An Exploratory Study on the use of Virtual Reality in Balance Rehabilitation*

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***Abstract*— Studies have shown the potential of Virtual Reality and motion tracking devices in physical rehabilitation. This paper addresses the topic of using non-immersive Virtual Reality therapeutic games with motion tracking in physical rehabilitation and describes an exploratory study performed in collaboration with a national public Rehabilitation Center about their use to motivate patients to perform exercises relevant for balance rehabilitation. The work involved developing and adapting mini-games to track patients posture; tests with patients recovering from Spinal Cord Injury suggest that this type of games can be helpful in the recovery process namely in patients' motivation for performing the therapeutic gestures.**

I. Introduction

People with central nervous system disabilities resulting from spinal cord injury (SCI) and stroke suffer from loss of motor and sensory function in the limbs affecting balance, independence, and mobility in general. Physical therapy helps recover mobility and patient-centered task-oriented training (including intensive repetition of the recovery exercises) is crucial in this rehabilitation [1]. However, the repetition of certain actions can be overwhelming and very tedious, which results in demotivated patients. Lack of motivation is a serious threat to the success of any rehabilitation program. Virtual Reality has been considered as having potential to help in rehabilitation; combining rehabilitation treatments with Virtual Reality games may provide a compelling and entertaining experience while doing motor recovery exercises. Moreover, games can be personalized for each patient and provide feedback allowing them to evaluate their progression, increasing motivation [2]. Recently, due to the development of Virtual Reality and the gaming industry, a plethora of tracking devices and head-mounted displays have become available at affordable costs making more viable the use of Virtual Reality based approaches to physical rehabilitation [3].

This paper presents an exploratory study on using affordable solutions for semi-immersive Virtual Reality games to motivate patients while performing balance rehabilitation exercises. It is organized as follows: section II is concerned with using Virtual Reality in physical rehabilitation; section III describes the development of a new mini-game and the adaptation of an existing one for balance rehabilitation of patients recovering from spinal cord injury; section IV presents the results of testing these games with voluntary patients; and section V draws conclusions and presents ideas for future work.

II. Virtual Reality Games in Physical Rehabilitation

In physical therapy, the determinants of motor recovery are early intervention, task-oriented training and repetition intensity [1]. However, the repetition of certain actions can be daunting and boring, which results in demotivated patients. The amount of movements required to induce a significant change is measured in thousands of repetitions, but, on average, a much smaller amount of a specific movement is practiced in a traditional daily rehabilitation session. The potential benefit of combining a rehabilitation treatment with Virtual Reality (VR) games is that it provides a gaming experience, and entertainment while doing motor recovery exercises [4]. Viau et al. showed that the movements performed in a virtual environment are similar enough to the ones performed in the real world [5]. Hence, virtual environments can provide an effective setting for rehabilitation. A possible advantage of using VR is that patient's performance may be better when immersed in a virtual environment because of a more intense focus on the task [2]. Moreover, games can be personalized for each patient, taking into account patients preferences and giving them the ability to evaluate their progression [2]. This may increase patient's motivation to practice. When motivated, patients are willing to spend more time playing the game and thus perform more motor exercises, which is most relevant in rehabilitation. Also, given the hardware recent affordability, VR exercising applications have the potential to be used both at the rehabilitation center and at home. If games are used at home patient performance data can be sent to the hospital for the medical review and tracked over time in order to observe the overall recovery, which is particularly interesting to keep patients motivated after leaving the rehabilitation Center.

Video games have been found beneficial for cognitive and motor skill learning in experimental studies both in rehabilitation and with healthy subjects [6]. Physiological

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data suggest that playing games can induce neuroplasticity reorganization that leads to long-term retention and transfer of skill [6]. Even just doing mental practice of an activity or being exposed visually to the activity being performed (images or video) helps in the skills retention needed for the activity [7]. This might be even more interesting in balance rehabilitation as when patients exercise in VR, the prefrontal, parietal cortical areas and other motor cortical networks are activated. This activation helps in the reconstruction of neurons in the cerebral cortex and retaining motor skills, as the prefrontal cortex is one of the important brain areas in controlling human balance [8].

Commercial VR games, such as "Kinect Adventures" and "Zen", have been used in a few research studies focusing on balance control. Beaulieu et al. results suggest that games from Kinect Xbox 360 as well as other commercial games can improve balance control [9]. However, these authors' research did not have a control group, so it is not clear if the balance control improvements were caused by using the games or by the natural recovery process. Kim et al. also tested the usability of commercial games in balance strengthening. They used "Kinect Adventures" games in a study and concluded that the commercial games can help in balance control [4]. Based on these studies, commercial games such as "Kinect Adventures" appear to be successful in improving balance control of elderly people with balance disorders. Unfortunately, these games are not appropriate to be played in a wheelchair or seated as they imply jumping, and thus are not applicable for SCI patients without customization, which is not available. Given their entertaining purpose, they also do not include any logging capabilities and might be too challenging for the patients.

