Usability evaluation of the RehabMarket: a CAVE-based game for stroke rehabilitation

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Abstract— Stroke is a major global cause of death and disability, with a range of rehabilitation approaches currently available. One such approach is Virtual Reality (VR), which has shown potential for improving rehabilitation outcomes in a more engaging and motivating way. In this paper, we introduce the RehabMarket, a VR-based activity using a CAVE system to stimulate limb movements and cognitive training for stroke survivors. We conducted a usability evaluation study of the RehabMarket with 10 healthy participants, and the results showed a high level of usability. These findings suggest that the RehabMarket is nearly ready for testing with stroke survivors, and could potentially provide an effective and engaging form of rehabilitation therapy for this population.

***Keywords*— rehabilitation, stroke, CAVE, Virtual Reality, exercise, therapy, exergaming**

I. INTRODUCTION

There are various diseases that can lead to severe consequences, some of which may result in death. Vascular conditions, with stroke being the second most common, are the leading causes of death worldwide. These two causes led to the deaths of 15.2 million people in 2015 [1], however, 50% have survived and had their lives impacted at various levels. Stroke remains the second-leading cause of death and the third-leading cause of death and disability in the world actually. The estimated global cost of stroke is over US$721 billion. From 1990 to 2019, the burden increased substantially (70.0% increase in incident strokes, 43.0% deaths from stroke and 102.0% prevalent strokes), with the bulk of the global stroke burden (86.0% of deaths) residing in lowerincome and lower-middle-income countries (LMIC) [19].

While anyone can suffer a stroke at any age, the incidence of stroke is higher among the elderly population. Stroke is also one of the leading causes of long-term disability. Certain risk factors can increase a person's chances of having a stroke, with some being modifiable, such as diabetes, hypertension, physical activity, and alcohol consumption, while others, such as age, gender, race, and genetics, are non-modifiable [2].

Different stroke types are determined using CT (computed tomography) or Magnetic Resonances (MRI) scans. Although CT scans are more commonly used for stroke diagnostics, MRIs give more detailed and assertive information and allow one to distinguish faster than CT scans if it is bleeding or thrombosis [3].

A stroke can be also categorized into two types: ischemic and hemorrhagic.

A study found that out of 795,000 people who experienced a stroke for the first time, 26% were unable to perform basic daily activities, and 50% had reduced mobility due to partial paralysis on one side of the body [1]. The number of people who survive a stroke and live with its consequences has increased globally with the advent of new therapies. In the US, 85% of people who have suffered a stroke are alive, with approximately 4 million people living with stroke sequelae [2]. However, many stroke survivors often face psychological and neuropsychiatric problems that can significantly impact their daily routines or preferred activities [4], such as post-stroke depression [5], language disorders [6], visual impairment [7], hemiplegia, and hemiparesis [8]. Therefore, it is essential to train the affected areas to regain the ability to perform daily activities [8].

Rehabilitation is crucial for a person to recover from an injury, be it physical or psychological. Traditional rehabilitation methods include the practice of exercises to stimulate the affected body part, using weights, and medicinal balls, among others [9]. However, the evolution of technology has played an important role in improving people's lives. Technology can enhance patients' motor skills, provide equivalent rehabilitation quality as conventional therapies, and improve patients' activities of daily living (ADLs). As such, technology offers a more motivating and dynamic way of rehabilitation when compared to conventional therapies, so is perfect to complement the traditional ones [10].

Rehabilitation often employs various technologies, such as games, robotic devices, virtual reality, sensors, and tablets. For example, the Virtual Reality Visuo-Motor Therapy System [17] allows patients to interact with a game using their movements, with every action reflected on the monitor. Another example is the use of depth sensors, which was studied to compare the feasibility of using motion-controlled games in stroke survivors with conventional therapies [16]. Another example is the Athene software implemented in a CAVE system. This software is based on the Unity 3D game

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engine, and it includes various virtual environments with a free run option in which the user can explore the area freely or use several routes of different lengths and difficulty levels [18].

Despite the advantages of virtual reality, some limitations still exist, such as discomfort while using head-mounted displays and the lack of locomotion in some activities. In previous studies, some patients asked for better graphics and more familiar environments [17].

