Exploring Direct User-Interaction Techniques in a Virtual Reality Game for People with Hand Impairments

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***Abstract*—This study presents a virtual reality game that aims to assist the rehabilitation of people with arm/hand impairments using direct user-interaction. Direct user-interaction consists of the use of gestures of the hand to interact with the virtual environment. We designed four hand-gestures according to traditional therapy exercises: wrist supination/pronation, fist, wrist curl, and finger curl, aiming to support the rehabilitation as well as keep users entertained. The virtual game was developed for Oculus Rift, using Unity, and Leap Motion to track the hands. We initially evaluated the game with non-disabled people to identify the user experience and how people without hand-impairments deal with the interaction techniques proposed. Results show that most of the participants would like to play the game more often. Some improvements are needed and tests with patients will be done in future work.**

***Index Terms*—Direct User-Interaction, Hand-Gestures, Physical rehabilitation, Virtual Reality Environments**

I. Introduction

Virtual reality (VR) offers opportunities for users to interact with a virtual environment. VR environments use visual, auditory and possibly haptic stimuli to bring immersion to the user through the use of helmets, glasses or projection structures to create the visual environment around them [1].

Several VR environments have been developed for health care, among them, VR applications for physical rehabilitation purposes [2]. Rehabilitation processes consist of a set of interventions to assist individuals who experience disability aiming "to achieve and maintain optimal functioning in interaction with their environments" [3]. In general, traditional rehabilitation starts in medical centers, and subsequently, the patient goes to units specialized in supervised therapy. The final stage is done at home, and may or may not be assisted by a professional.

The exercises performed in traditional physiotherapy sessions are usually tiring and do not present a cognitive stimulus to the patients, who finds themselves unmotivated to do them [4]. Studies show that VR applications are more effective than traditional rehabilitation because they provide excitement, physical fidelity [5], and influence therapeutic commitment through engaging activities [2]. Further, VR experience contributes to reducing anxiety or stress [6]. However, these applications often use devices for the user's interaction with the virtual environment, which range from small controls to large application-specific structures. The use of these devices can make some interaction experiences inaccessible for individuals who have motor difficulties in the upper limbs, for example. User interactions that can be trivial for most non-disabled people often pose challenges for people with arm/hand impairments.

These aspects motivated this work, which aims to use VR as an incentive to rehabilitation activity, by adding an aspect of gameplay to the treatment to entertain the patients and instigate them to carry out therapeutic exercises, in addition to including direct user-interaction possibilities considering the hand impairments of future target users.

From this scenario, this work presents a game in virtual reality that includes tasks similar to those performed in traditional therapeutic exercises. The tasks are performed by direct user-interaction in the VR game. In addition, the game aims to be cognitively interesting, entertaining the user and increasing their engagement with rehabilitation tasks. Our VR game goal is to keep users interested, not necessarily referring to the treatment and their deficiencies, preventing them from missing physiotherapy sessions and recovering their best form more quickly. Also, the proposed game aims to make accessible experiences that usually require the use of complex movements that the target audience would not be able to perform. This is done by exploring interaction options to offer users different possibilities for interacting with the game, in order to avoid frustration arising from the players' motor difficulties. For that, we initially tested the game with non-disabled individuals aiming to identify how they deal with the virtual environment and the required interaction.

We carried out tests involving five non-disabled participants. Results show that the game was pleasant and the devices used were easy to use. The interaction techniques used were easy to perform for most users; however, some of the interaction techniques need to be improved to facilitate its execution.

This article is organized as follows. In the next section, we present studies about the use of VR environments for physical rehabilitation, presenting some existing solutions, and highlighting the observed limitations. Next, we describe the proposed game, detailing the hand-gestures proposed for the direct user-interaction with the game. Later, we detail the evaluation procedure conducted with non-disabled people and the results obtained. Next, we discuss the results. Finally, we present the conclusions of this study and propose future work.