Commercial games might be used in therapy to increase fun and motivation, but in order to have a significant impact on the patients' recovery they should be specifically tailored to the patients, taking into the account their limitations and adapting the gestures used. On the other hand, existing VR games for rehabilitation are more exercises than actual games, lacking the motivational characteristics needed for these patients; this situation motivated our work.

III. Developing the Balance Therapeutic-Games

In the scope of this work the development and adaptation of the games was done in collaboration with the Rovisco Pais Rehabilitation Medicine Center in Portugal. In a previous collaboration with this Center, a set of mini-games for rehabilitation was developed using the Leap motion sensor to track the patients' hands [3][10]. The games were successful but presented a limitation: the patient's posture could not be tracked resulting in situations in which patients leaned toward the hand not completing correctly the movement (e.g. raising the hand to the mouth). Based on this experience, it was decided to track the whole body to ensure the correct execution of the movements. The tracking sensor selected was Kinect v2 as it provides full body tracking, was available for an affordable price, and had already been used to monitor the patients' movements in neurological rehabilitation [11][12].

The work started with several visits to the Center, meetings with the doctors and the therapists, as well as observation of the patients during treatments to identify possible opportunities to increase motivation while performing the tedious/repetitive rehabilitation movements. From this observation an interesting opportunity appeared: developing a game to help recover upper body balance. The game would make possible to insert patients in situations they cannot experience in real life due to their condition with significant motivation level increase, especially for many young SCI patients [13]. Based on this premise, a car race game was developed in Unity, a game development platform (unity.com), which was used due to its easy integration with motion tracking devices and SDKs.

The game was implemented considering motivational concepts important for effective game design to increase player's engagement and motivation [1]: reward (the winner is rewarded with cheerful lights and sounds); positive feedback (while racing, players can gain points, which are displayed on the screen and the more points they have, the faster they can drive); clear instructions (the goal of the game is to finish the circuit); socialization (the game can be played in two-players competitive mode); and optimal challenge (the control of a vehicle is not trivial and requires learning). The rules of the game are as follows: the player controls a vehicle by moving their upper body (Figure 1). Only the inclination of the torso matters in the control of the vehicle; the hands can be in any position. If the player leans forward the vehicle moves forward; leaning backward will move backwards. The same mechanism works for turning. These gestures were selected after discussions with the therapists that train SCI patients concerning trunk balance. The more the patient leans, the faster the vehicle will go; to break the player must lean back. Braking won't be instantaneous, reflecting real world dynamics. If the vehicle goes off road for a long time, players can reset to the starting position by putting both hands above the head. The mini-game can be played in single-player or in two-player competitive mode (Figure 2). When played as a competition, the winner is the one who first complete the circuit. Players can set how many rounds they must complete. The one who first drives the specified number of turns wins. The game can be played both standing or sitting; an important feature as most patients must play seated. Before playing, the player's straight posture is measured (Figure 3). This calibration procedure is needed to store the reference angles needed to compute the correct leaning parameters. Several parameters are logged during the game: number of times the player goes off road, leaning parameters, maximum inclination in backward, forward, left and right directions.

The game was tested with the collaboration of 9 healthy students, who were briefed about the game and gave their

informed consent, to evaluate its generic usability (ease of use and learn) and identify potential issues. The participants played in single and two player modes, while observed, and answered a questionnaire. Most participants considered the vehicle not easy to control and suggested to implement an easier control mechanism. Even though they enjoyed playing the game, they recommended improving the content to make the game more appealing. All the participants reported that they enjoyed more playing against another player and in a social environment. These results suggest that the game needed further improvement before used in a real test. An important conclusion was the relevance of social aspects.

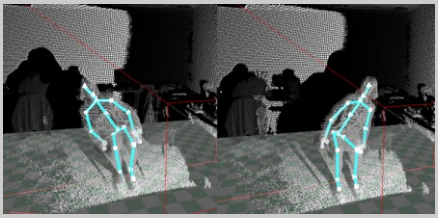

Figure 1. Movement to control the vehicle to turn right or left.

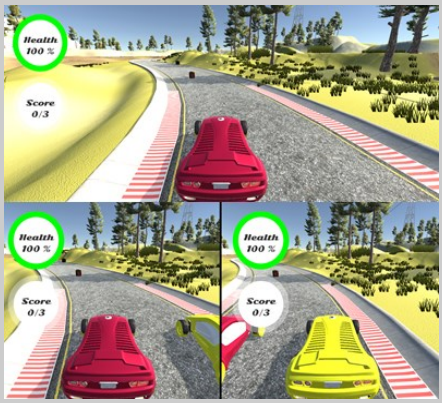

Figure 2. Game in single (top) and two players mode (bottom).

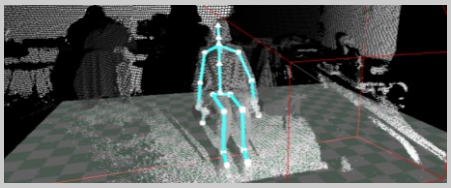

Figure 3. Posture calibration.