This paper introduces the RehabMarket, a CAVE-based activity that allows stroke survivors to train their physical and cognitive capacities. The game consists of supermarket activities where the user needs to interact with products inside the virtual environment, as shown in Figure 1. The RehabMarket can be used for rehabilitation as it stimulates the movements of the upper and lower limbs and cognitive skills. In Section II, we describe the implementation of the RehabMarket and the methodology of a usability study, including its technical aspects, along with a brief description of the design process. On section III, we report on the results, which are then discussed in sections IV.

Fig 1. RehabMarket environment

II. Methods

A. Setup

The game was developed using Unity [11], in combination with the KAVE KinectForWindows_UnityPro [11] and the Kinect camera [11]. The KAVE system allows the game environment to be projected on all four walls using four projectors, simplifying the programming required for necessary interactions. Additionally, the Kinect sensor enables natural interaction without the need for handheld devices. The KAVE system simulates a supermarket environment, providing an immersive experience for users. Shelves with products are represented on the lateral walls, while the front wall displays a monitor with information about the level and feedback to guide the participant during the game. RehabMarket comprises a game with ten levels [15]. As the levels progress, the degree of difficulty associated with each level also increases to make the activity more challenging. During the levels, the participant's movements are tracked. In case the movement is not well performed, it should be corrected with the help of a supervisor in order to reach the goal.

During the first two levels, the participant simply needs to drag two products, one from the right wall and one from the left wall, to a specific target location, as illustrated in Figure 2. Subsequently, the physical and cognitive abilities of the participant are increasingly challenged, as they must interact with various types of products and the associated prices. In some of the more difficult levels, the participant is required to separate products from boxes and drag the products to the shopping baskets, while the boxes are dragged to the crates, as shown in Figure 2.

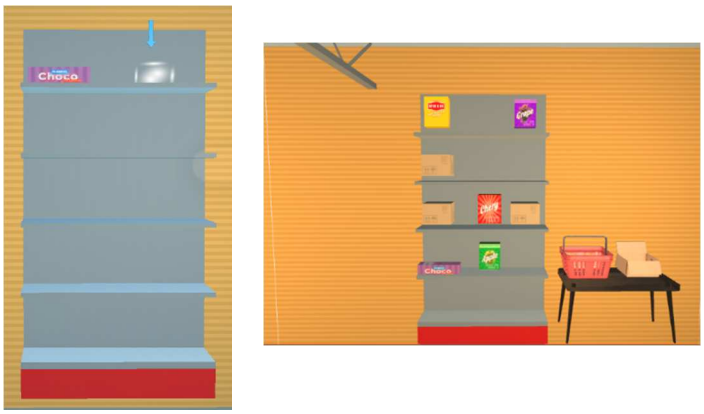


Fig 2. Different difficulty levels of the RehabMarket

Another example of a more complex level is when prices and a budget are introduced. Here, each product has a price, and a random value of the budget is set. The participant must drag the products to the basket in order to reach the maximum value of the budget. The different levels in RehabMarket are summarized in Table I. The primary goals of RehabMarket are to stimulate the movement of upper and lower limbs while training cognitive capacities.

TABLE *I*. Different levls of RehabMarket

Level	Objective
Main Menu	Click “Play”
1	Drag products on the same shelf
2	Drag products on different shelves
3	Drag products to shopping basket
4	Drag boxes to crates
5	Drag products and boxes
6	Approximate 2 seconds to the products
7	Drag products that are on the shopping list
8	Shopping list is visible for 10 seconds
9	Products with prices and a budget to use
10	Budget visible for 10 seconds
Last	End of the game

B. Participants

The study involved user testing with 11 healthy participants, comprising seven male and four female individuals, aged 20 to 33 years (mean age = 25 years, SD = 4.22). Of the participants, 63% held a Master's degree, 9% held a Bachelor's degree, and 28% had completed their secondary education. The participants represented diverse fields, including students, researchers, and psychologists.

C. Procedure

The procedure for each participant was guided by a script, and the setup was standardized for all participants. Prior to the start of the experiment, participants received detailed information about the study and its purpose and were given the opportunity to ask any questions they had before signing an informed consent form. Participants also provided consent for the collection of photographs during the study.

Participants were informed that the RehabMarket was developed for stroke rehabilitation, with the goal of stimulating the physical and cognitive abilities of patients. However, before testing the game with stroke survivors, it was necessary to conduct tests with healthy individuals. Participants received instructions on the game mechanics, how to play, and the objective of each level. The interaction ended when all 10 levels were completed.