II. Related Work

VR environments have been widely studied as an alternative to traditional therapy in post-injury rehabilitation caused by stroke. Saposnik and colleagues [7] compared the effectiveness of rehabilitation using games by separating patients into two groups. The first group participated in traditional recreational therapy, i.e., playing cards, bingo, and similar games. The second group used a VR system for the Nintendo Wii, a game console developed by Nintendo that has its motion detection control as the main feature. The group that used VR spent less hours in each therapy session and showed higher recovery of motor skills than the other.

The study by [8] used the Playstation 2 EyeToy in rehabilitation therapies. The EyeToy is a camera sold separately to the Playstation 2 that uses computer vision to identify the player's movements and transform them into actions within the game. The authors used commercial games in the therapies and the patients were interested in the games, but were frustrated with the difficulty and needed help from therapists to complete the requested tasks.

Still on the use of commercial games in rehabilitation, Hung et al. [9] conducted a study to identify the opinion of patients and therapists on its use in therapeutic processes. Twenty four mobile games were analyzed. They concluded that traditional therapy is less effective, current rehabilitation systems with games are not so exciting, and patients prefer the use of commercial games in therapy. However, the authors highlight three recommendations for creating games aimed at rehabilitation:

- The game must have sufficient logical challenge to keep the user interested
- The game should allow the user to take the initiative and should not have time restrictions, as this can make the player feel nervous
- The game must have a simple and intuitive interface

These aspects show that, despite attracting more patient interest when compared to traditional techniques, the games still do not meet all the needs of the target audience. Thus, it is necessary to develop games with the main objective of being used as therapeutic exercises.

Kelly Bower [10] reports that commercial motion-controlled games are very difficult for patients, and often the difficulty cannot be adjusted. In addition, users' deficiencies cause them to receive negative results and feedback, frustrating them. Therefore, she developed a motion-controlled game that was suitable for patients. The results showed that the patients liked the developed application, found it useful and would like to continue using it in therapy. However, most patients reported a slight increase in pain during exercise.

A research conducted by [11], analyzed the rehabilitation methods using games to define the requirements that VR applications should have to better support the treatment of patients. The researchers conducted interviews with experts and patients. According to that, the system should be related to culture, engaging, cheap and easy to configure, in addition to authenticating the patient, preventing someone else from doing the exercises for him, and alerting when the movement was incorrect. The data generated in the game session should contain the exercises performed, the number of repetitions for each one, the distance or degree of movement and the quality of its execution, in addition to the time spent, and should be saved on a website for consultation by therapists. The researchers also noted that patients need warm-up at the beginning of the exercise session, breaks between tasks and that sessions vary from one hour to a maximum of two and a half hours. Although the authors highlighted the requirements above, they mention that they have not yet developed a system with these requirements.

For its part, the study by [12] used gesture recognition from the Leap Motion sensor to create a game that would help with rehabilitation. Gestures provide an intuitive form of communication not only between people, but also between human and computer. The advantage of using gestures is that it is not necessary to manipulate a control, as interactions are made directly with the user's hands. The authors developed a VR application to support the recovery of patients with impairments in the upper limbs. Although they tested the game with physically impaired people, the study does not show the game's impact on the subjects.

III. Proposed Game

In this section, we first describe the aspects considered in the design of the game. Then, we describe the game and its implementation. Finally, we detail the proposed user-interaction techniques and how they are used in the game.

A. Requirements

We designed a VR game to stimulate the wrists, hands and fingers. Patients that are exercising those body parts' fine movements have often at least partially recovered less precise movements, such as arms and shoulders [13], increasing the number of possible movements to be used in the application. Also, the game focus on patients who have only one side of the body paralyzed. Thus, all the user interactions in the game are performed by using one-single arm (the left arm). The right arm is used to assist the left one and for interactions unrelated to rehabilitation.