Taking into consideration these results, it was decided that adapting an existing multi-player game would be easier than investing time to fine-tune the car control mechanisms. An open source game "Tanks" was selected as it had an interesting environment and internal logics. It was adapted so that the avatars are controlled by the same upper body movements tracked with the Kinect v2, as the first proposed game. Several aspects can be customized (e.g. winning conditions, target distance, and colors) as well. After several iterations to improve this mini-game, the doctors and therapists agreed it was ready to be tested with patients concerning its usability.

IV. Test, Results and Discussion

The adapted game "Tanks" was tested by 6 male SCI patients (aged between 38 and 66 years old) that satisfied the inclusion criteria (see below), 4 were paraplegic and 2 were complete tetraplegic. The test was performed under the supervision of a therapist and a doctor. Prior to the test, an Ethics Committee approval was obtained. This Committee assessed if the inclusion/exclusion criteria, as well as the benefits for the patients and possible side effects, were acceptable and considered the experiment would be carried out in an ethical manner according with the international law.

Inclusion and exclusion conditions are a fundamental issue for any application that is to be used by patients in their rehabilitation program, and thus doctors and physical therapists established the following criteria:

- Inclusion criteria: patients with medullary lesions below T6 (complete or incomplete); patients with incomplete medullary lesions above T6.
- Exclusion criteria: patients with complete medullary lesions above T6; patients with preserved torso equilibrium.

During the experiment the patients were first informed about the procedure and gave their consent, then, they were asked to play alone in order to get familiarized with the control of the avatar and the environment. In a second stage, they played with a healthy user (Figure 1), in a two-player competitive mode. Patients were seated on a normal chair or on a wheelchair, according to their condition. After playing they were asked to fill a questionnaire divided in five sections: 1.General questions focused on the patient's familiarity with computers, computer games, and virtual reality; 2.Questions regarding the level of satisfaction or discomfort experienced while playing; 3.Questions focused on the patient's opinions about the game, its usability, and its potential in rehabilitation; 4.Questions regarding preferences and social environment (individual or in a group); 5.Open questions and suggestions for improvement. More details concerning the complete questionnaire can be found in [14].

Analyzing the patients' answers to the questionnaire, we noticed that half of the patients had never used computers, four had never played computer games, and only half of the patients were familiar with the concept of Virtual Reality. All reported that they felt comfortable while playing, even though the control of the vehicle was still challenging. All the patients successfully finished the game, enjoyed it, would play it at home, and preferred to play the game in the two-player competitive mode. Moreover, doctors and therapists stated that this type of game (controlled by upper body movements) can be very useful in balance rehabilitation. These results suggest that the adapted "Tanks" game provided an enjoyable experience for these patients, and they were willing to have it included in their therapy routine. Some patients even expressed that it would be fun to play

online with other people with SCI. These were positive results and fostered ideas for improvement. The doctors and therapists supervising the experiment proposed the following changes to the game to improve the overall experience and its therapeutic effect: 1. create a progression loop, in the terms of the skill progression [13], starting the gameplay using simpler easier to perform trunk and hands gestures for the control of the avatars and slightly increase its complexity; 2. create levels, to make the gameplay longer and more engaging; 3. seat all the patients on a wheelchair, so that they are secured from falls, in case of balance loss; 4. Adapt the control of the avatar according to each patient's condition.

Figure 4. Patient playing the game during the test.

After the tests, the patients asked to install the adapted game in the Center living room, so they can socialize and play in the evening. This shows that, despite some limitations, the game was well accepted and fun to play.

V. Conclusions and Future Work

This paper describes the development of therapeutic games aimed at motivating patients to repeat gestures relevant to balance rehabilitation. This was done in collaboration with a team of doctors and therapists of a rehabilitation Center, experts in treating spinal cord injury and post-stroke patients. A game was developed and another was adapted and tests with patients suggest this game was well accepted and is more motivating and engaging when played in a two-player competitive setting (confirming that social aspects in rehabilitation are extremely important). While the game still has limitations, the whole process shed light on how to develop this type of applications, and the tests with patients provided several ideas on how to improve it to include in the therapy routine of SCI patients, and patients recovering from stroke. We also learned that to produce an effective rehabilitation game, the player must be entertained and its development should be done by a team of designers, developers, doctors and therapists. This work also confirmed that the skeleton tracking provided by Kinect v2 is good enough for interactive applications where a high accuracy is not mandatory and the person can perform the required movements in the device's working space (4x4m).

The current games can be further improved with the help of doctors and therapists, regarding the specific movements from which the patients would benefit the most. A possible direction could be adapt successful open source games providing a good design and an engaging content, but also the possibility to customize the game to use relevant upper body movements. This would allow extending existing games to support calibration, personalization to the patient's needs and preferences, and add logging of relevant parameters for monitoring.

To conclude, we agree with Pogrzeba et al. that "future technological developments should take up the challenge to combine markerless motion capture systems with principles of a client-centered task-oriented approach and prove efficacy using randomized controlled trials with long-term follow-up" [12]; this is also a future direction for our work.

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