D. Data Collection and analysis

The duration of the experiment for each participant was recorded by taking note of the start and end times, as well as the start and end times for each level. At the end of the experiment, participants were asked to complete six questionnaires:

A *custom questionnaire* containing questions about the participant's opinions on various aspects of the game. The questions aimed to understand the participant's thoughts on the environment, the fact that the game was presented in the CAVE system, the interaction with the environment, and the ability to play without errors. The custom questionnaire included five Likert scale questions, rated from 1 to 5, and five open-ended questions. The Likert questions were as follows:

- How appropriate do you consider the fact that the game is in a supermarket environment?
- How helpful do you consider the use of the CAVE system?
- How helpful do you consider the requirement of the natural user interface to play?
- How operational do you think the game is?
- How ready do you think the game is to be played without user errors?

The open-ended questions in the user test were as follows:

- How do you compare this game to the real-life activity of going to a supermarket?
- What are the positive aspects of using gamification elements (such as correct and incorrect feedback, and different levels of difficulty) in this activity?
- What are the negative aspects of using gamification elements (such as correct and incorrect feedback, and different levels of difficulty) in this activity?
- How did the different levels of difficulty affect you?
- Do you have any comments about this experience?

The *User Satisfaction Evaluation Questionnaire* (USEQ) [12]. This questionnaire is designed to assess the participant's level of satisfaction after completing the study. It consists of six questions, which are rated on a Likert scale from 1 to 5, where 1 means "Not at all satisfied" and 5 means "Very satisfied." One question (the fifth) is phrased negatively. The score for each answer (except for the fifth) is determined by adding 5. The score for question 5 is calculated by subtracting the response from 6 (i.e., 6 minus the response).

The *Presence Questionnaire* [13]. This questionnaire aims to assess the level of immersion and the user's ability to interact with the game itself. The goal was to understand the participant's sense of presence during the course of the game, for example, if the user felt involved in the environment, if he/she was able to interact with the requested tasks successfully, and if the activities present in the game were appropriate to the activities practiced in real life. This questionnaire is composed of 5 topics: realism, possibility to act, quality of the interface, possibility to examine, and self-evaluation of performance.

The System Usability Scale (SUS) [14] is one of the best-known and simplest methods to ascertain the usability of the system.

The *Virtual Environment Verisimilitude Questionnaire (VEVQ), is* a custom questionnaire created by the NeuroRehabLab team. With this questionnaire, the goal is to assess the degree of realism or similarity with a real environment, that is, how realistically the game was represented, considering the interaction, the environment, and the tasks to be performed.

Quantitative data were analyzed using Microsoft Excel.

III. Results

A. Duration

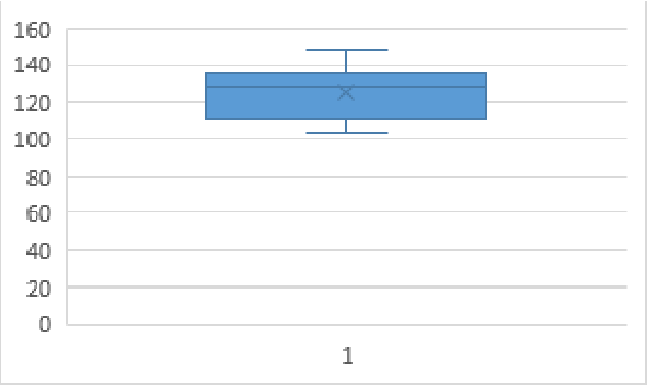
The duration that each person took to play the game depended on their speed in performing the moves and understanding each level while interacting. The mean duration was 13 minutes and 53 seconds (SD = 2 minutes and 24 seconds). The fastest player had a playing time of 9 minutes and 45 seconds, while the slowest player finished the game in 17 minutes and 51 seconds. The duration that each participant took to complete each level was also recorded. The fastest level for users was level 2, with a mean time of 21 seconds. On the other hand, the level that took the longest to complete was level 5, with a mean time of 3 minutes 22 seconds.

B. USEQ

After the results were analyzed, we concluded that the total USEQ's median score was 4.64, with a minimum of 3.82 and a maximum of 4.73.

C. Presence Questionnaire

In Graph 1 are shown the scores obtained on the Presence Questionnaire. The maximum score is 168. In our study, the median score was 129. By looking at Graph 1, it is still possible to check the scores obtained. As it shows, the minimum obtained score was 103, while the maximum one was 148.