We designed four types of direct user-interaction in the game based on conventional therapy exercises proposed by [14], [15] and [16]. We consider it important to include these exercises because, as highlighted by [17], the movements learned in a VR environment can be transferred to the real world to perform equivalent motor tasks.

We choose a theme for the game that allows these interactions not to be treated as something strange to the player, so that the game could be ludic. Although some exercises involve common movements in daily life, such as grabbing an object, many of them proved to be difficult to apply in an environment unrelated to therapy. Therefore, we choose a world of magic as the theme of the game. Here, the player is a magician capable of casting spells, and each spell would be casted with a hand movement corresponding to an therapeutic exercise. Thus, a movement that might not make sense in a usual situation ends up becoming plausible, given that spells are usually represented with this type of movement in films, games and books.

B. Description

Our game consists of a 3D-virtual magic world where the player will be a wizard at a fixed point on the map and must face several hordes of enemies by performing different spells with their hands. The spells consist of exercises made by the user to defend themself from enemies, such as close the hand in a fist, rotate the wrist, curl the wrist and curl the fingers. These exercises have different levels of difficulty so that there could be a sense of progression in the game. Because it is a spell-fighting game, each exercise will be a trigger to fire a spell, which can be offensive or defensive.

Because rehabilitation exercises need repetition in order to have their effect maximized, we proposed an infinite gameplay loop. The first four levels of the game aim to teach the player each of the spells they can use. After these, the stages are infinite. The game also allows the physiotherapist to build levels in the game by configuring the level completion time and the number of enemies and spells.

The game interface is simple and minimalist, limited to showing the player videos teaching him how to perform each of the spells, and messages stating their goal at each stage.

C. Implementation

The game is developed for Oculus Rift, using Leap Motion to capture user input. The game engine used was Unity, using Visual Studio as a development environment with the C# language. The APIs provided by Oculus and Leap Motion were also used as an integration for the development in virtual reality and to capture the movements of the player's hands, respectively.

The game's main feature is its combat. The gameplay consists on the player fixed in one point and enemies are spawned around them. Enemies shoot projectiles at random intervals from 5 to 20 seconds. Also, each enemy has one element from fire, ice, earth and lightning, which grants them a weakness and a strength. Fire is strong against earth, which is strong against lightning, that is strong against ice, that closes the cycle against fire. Strong elements cause double damage, and weak cause half damage. The player must wisely choose which spell to use against each enemy.

Spells are triggered by different exercises performed by the user through direct interaction. The exercise detection algorithm runs the state machine at each frame, as shown in Fig. 1.

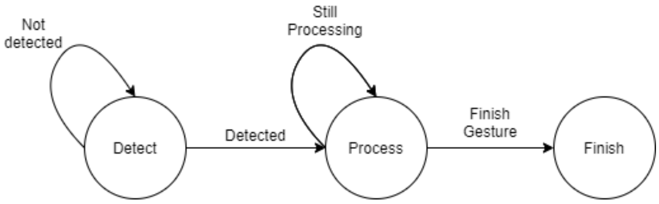

Fig. 1. Exercise detection state machine.

The first state (**Detect**) checks whether the player is doing the correct posture to start one of the exercises. If it is detected, its processing (**Process**) begins. This step usually consists of an indicator that shows the player that the exercise has been detected and that they must perform it for a certain amount of time before the spell can be cast. This indicator varies with each spell. Finally, after processing has finished, the player must make a final gesture for the spell to take effect (**Finish**). Only then does the process end and the cycle begins again. At any time during this process, it is possible to cancel an action by making a fist with the right hand.

D. User-interaction techniques and levels of the game

Below is an explanation of how each interaction technique works, and how they are used in each level of the game.

Fig. 2. User performing the wrist supination/pronation exercise in the virtual environment. Barrier active (left, in blue) and inactive (right).

1) Wrist supination/pronation: The wrist supination/pronation exercise triggers the only defensive spell of the game. Once the player points the palm of their hand up, a transparent blue barrier will be formed around them (Fig. 2). While the barrier is active no other spell can be casted. It will last until the player points their palm down.

