Department

Using Virtual Reality to Increase Motivation in Poststroke Rehabilitation

VR Therapeutic Mini-Games Help in Poststroke Recovery

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***Abstract*—Virtual reality (VR) applications meet fundamental principles of rehabilitation: intensity, task oriented training, biofeedback, environments rich in stimuli, and motivation, all pivotal factors for the success of rehabilitation programs. This paper describes the development process of a set of VR minigames developed to increase the motivation of stroke patients while performing repetitive upper limb movements.**

TECHNOLOGY MAY SIGNIFICANTLY improve the lives of people suffering from incapacity or deficiency affecting millions worldwide. Virtual reality (VR) is already used to help patients endure pain and disease treatment[1–4] as well as recover from stroke,[5,6] among other applications in medicine. VR has a significant potential for rehabilitation[7,8] as it allows the creation of virtual environments (VEs) providing multiple stimuli and fostering the improvement of motor and cognitive capacities while motivating and engaging the patients. Moreover, VR applications may meet the four basic principles of rehabilitation: intensity, task oriented training, biofeedback,

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and motivation, all pivotal factors for the success of rehabilitation programs.[6,9,10,11]

The following benefits of using VR in rehabilitation have been reported in the literature:[7] better performance, improvement of the affected limb and cognitive functions, neuroplasticity stimulation, and greater autonomy in the daily life activities, while increasing the patients' motivation and collaboration during the rehabilitation program. In particular, some authors have "found evidence that the use of VR and interactive video gaming may be beneficial in improving upper limb function and ADL (Activities of Daily Living) function when used as an adjunct to usual care (to increase overall therapy time) or when compared with the same dose of conventional therapy."[7] This makes VR an exciting tool in the future of therapy, "not only because it was proven to be effective among sick and healthy subjects, but also because it had very little side-effect and was much safer than other aggressive or offensive therapies."[8]

Recently, affordable sensors developed by the gaming industry have been explored for rehabilitation.[6,12] This synergy between benefits and affordable technology makes VR applications a natural approach for stroke rehabilitation, one of the main causes of incapacity worldwide. Aware of this potential, and concerned with the lack of motivation of stroke patients while performing repetitive upper limb movements in acute, subacute, and chronic phases, a group of professionals at "Centro de Medicina de Reabilitação da Região Centro—Rovisco Pais," a National Rehabilitation Center in Portugal, contacted the Universidade de Aveiro to develop VR therapeutic serious games aimed at increasing motivation by providing everyday life context to the movements. Several VR applications were developed using a Leap Motion sensor (www.leapmotion.com) to track upper limb movements. These applications help patients perform relevant shoulder, arm, and hand movements, while immersing them in an informal game-like VE. This paper describes the development of the applications and the main results of a study involving a group of 12 patients of the rehabilitation center.

VR APPLICATIONS

With the goal of maximizing the usefulness and efficacy of the applications and taking into consideration the specific nature of their users and context of use, the initial phase of the process involved a series of visits to the rehabilitation center and meetings, first with a group of interested physiatrists, and later also with physical and occupational therapists. These meetings helped establish a common ground of mutual understanding of what patients need and what the technology can provide, thenceforth facilitating the communication between the teams. The first outcome of these meetings was the awareness that the ideal VR platform should encompass not only a set of "minigames" to motivate patients during the essential, but tedious sessions of upper limb rehabilitation (the initial goal), but also the possibility of personalization of the games as well as remote monitoring of the patients' progress, allowing a better follow-up of the patients' evolution beyond the rehabilitation center. This is a very important feature allowing patients to actively participate in their program at home. As a result of this initial phase, a set of decisions concerning the design and implementation of the applications were made, and the physiatrists and therapists stayed involved during the process, regularly giving feedback and helping establish intermediate goals.

> The VR platform should encompass not only a set of minigames to motivate patients, but also the possibility of personalization and remote monitoring of patient progress.

The Leap Motion controller was selected as the sensor to monitor both coarse gestures (shoulder or elbow movement, detected due to change of hand position) and fine movements (finger pinches) since it detects the position, orientation, and current state of the hand. The games were developed in Unity3D (unity3d.com). This platform allows the creation of VEs as well as game logic and facilitates the virtual world creation interface as well as native integration with an Oculus Rift DK2 Head Mounted Display (www.oculus.com/rift) and the official Leap Motion SDK package.

The system includes a backend server controlling access to the database and the front-end three-dimensional applications used by patients, as well as a configuration web page. This allows for storage and management of game

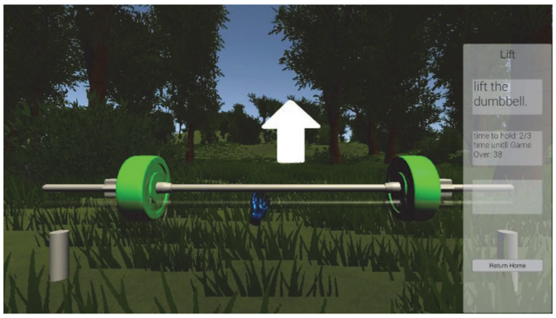

Figure 1. "Lift" game: user lifts barbell to a specified height a target number of times.