Graph 1. Presence Questionnaire results

D. System Usability Scale (SUS)

Considering the scores obtained by each participant. The median score obtained from this questionnaire corresponds to 77.5, with scores above 68 being considered good according to previous research [14]. This result suggests high usability, with a B grade classification. The minimum score was 60 and the maximum was 100.

E. Virtual Environment Verisimilitude Questionnaire

The maximum achievable score was 70, with only one participant achieving this score. Conversely, the lowest score was 41. As the maximum is 70, and the median score was 55, we can conclude that the game had a high level of similarity with a real shopping task.

F. Customized Questionnaire

Here, participants reported that the supermarket environment and the use of a CAVE system in the game could be advantageous and beneficial for post-stroke rehabilitation. Most participants also believed that the game was functional and could be played without errors. The median score obtained from this questionnaire was high, 4.73. The minimum score was 3.82 and the maximum was 4.82.

Regarding the open-answer questions, users commented that the game was very realistic, as the movements required in the game were similar to those in real life. When asked about the positive aspects of gamification in this project, many users responded that it made the game more dynamic and enjoyable, even for a mundane task like shopping. They also appreciated the accurate feedback provided, which helped them understand their performance. Conversely, when asked about the negative aspects of gamification and feedback, some participants did not identify any negative points, but others mentioned that it might be challenging for the older adult population to understand the gamification or take the activity seriously. Participants reported feeling increased difficulty levels and soreness in their arm and leg muscles, requiring more physical and mental effort to overcome each level. Finally, the participants unanimously agreed that the activity was an enjoyable game to play and that it had potential for future development.

IV. Discussion

The results of all tests and feedback provided show that, in general, the developed game fulfills all the principles necessary to be potentially successful for the purpose for which it was intended, in this case, rehabilitation of post-stroke survivors. Although we have involved health professionals in the design of activities, it remains to validate with real patients in the future.

The results of the USEQ questionnaire indicate that the users were highly satisfied with playing the RehabMarket and suggested that it has the potential to be a valuable addition to post-stroke rehabilitation programs, as it can improve patients' satisfaction with the rehabilitation process and motivate them to engage in rehabilitation exercises more regularly. SUS results were good, as most participants scored above 68, corresponding to the "good" rating. This indicates that the users found RehabMarket to be highly usable and easy to use.

The results of the VEVQ showed that RehabMarket was similar to reality, with a high level of realism in the virtual environment and the tasks performed within it. This suggests that RehabMarket effectively simulates real-world scenarios and activities that patients might encounter during post-stroke rehabilitation. The high level of realism can enhance patients' engagement and motivation, as it can help them feel more connected to the rehabilitation process and the tasks that they are performing.

In similar studies, participants did not feel comfortable with the game environment because of using complicated setups [17]. The results of the questionnaires have shown that the supermarket environment is advantageous as it is a known environment that is part of the activities of daily living. Another limitation found in previous studies was the fact that the participants were in a static position, moving only the upper limbs [17]. In the RehabMarket, this is no longer a problem since the lower limbs are also stimulated by challenging the person to move from one side to the other to drag products to their final destination. The feedback from the participants of the user test sessions was also in line with what was expected to happen. The goal of developing a technology that could address the gaps in previous stroke rehabilitation approaches was achieved by designing a game that could stimulate the upper and lower limbs while also providing cognitive training.

One limitation of this technology is its low level of portability. Since the CAVE is a system that is already built in a certain space and it is not easy to transport. The fact that user tests did not count on the participation of people who suffered a stroke can also be considered a limitation. None of the participants had any kind of physical or cognitive disability. However, before taking the technology to the target audience, it first needs to be well-tested to make sure that it is functional and usable, and this was the main goal of the

usability test presented in this document. Results have shown that the RehabMarkt is ready to, in future work, be tested with stroke survivors and the elderly population. Future work will also include making the game playable in another type of environment, more portable, and accessible to all people who want to experience it.

V. Conclusion

The aim of this study was to evaluate the initial usability of RehabMarket. The results obtained from user testing sessions indicate that RehabMarket is highly usable, ecologically valid, and has the potential to aid in post-stroke rehabilitation. The tests demonstrated that the game stimulates the motor function of participants and was well-received by users. In summary, these findings suggest that RehabMarket has the potential to enhance the quality of post-stroke rehabilitation and improve patients' recovery.

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