The wrist supination/pronation is considered a low difficulty exercise to be performed by the patients, and thus it is the first introduced to the player.

2) Fist: The fist is also a low difficulty exercise. It consists of the movement of closing the hand in a fist, then opening it again.

An important detail of the implementation of the detection of this exercise is that the hand must be pointing forward when the hand is closed. This was done to avoid intersection between the movements of each exercise, preventing one from being detected when performing the other.

When closing the hand, the transition from **Detect** to **Process** occurs. Thereafter a transparent blue sphere is displayed in the player's hand and its size grows until it reaches a maximum radius. That is the indication that the player can open their hand to cast a lightning bolt onto the enemies (Fig. 3). If there are several enemies close to each other, the lightning will chain from one to another.

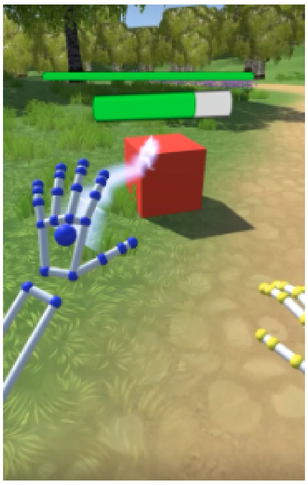

Fig. 3. Example of fist exercise. Chain lightning after opening fist.

3) Wrist curl: The wrist curl is of medium difficulty, so it triggers a more powerful spell. Once the player flexes down their wrist, a pink circle will appear showing where a giant boulder will fall. The circle will grow in size until it reaches a maximum radius, when it will be ready to be triggered by flexing up the wrist (Fig. 4).

This exercise required adaptations to be used in the game. In a conventional therapy session, a weight is used when performing the movement, like a bottle of water. This cannot be done when using Leap Motion, as its detection is optical. An object in the player's hand would obstruct the view of the sensor and, consequently, would hinder the tracking of movements.

4) Finger curl: The user must touch the tip of each finger on the tip of the thumb, starting with the index finger and ending with the little finger. This exercise is the most difficult to perform, so the magic attributed to it is the strongest in the game.

This exercise should be performed with the palm facing the player's face, since Leap Motion needs to visualize the touch of the fingers. By touching the tip of the index on the tip of the thumb, the state machine goes from **Detect** to **Process**. A red

Fig. 4. Pink circle shows where boulder will fall (left) and enemy being hit after the fall (right).

sphere appears in the player's palm. This sphere grows in size for each finger that performs the movement. After performing it with all fingers, the sphere reaches its maximum size and the user can use the magic. To do this, they must turn their hand and point the palm at the target (Fig. 5).

When the hand is turn, the transition from **Process** to **Finish** occurs. Then a bolt of energy leaves the player's hand and lasts for 5 seconds. This beam deals continuous damage to enemies.

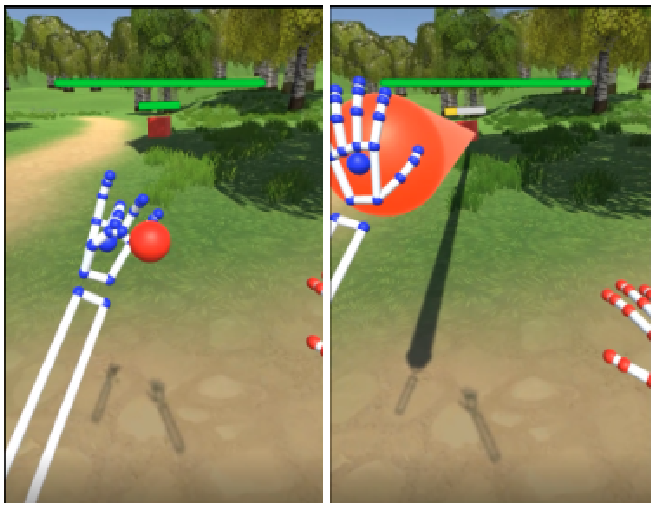

Fig. 5. User performing the finger curl exercise in the virtual environment. Finger curl movement (left) and spell being fired (right).

