Immersive Virtual Reality as a Supplement in the Rehabilitation Program of Post-Stroke Patients

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Abstract— **In a time when prolonging the quality of life better is not just through long-established medical practices but by technology assisting humans, various projects are challenging the traditional methods of caring for a patient. In stroke, desktop virtual environments (DVEs) are being used to supplement the patient's rehabilitation. The type of rehabilitation provides another means for patients to actively participate in the rehabilitation program through motion mirroring using their television or computer screens. However, immersive virtual reality (VR) is also gaining popularity and is challenging the common DVEs in its effectivity through involving more sensory stimulation of the nervous system. The project aims to answer the questions: *Would immersion of a patient in VR positively help in their rehabilitation, and what are the patient's needs that has to be addressed for it to be effective?* To supplement the patients in their rehabilitation program, a mobile VR application is created using VR peripherals available commercially. The basic principle is that immersion in VR will add more sensory and cognitive stimuli to the stroke patient's traditional hospital rehabilitation. Findings of the study show positive effects of including immersive VR in the rehabilitation program of post-stroke patients. In the present, little information is available on the effects of immersive VR in motor rehabilitation. The study quantifies and qualifies its use specifically in the motor rehabilitation of stroke patients.**

Keywords—immersive virtual reality; stroke rehabilitation; motor rehabilitation; virtual reality application

I. Introduction

According to the World Health Organization (WHO), stroke remains to be the second leading cause of death and the number one cause of disabilities among adults worldwide [1,2]. As much as 50% of survivors develop disabilities at the event of stroke. Some disabilities fall on motor function loss and cognitive impairment. To recover these function losses, stroke rehabilitation is given to the patient. The goal of stroke rehabilitation is to be able to improve the physical, mental and emotional functions post-stroke [3]. This should start as soon as the patient is able to undergo the program, and is in a medically stable condition [3]. Another type of recovery, particularly neurological recovery is linked to neuroplasticity or the reorganization of the neural pathways [4]. Although the particular kind of recovery is also influenced by rehabilitation, it is not dependent on it [5] and is not often measured in the rehabilitation process of a patient. While rehabilitation for motor and functional loss by therapists is widely accepted, developing technology is paving a new way for assisted rehabilitation.

Although the traditional hospital rehabilitation programs prove to be effective in the motor re-learning of post-stroke patients, the environment to which the rehabilitation is done is limited to available inanimate tools. Interaction is limited as well to his/her safety and to specific commands. Supplementing the limited exposure to a more realistic, interactive, responsive and safe environment with VR for more cognitive stimulation and participation will perhaps enhance the motor recovery of the patient.

One technology that can make more cognitive stimulation and participation is the use of virtual reality (VR). VR is a 3D computer-generated environment that can be explored or interacted with a person [6]. Classified as immersive and non-immersive, the latter is exocentric where the user is outside the

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environment and the former being egocentric where the user is part of the environment [7]. Examples of the immersive VR are those that use head mounted displays (HMDs) such as the Oculus Rift, Google Cardboard, and Samsung Gear VR, and for the non-immersive, Microsoft's Xbox and Nintendo Wii [8].

The main objectives of the study is to be able to identify stroke patients' needs and their acceptability of VR Rehabilitation, and to be able to quantify the effects of VR on their motor function recovery, particularly in walking and balance.

II. Related Work

A. The Brain

After stroke, certain parts of the brain may have been damaged by the sudden loss of blood supply in the organ. When the motor cortex gets damaged, a person's cognitive function gets compromised as well. The cognitive function is the processing, and analysis of continuous information a person is receiving. It involves reasoning, judgement, attention and memory organization [9]. Any event normally uses all sensory stimulation from the visuospatial perception, motor, balance, speech and touch, but when a person experiences mild to moderate stroke, some parts of the brain responsible for these senses are damaged leading to the hypothesis that the mentioned functions might be necessary in the recovery of motor functions.

Another concept that important in recovering stroke patients is neuroplasticity. It is the ability of the central nervous system (CNS) to undergo structural and functional change in response to new experience. According to Ungerleider et al, motor can be learned and performed without thought when overlearned, and this memory of the motor skill however requires repetition [10]. Closely related to motor memory is motor imagery which is defined as a "dynamic state during which the representation of a specific motor action is internally reactivated within working memory without any over motor output that is governed by the principles of central motor control" [11]. Studies have shown that motor imagery and mental practice of it in stroke patients involve all stages of motor control [12] providing a reason that immersive VR could be used to enhance motor imagery and its mental practice and perhaps impact on recovery.