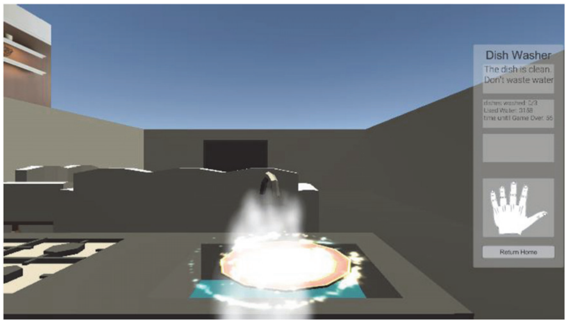

Figure 3. "Dish Washer" game: user opens and closes the hand to wash the dish a number of times.

configuration data (game instance, number of iterations, maximum completion time, difficulty level, and other aspects of the game), and game results (task completion, time elapsed, and specific values concerning the patient's movements as the longest distance reached).

Our first goal was to define which gestures were relevant for the exercises to be performed by patients during the games. The "Enjalbert Test" was selected as the basis for the applications to be developed since it was already used to evaluate patients' progress at the rehabilitation center.[13] The test, a five-level scale, is used to access the current state of the upper limb movement recovery for a poststroke victim and includes different movements, ranging from 0 (no upper limb movement) to 5 (fine pincer movements with all fingers).

- Lifting and holding the hand in place (shoulder).
- Bringing the hand to the mouth (shoulder and elbow).
- Opening and closing the hand (hand).

Figure 2. "Apple Eater" game: user takes an apple to the mouth a number of times.

- Executing fine pinch movements with the index and middle fingers (hand).
- Executing fine pincer movements with the ring and pinky fingers (hand).

An important requirement was that the games should evoke real life situations and be aimed at helping patients recover capacities for an independent life. Thus, it was decided to develop five minigames, focused on movements involved in progressing through the Enjalbert scale. The games developed to exercise the first three gestures passed a first round of tests with patients (in the same order as the list above).

The games should evoke real life situations and be aimed at helping patients recover capacities for an independent life.

- Lift: The patient should lift a barbell above a specified line (see Figure 1) and hold it for a predefined time before bringing it back down. This action should be repeated for a predefined number of times.
- Apple eater: The patient should reach one of the two apples (see Figure 2) on a table and bring it to the mouth.
- Dish washer: The patient should wash the dishes, opening and closing their hand to turn ON and OFF the sink's faucet (see Figure 3). The patient must keep the hand open until the dish is entirely clean.

Two more games were developed to exercise "finger pinch" movements that required users to pick objects from a box and drop them on a table

Figure 4. VR system used at the rehabilitation center. 1) Computer. 2) Monitor. 3) Oculus Rift head mounted display. 4) Leap Motion controller. 5) Speaker.

using different pinch gestures. However, due to the unreliability of the Leap Motion controller for very fine gestures, doctors concluded these games were not responsive enough to be tested with patients.

Data such as the duration of each movement, number of repetitions, height of the barbell line, number of apples on each side of the table, number of dishes, or what is considered an open hand are configured through a backend web page. A calibration application was also developed to configure the games according to the patient's condition, essential for allowing the patients to accomplish the task. With this application the limits for values such as ''maximum height when lifting arm'' or ''maximum hand opening'' can be set for each patient and updated according to the patients progress along their rehabilitation program.

As part of the development process, several rounds of preliminary tests were performed at the rehabilitation center with the help of doctors, therapists, and volunteer patients who played the games. This formative evaluation phase had a twofold purpose: Identify and correct possible limitations of the applications and assess whether the patients liked and were motivated by the minigames. Some modifications were made, mostly regarding the distance between the virtual hand resting position and the interaction objects, since in an initial phase applications were only tested by users with full control of their upper limb and these issues were not noticed. Another relevant improvement was the addition of a score and a ''success'' sound effect at the completion of the task, in a way to provide positive feedback and encouragement, and allow for competition among patients, features that were considered important to increase motivation. On the other hand, when patients did not attain the goal, discouraging sounds or negative messages were not given so as to avoid patient frustration.

Beyond testing the minigames, these preliminary testing sessions were also meant to instruct the therapists on how to use the system, especially the configuration settings, as they would be the main users.

USER STUDY

A VR system was installed at the rehabilitation center to enable its patients to use the developed applications. The VR setup is composed by the following elements, as shown in Figure 4.

- A desktop computer to run the applications and local backend server (marked "1" in the figure).
- A 4k definition monitor to display the VE, when running the applications in a nonimmersive setting ("2").
- An Oculus Rift DK2 HMD (head mounted display) to display the VE, when running the applications in a fully immersive setting ("3").
- A Leap Motion controller to track the position and orientation of the patient's hands, so they can be represented and used in the VE ("4").
- A speaker positioned in front of the patient to provide audio feedback ("5").