At the first level of the game, the player learns how to create a barrier to defend himself, by performing the *wrist supination/pronation* exercise. At level two, the player learns how to cast a lightning bolt by making a *fist*. On the third stage the player will be able to summon a giant boulder by making a *wrist curl*. Finally, at the fourth level, the user can cast an energy blast towards the enemies by curling their fingers.

From this moment on, the player has access to all spells. After the fourth level the stages are infinite, where random sets of enemies are generated in waves, progressively increasing the number of enemies and, consequently, the difficulty of the game and the possibility of performing the four different spells. The randomness of this stage aims to ensure that two game sessions are never the same, keeping the player always encouraged to continue playing and overcome their last playthrough. The player's goal is to stay alive for as many stages as possible. Thus, there is a way to measure your progress over several playthroughs.

The game also includes a way for a physiotherapist to build a level. In a configurable file, the physiotherapist can define which spells are available, how many enemies of each type the player must face and the time before each enemy spawns. It is also possible to define whether the objective of the level is to defeat all enemies or just survive for a while.

The first line of the file defines how long the level will last. It can be a stage in which the player must survive for a certain amount of time, or its goal can be just that the user defeats all enemies. In the first case, the file line should indicate the word *"TIME"* followed by the number of seconds that the player must survive, or -1 if there is no time restriction.

The following lines control the creation of enemies. Each line determines 3 parameters: the element of the enemies to be created, the number of enemies and after how many seconds from the beginning of the level they will appear. Therefore, if one type *"FIRE 3 20"* the game will create 3 enemies of the fire element 20 seconds after the start of the level. There can be as many lines as needed to create enemies. The words for each element are *"FIRE", "EARTH", "LIGHTNING", "ICE"*, and *"NORMAL"*.

The last line of the file determines which spells the player can use at this stage. It starts with the command *"MAGIC"*, followed by the names of the exercises corresponding to the available spells. Those are *"FIST", "ROTATION", "WRIST_CURL"*, and *"FINGER_CURL"*, for fist, wrist supination and pronation, wrist curl and finger curl, respectively.

IV. Evaluation Method

We initially evaluated the game with five non-disabled individuals aiming to identify how the users, who have no physical impairments, deal with the interaction techniques proposed in the game. Also, we intended to evaluate the usability and user experience. Below, we present the participants of this study, the procedure of the test sessions, and the results obtained.

A. Participants

Five participants (3 female and 2 male) aged between 22 and 26 years old took part in the tests. They are identified here as P1, P2, P3, P4, P5. Each participant has a different level of experience in VR, as shown in Table I.

TABLE I
Characterization of the participants

Id	Age	Genre	VR usage frequency	Prev. hand-interaction in VR experience
P1	23	M	Up to once a month	Good
P2	26	M	Once a week	Good
P3	23	F	Never	Poor
P4	23	F	Up to once a month	Poor
P5	22	F	Up to once a month	Fair

B. Procedure

The evaluation procedure was divided in three steps: pre-test, playtest and post-test.

The objective of the pre-test questionnaire is to previously identify the participant profile to know their data related to the use of virtual reality systems, as well as to identify their physical state (hand pain level and nausea symptoms) before interacting with the game.

After finishing the pre-test questionnaire, the players were instructed to play the game freely, using as many attempts as necessary to be able to experience all of its levels and spells. The players were offered help in the event of difficulties with the equipment or in carrying out the proposed movements. The playtest was ran on a Windows machine, with the Leap Motion attached to an Oculus Rift.

Finally, after playing the game, an 5-scale questionnaire was applied for each participant, which aimed to evaluate the usability and user experience playing the game, in addition to assessing the interaction techniques.