B. Virtual Reality and Rehabilitation

There has been continuous exploration of the effects of VR, both immersive and non-immersive, in motor rehabilitation. The primary motive is because cognitive rehabilitation is recognized to also affect individuals recovering from motor deficits. As defined by the Brain Injury Interdisciplinary Special Interest Group (BI-ISIG) of the American Congress of Rehabilitation Medicine, cognitive rehabilitation is a "systematic, functionally-oriented service of therapeutic cognitive activities, based on an assessment and understanding of the person's brain-behavior deficits" [13]. According to McEwan, et al., there are strong effects of involving motor imagery in functional recovery. For stroke, motor imagery improved performance in activities of daily learning (ADLs) [14].

While there are numerous studies that show positive effects of including VR in the program as opposed to rehabilitation without VR, they are limited to non-immersive VR. Examples are iCtus and Kinect-based games [15, 16]. Specific evidence of immersive VR and its effects on stroke however is still lacking. Certain studies on immersive VR and motor functions have been done, but they focus on upper limb motor functions. An example is the pilot study by Stewart, et al. In the study, results showed successful improvement of movement and performance when subjects with chronic stroke were immersed in four VR games [17]. The games focused on arm and hand movement. A study by Kizony, et al., [18] developed an immersive VR system which was used in stroke and paraplegic patients. They evaluated the subjects' performance during their use of the system. There were no quantitative discussions on the product's effect on the patients however. The same goes with McNeil, et al., [19] which focused mainly on the development of a rehabilitation program using off-the-shelf HMDs, sensors and PCs and its usability to the patients. Another study by Cameirao et al. immersed several subjects with acute stroke in VR. The interventions included hitting, grasping, and placing which are upper limb movements [20]. The results show improvement in their performance of ADLs.

Many studies support the claim that VR has positive effects on cognition, motor imagery and rehabilitation in general. However, specific discussions with relation to stroke, particularly with immersion in VR is still lacking. Due to limited information, a pilot study in the Philippines is done to address the issues on the technology's use in stroke.

III. Application Development

Mobile-based VR is chosen because accessibility, cost and ease of deployment are major factors of the study. The Unity Game Engine, along with Samsung Galaxy S7 and Samsung Gear VR is used in the study. The created application focuses on the following motor functions: 1) walking, and 2) balance. Both functions were focused on for the reason that more than 70% of stroke survivors develop upper and lower limb weakness post-stroke [6]. The scenes are interactive, and use head tracking and clicks as input from the user. Because external sensors such as controllers in the VR rehabilitation program except for the accelerometer/gyroscope of the headgear and smartphone were not made available, a pointer was used as one of the inputs. Both inputs will be followed through with models depicting appropriate limb movements required for the specific scenes. The goal of the scenes is to present as much sensory stimulation as possible while presenting them as close to reality as possible by adding audio and visual effects, and obstacles in the environment. There should still be a first person point of view (POV) action even when the subject cannot complete the actual movement needed.

FIGURE 1 Scene 1: The final scene after adjusting to the patient needs. Obstacles and different levels of terrain were used to simulate a more realistic walking experience for the patient.

Two scenes were created to address both motor functions. In Scene 1 (Fig. 1), the user is immersed in an environment where the subject will be walking. The goal of the scene is for the user to be able to walk around a park for a certain period of time. Since it is in the first person POV, when the subject looks down, s/he will see his/her arms and feet moving. The walking action in the scene uses a head gesture that signifies when the user would want to walk or stop. Some obstacles are presented here such as rocks, plants and ramps to evoke different movements from the first person character in the scene. In Scene 2 (Fig. 2), the subject is still immersed in the same environment from Scene 1. The character, however, cannot walk around. In front of the subject is a ramp with a ball and a blue box. The goal is for the user to be able to roll the ball and balance the ramp. At the end of the ramp is a box that the ball must collide with which translates to a score. The scene will end once the user reaches a certain number of points. The movement of the ball is controlled by the head tilt or body sway (left to right) of the user.