To evaluate the developed minigames, a pilot study was conducted after a formal authorization by the rehabilitation center ethics committee and a careful selection of the patients that should participate. The aim of this study was to establish which selection standards should be applied regarding which patients could use the applications and benefit from them, as well as to obtain data regarding the patients' satisfaction with the games.

The main questions to be answered by our study were:

1) At what level of recovery could the patients start using the minigames?

2) Which exclusion criteria should be used?
3) Which particular stroke sequelae cause unusual results in a patient's capability and enjoyment when playing?
4) Is this type of treatment well accepted by the patients?
5) Is there a preference regarding the level of immersion (nonimmersive versus full immersion)?

A group of 12 patients (six female) aged between 39 and 71 in several phases of recovery and suffering from different stroke sequelae were selected to test the applications, using both the immersive and nonimmersive versions of the games. The patients used the applications while seated and then answered a questionnaire regarding their satisfaction with the minigames, always accompanied by a developer and a therapist.

First, the patient was instructed about the test and the equipment he/she would be using. The patient then played the minigames twice, using the computer screen as the display and the Oculus Rift DK2 HMD. To prevent bias, half the patients used the nonimmersive version of the applications first, while the other half started by using the HMD.

After the games were concluded (successfully or not) the patient answered orally part of the questionnaire (concerned with familiarity with technology; nonimmersive versus fully immersive and general questions). The remaining sections of the questionnaire (doctor/therapist credentials; patient information; occupation therapy) were answered by the doctors and therapists.

RESULTS AND DISCUSSION

Although most patients were not familiar with computer games (9 out of 12 had never played videogames) or VR (10 out of 12), the minigames were well accepted both in the rate of success and in satisfaction. Only two patients were not able to successfully complete all three minigames and only one was not able to complete any of them. All the patients who were able to play came away satisfied, claiming to have enjoyed the experience and expressing interest in including VR as part of the rehabilitation therapy. "Lift" was the preferred game, followed by "Dish Washer."

Although no significant differences in performance or acceptance between the fully immersive and nonimmersive games were noted, when asked, most patients claimed to prefer the fully immersive version of the system. Two patients preferred the nonimmersive version of the minigames. One of the patients had never used a computer before and found full immersion to be too invasive. The other patient suffered from proprioceptive sensitivity and, as explained by the doctors, stroke victims with this particular sequela feel the need to look at their hand in order to execute the movements. Thus, not being able to see the real hand when using the HMD may have caused the patient to feel less attracted to the fully immersive version, despite being able to successfully play in both versions.

No patients expressed feeling any type of cybersickness during or after playing. This was expected as none of the minigames involves any virtual full body movements, or rapidly changing images, which are important causes for this kind of side effect.

When asked in which setting, individual or social, they would prefer to play the games, the results were approximately the same for both. It was also noted that one patient participating in the study had previously played the minigames, during the preliminary tests, with greater success. Although being able to complete all three games both times, during the study the patient was suffering from depression, which was considered to be a plausible cause for the decrease in performance.

No hardware related issues specific to Oculus Rift were observed; however, there are visual and cognitive stroke sequelae (besides depression) that may hamper the usage of immersive VR in patients' therapy. Examples of such conditions are hemineglet and assomatognosia, involving deficits in recognizing the hemispace and hemibody contralateral to the injured brain hemisphere

Some limitations were found regarding the use of the Leap Motion sensor as a tracker. Two specific issues were considered relevant: the position of the sensor on top of the table proved too hard to reach by patients in early phases of recovery. This obstacle was overcome by placing a board on the patient's lap and positioning the sensor on it. In the "Apple Eater" game, because the patient's mouth position in the virtual environment was static, unless the patient kept his/her back straight throughout the full exercise, this position would no longer correspond to the actual mouth area of the patient. This issue was amplified by the fact that the patients would lean forward to reach the objects, and was alleviated by reminding the patients to keep their back straight during the procedure.

CONCLUSION

Overall, the potential use of the minigames in occupational therapy in poststroke rehabilitation was very well received by patients, doctors, and therapists, with its major benefit being the increase in a patient's motivation for recovery through the use of fun and relaxed environments, which successfully distract the patient from the dull clinical setting at an affordable cost.

The collaboration continues with the development of more applications, both aimed at upper limb movement recovery and rehabilitation for other stroke sequelae and further tests to introduce this approach in the routine therapy of the rehabilitation center at least in some phases of their recovery. The next phase will be the evaluation of the efficacy of this approach as an additional therapeutic instrument in the rehabilitation of poststroke patients in acute, subacute, and chronic phases, through a longitudinal study involving a larger number of patients with a wider variety of conditions, both at the rehabilitation center and at home. For instance, if gender or age correlations were noticeable, this study would provide guidelines on how to use VR with different patients.

Augmented reality based physical therapy games using smartphones might also be a promising direction as they lower the barrier to greater home-based use and technological literacy of the population is increasing. Compared to conventional approaches, AR alternatives allow adapting the exercises to the patients' interests and habits potentially increasing their motivation. Nevertheless, immersive VR-based games may be ultimately more engaging.

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