C. Results

The following results will be described according to the information collected from the questionnaires. All participants have already had previous experience with VR environments, but only P1, P2, and P5 consider themselves experienced when interacting with the hands instead of controls in virtual environments. Of the 5 participants, only P2 uses VR devices more than once a month.

When asked about the ease of use of the game in general, and the ease of learning the game's commands and firing spells, P1, P4, and P5 considered it easy or very easy, while P3 had difficulty and P2 did not find it neither easy nor difficult.

By looking at Fig. 6 it is noticeable that participants with less experience in hand-interaction had, in general, a better user experience. Also, P2, who uses VR more often, was the one who found the game less interesting thinks and that others could not easily play the game.

All players considered the game could be useful as support for hand therapy, and only P2 would not want to play it again even without the need for treatment.

Regarding the interaction with the application, most players found that Leap Motion and Oculus were easy to use and that the direct interaction with the hands was pleasant. Only one user (P2) disagreed with these claims. All participants found the game fun and enjoyable, and only one of them (P3) did not find the game grew more interesting at each stage.

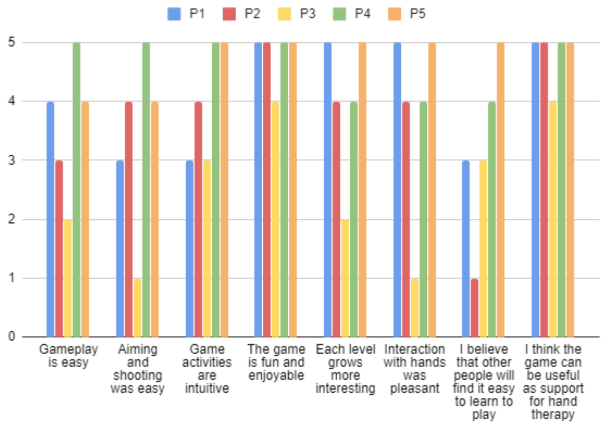

Fig. 6. Usability survey results: the scale goes from strongly disagree (1) to strongly agree (5).

Regarding the interaction techniques used for the spells, it was unanimous that the first two movements (wrist supination/pronation and fist) were easy to perform. However, three of the users found the wrist curl exercise difficult, with one finding it neutral and the other finding it very easy. The finger curl movement had the greatest division of opinions, with uniform distribution among all 5 difficulty options provided (Fig. 7). Participant P1 mentioned all the exercises were easy to perform. Participant P4 had difficulties in the wrist and finger curl exercises; however, she rated the game with the highest scores, indicating that the game is easy to use, intuitive and enjoyable.

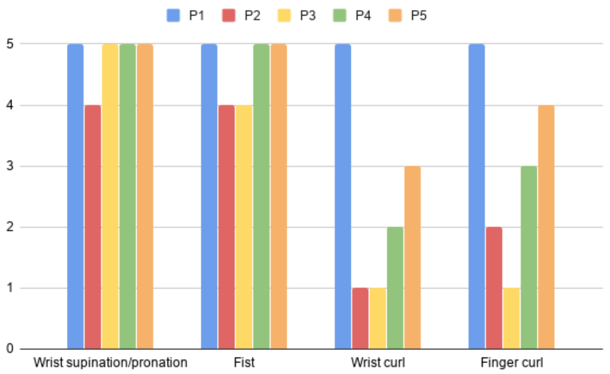

Fig. 7. Interaction techniques survey results: the scale goes from very hard (1) to very easy (5).

Users also were questioned about the level of pain in the left hand after the interaction. Three of the participants reported an increase in the level of pain, of which P2 and P5 had mild pain and P3 had severe pain. Only one user experienced nausea or mild dizziness after playing. P3 was the participant one who had the most difficulty using the equipment, at various times having problems with the detection of the exercises, resulting in a repetition of movements bigger than expected. Although opinions have diverged as to how real the game experience felt, all players reported that they felt immersed while playing.

