads higher that what was required to complete the exercises. In addition to the standard distance between the participant and the screen to reach at successful calibration, which is noticed in this study to be 2 meters. Screen´s size, height, and distance from the users are three factors that should be standardised and adjusted at the training time to optimise participants' vision and posture, and a successful calibration. Table 2 summarises the identified usability, accessibility, and user acceptance issues, which will be considered in the next refinement process.

TABLE II. THE IDENTIFIED USABILITY, ACCESSIBILITY, AND USER ACCEPTANCE ISSUES

Category	Sub-category	Identified issues (*N*[a])
Usability	Efficiency	• The latency between the synchronisation of the user's actual body movements and *his* presented virtual avatar´s movements (*N=1*)
	Memorability	• The absence of a mechanism for a reachable human support when needed (*N=5*)
	Errors	• Calibration process may take the user many attempts to be successful. The system did not provide voice or text feedback after each calibration attempt by user (*N=1*)
Accessibility	Perceivability	• Trainer´s avatar was the smallest one located on the upper left corner of the screen, whereas participants tended to follow the centered and biggest avatar on the screen thinking that is trainer´s avatar (*N=1*) • The absence of a mechanism allowing users to select the MUE background according to their preference (beach, forest, etc., (*N=3*) • Screen size (55 inches) caused some difficulty in recognising the environment presented on the screen (*N=1*)
	Operability	• Participants voices were too soft and low to be detected by the built-in microphone in the depth camera. Other users (trainer and researcher) in the MUE were not able to hear the participants. • Screen height caused participants to raise their heads during the exercises, which affected their required postures. • Screen height, size and distance of interaction were not standardised, which caused some difficulties in interaction with the MUE.
	Understandability	• Calibration screen was in English, while participants spoke Portuguese only (*N=1*)
User acceptance	Perceived usefulness	• Fear of the potential of using AI to supervise the virtual training session. Fear to replace the natural interaction with virtual one (N=2) • The absence of gamification approaches in the MUE, as it could enhance users´ motivation and commitment to exercise, especially who suffer from depression or experience low feelings (*N=1*)

[a]Number of participants who reported or experienced the issue.

The results of this study showed that the majority of participants were satisfied with the MUE. They perceived it as an efficient technological tool to exercise and socialise with other people. Moreover, the majority could easily learn how to interact with the MUE, however, they agreed that they still preferred in-person, human support during the training. The MUE was accessible for most of the participants, as they could easily recognize the avatars and buttons in the environment. Additionally, they were satisfied with the design of the environment and could easily use their body motions and voice to interact. Also, they could easily read the texts in the MUE and understand the concept of training in a group virtually. Most participants agreed on the perceived usefulness and ease of use of the MUE.

Although the majority of participants thought that the MUE could help them to socialise with other older adults, they had a strong preference for in-person social interactions. They also appeared to have significant reservations about how they could use the MUE to socialise with other older adults, pointing to a need for better exemplars and scaffolding of these behaviours.

V. CONCLUSIONS AND FUTURE WORK

In summary, this study offered valuable insights of the usability, accessibility, and user experience of the VR2Care MUE as a multiuser environment to promote older adults' physical activity and socialisation. Six participants from a nursing home in Portugal were recruited for the evaluation. The detected issues were derived from a survey data of the older adult participants, as well as the researchers´ observations in the field. The main detected issues were:

1. The instability of avatars´ movement during the training sessions.
2. The need to provide a mechanism within the MUE to allow participants to contact in-person support.
3. Voice/text feedback for a multilingual calibration screen to keep users aware about the progress of the system calibration.
4. Avatars´ location and size must be aligned with the expected roles in the training sessions.
5. Users were not able to choose the environment background according to their preferences.
6. The MUE lacked gamification approaches to enhance users´ motivation and commitment.
7. Voice agism affected most of participants voice strength so that other MUE users could not hear them.
8. Raising awareness among older adults and educating them about the benefits of new technologies, could help in reducing the fear of using AI and VR in training sessions, besides the continuous involvement of them in the co-creation process.
9. Screen´s size, height, and distance from the users should be standardised and optimised according to users´ needs and systems´ calibration demands.

The identified usability, accessibility, and user acceptance issues will be considered in the coming refinement process of the MUE. Also, another usability and user acceptance evaluation study with a larger sample size of 60 participants will be conducted in four pilot sites from three EU member states, Portugal, The Netherlands, and Italy to allow longer usage of the MUE and by a more diverse user group.

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