The main positive aspects pointed out by the test participants were the game's creativity, its interactive commands and the fact that the application turns something unpleasant, like a physiotherapy session, into something playful that goes by quickly. The interface and instructions of the game were praised for being simple and easy to understand, and the environment was considered pleasant. In addition, it was pointed out that the game presents a good level of challenge, being neither too simple nor too difficult. Below is a comment from P5:

"The game is easy for the user to understand. It is easy to understand that you must do an 'OK' with your hand to start the next level of the game. The tutorials for the new commands at the beginning of each level are very clear and objective. The commands were easy to understand without need for further explanation. The game environment is very pleasant because it is a large space with lots of green and trees. The difficulty of the game is good, not being too simple to win but also not being too difficult to play and finish the levels. It has a good level of challenge, which gradually increases. The left hand exercise is well done and I believe it can be very useful for the rehabilitation of that limb. The game also showed no errors and the interface to show when enemies will attack, their health and player's health were very good".

Most of the negative aspects reported were related to the application's limitations in distinguishing which spell the player wanted to perform, especially during the execution of the wrist curl. Even without objects obstructing the vision of Leap Motion, this exercise presented implementation difficulties. The initial position of the hand is not well tracked by the sensor, which causes strange movements on the screen, even though the player is performing the movement correctly. It was also mentioned that the game should have a way of regenerating life and that it is not clear whether the enemies were defeated or teleported to another location, as they simply disappear. P3 complained of pain after playing.

V. Discussion

We explored four interaction techniques in a VR game, that consist of physiotherapeutic exercises made by the user while playing the game. In this study, we evaluate the game with healthy participants aiming to identify the improvements required.

Given the feedback from users evaluated, it can be concluded that the application has fulfilled its objective of being playful and fun even for those who do not need hand therapy. Despite reporting some difficulties with interacting with the game, most players responded that they would like to play it again without needing therapy.

Regarding the interaction techniques, the wrist supination/pronation and fist exercises were easier to understand and perform by all the users. These exercises were easy to perform even to the users who do have never used VR (P3) or who have no VR experience (P4), with this, we can suggest that easy-to-perform exercises may be suitable regardless of VR experience.

The wrist and finger curl exercises were most difficult to perform; thus, their implementation requires to be reviewed, or even the movement changed to one more easily detected by Leap Motion and performed by users.

It is important to note that even healthy users reported that they felt pain and difficulties in performing some exercises. This serves as a warning for the future test to be carried out with patients, as they will probably have difficulties as well.

In addition, some participants reported that it was not clear which movement should be made to perform each exercise, which indicates that the tutorial shown was not enough to teach players how the game is played. A possible solution to this problem would be to provide visual indications of how the player should position his hand to perform each exercise, and not let them progress until they have successfully conjured the spell.

The interaction techniques using hand-movements can influence the contribution of the game for users. Therefore, it will be interesting to include customization options, so that the game and the interaction techniques can be adapted according to the interest and needs of each user. These aspects could be very useful for target users. No therapists were involved in this study, but their feedback on the modifications necessary to improve the game for its therapeutic purpose would be pertinent.

VI. Conclusion and future work

In this work, a game was developed that seeks not only to treat individuals with hand/arm impairments, but to entertain them during the process. Traditional rehabilitation therapy exercises were used as game interaction techniques, inserted in a playful scenario compatible with the required movements.

Tests carried out with non-disabled users showed that the virtual game was able to entertain even those who were not, initially, the main target audience of the game. Despite this, detection problems were observed in the player's movements and some users reported pain after playing it, which is a point that raises concern about the result of future tests with actual patients. These aspect will be considered to improve the techniques used in the game.

In future work, we intend to improve the game and evaluate it with both physiotherapists and users with hand impairments to verify its feasibility for use in treatment accompanied by conventional therapy.

It is also possible to improve the detection of exercises that trigger spells and, for those that are difficult to recognize by Leap Motion, such as wrist flexion, it should be considered to change the movement to another exercise that is more compatible with the equipment. Other improvements can also be made, such as the possibility of choosing the hand with which to use the spells, or even the use of both hands simultaneously, in addition to the creation of new spells using other exercises.

References

[1] Z. Qinping, "A survey on virtual reality," *Science in China Series F: Information Sciences*, vol. 52, no. 3, pp. 348–400, 2009.

[2] T. Rose, C. S. Nam, and K. B. Chen, "Immersion of virtual reality for rehabilitation-review," *Applied ergonomics*, vol. 69, pp. 153–161, 2018.

[3] W. H. Organization *et al.*, *World report on disability 2011*. World Health Organization, 2011.

[4] R. Colombo, F. Pisano, A. Mazzone, C. Delconte, S. Micera, M. C. Carrozza, P. Dario, and G. Minuco, "Design strategies to improve patient motivation during robot-aided rehabilitation," *Journal of neuroengineering and rehabilitation*, vol. 4, no. 1, p. 3, 2007.

[5] M. C. Howard, "A meta-analysis and systematic literature review of virtual reality rehabilitation programs," *Computers in Human Behavior*, vol. 70, pp. 317–327, 2017.

[6] J. Moline, "Virtual reality for health care: a survey," *Studies in health technology and informatics*, pp. 3–34, 1997.

[7] G. Saposnik, R. Teasell, M. Mamdani, J. Hall, W. McIlroy, D. Cheung, K. E. Thorpe, L. G. Cohen, and M. Bayley, "Effectiveness of virtual reality using wii gaming technology in stroke rehabilitation: a pilot randomized clinical trial and proof of principle," *Stroke*, vol. 41, no. 7, pp. 1477–1484, 2010.

[8] D. Rand, R. Kizony, and P. T. L. Weiss, "The sony playstation ii eyetoy: low-cost virtual reality for use in rehabilitation," *Journal of neurologic physical therapy*, vol. 32, no. 4, pp. 155–163, 2008.

[9] Y.-X. Hung, P.-C. Huang, K.-T. Chen, and W.-C. Chu, "What do stroke patients look for in game-based rehabilitation: a survey study," *Medicine*, vol. 95, no. 11, 2016.

[10] K. J. Bower, J. Louie, Y. Landesrocha, P. Seedy, A. Gorelik, and J. Bernhardt, "Clinical feasibility of interactive motion-controlled games for stroke rehabilitation," *Journal of neuroengineering and rehabilitation*, vol. 12, no. 1, p. 63, 2015.

[11] M. AlMousa, H. S. Al-Khalifa, and H. AlSobayel, "Requirements elicitation and prototyping of a fully immersive virtual reality gaming system for upper limb stroke rehabilitation in saudi arabia," *Mobile Information Systems*, vol. 2017, 2017.

[12] A. Karashanov, A. Manolova, and N. Neshov, "Application for hand rehabilitation using leap motion sensor based on a gamification approach," *Int. J. Adv. Res. Sci. Eng*, vol. 5, no. 2, pp. 61–69, 2016.

[13] S. Brunnstrom, "Movement therapy in hemiplegia: a neurophysiological approach. 1970."

[14] "Expert hand exercises for stroke patients (with pictures video)," Jan 2020. [Online]. Available: https://www.flintrehab.com/2018/hand-exercises-for-stroke-patients-with-pictures/

[15] "Stroke exercises for your body: Saebo, inc." [Online]. Available: https://www.saebo.com/stroke-exercises-for-your-body/

[16] H. H. Publishing, "5 exercises to improve hand mobility." [Online]. Available: https://www.health.harvard.edu/pain/5-exercises-to-improve-hand-mobility-and-reduce-pain

[17] S. Rahman and A. Shaheen, "Virtual reality use in motor rehabilitation of neurological disorders: a systematic review," *Middle-East J Sci Res*, vol. 7, no. 1, pp. 63–70, 2011.