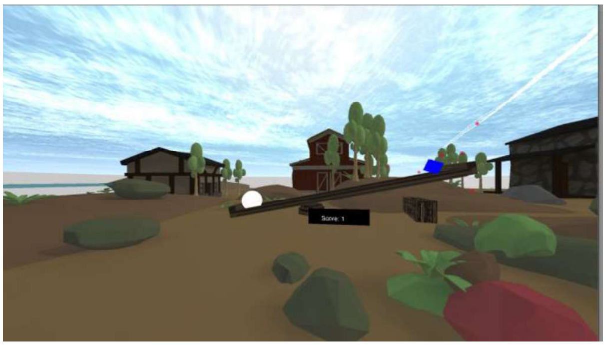

FIGURE 2 Scene 2: The goal of the scene is to be enhance the subject's balance through head and body tilting. Adjusting the ball's weight gives a more challenging experience to the subjects.

IV. Application Validation

A. Subjects

Eight test subjects from the rehabilitation department of Quirino Memorial Medical Center in Quezon City joined the study. They were randomly distributed into two groups. The first group is the control group and is only given the standard hospital setting therapy: one that uses standardized medical tools and toys which is administered by a physical therapist. The second group is given the hospital setting therapy with a supplement of VR therapy. Subjects who are eligible for the test should be patients who have suffered mild to moderate stroke only (Functional Independence Measure score of 36-62). The patients should not have any significant vision and hearing disabilities. For the patient selection, other factors such as date of onset of stroke, gender, age and other disabilities caused by stroke were not considered.

B. Exercise Interventions

The intensity of the hospital rehabilitation program is determined by the initial assessment of each individual. Although the hospital rehabilitation exercise may be different from subject to subject, the study is still acceptable since it aims to measure how the VR Rehabilitation translates in a realistic sense which means that every patient undergoes different intensities and exercises in their rehabilitation program. The test group, after receiving the traditional rehabilitation methods is given time for the VR rehabilitation. The VR rehabilitation finishes when the patient from the test group finishes all tasks in both scenes. The testing is done once a week for a month with weekly assessment of both groups. The weekly assessment is done by the same therapist per patient to avoid possible differences and biases of scoring since the measures used to assess the subjects are also dependent on the therapist's observation of the patient.

V. Results and Analysis

To quantify the effects of immersive VR as a supplement in the rehabilitation program of the patients, standardized procedures and measures were used. The measures are used before and after the rehabilitation program and indicate success or failure of the program [21]. Three measures and tests were used as baseline and progress measurements of the participants which focus on walking and balance. The Berg Balance Scale records the lowest response category of the patient that applies in the 14 items provided. The subjects are asked to maintain a specific position for a period of time. Points are deducted if time or distance requirements are not met, if the subject warrants supervision or if the subject touches or receives external support or assistance from the examiner. The scoring system is a five-point ordinal scale from 0-4. For stroke patients, a score less than 45 indicates that the individual may be at greater risk of falling while a score greater than 45 indicates functional balance independence [22]. The second test is the Modified Clinical Test of Sensory Interaction in Balance (CTSIB-M) which assesses the patient's balance while compromising one or more sensory inputs. Four conditions are supposed to be met for a 30-second period each. The first condition makes all the sensory systems (vision, somatosensory and vestibular) available. The second condition compromises vision, the third compromises both the vision and the somatosensory systems while the fourth condition compromises all but the somatosensory system. The test aims to get insight on whether the sensory systems for balance are being used effectively [23]. The third test is the Timed Up and Go (TUAG) test which aims to assess mobility, balance and fall risk in older adults. A patient is instructed to sit on a chair, place his/her back against it and rest his/her arms on the chair. When the tester says “go” the patient walks for three meters back and forth. The timer starts when the tester says “go” and should stop when the patient’s buttocks touch the seat. The cutoff score for stroke patients is 14 seconds [24] which means getting below it is an indication of greater functional independence.

At the beginning of the study (Week 1), baseline measurements were taken using the three tests to all participants. It was done before receiving their hospital rehabilitation program for the day. All participants were given hospital rehabilitation twice a week for four weeks. Figure 3 shows a patient undergoing the VR therapy. The experimental group received immersive VR rehabilitation once a week. Because Scene 1 is centered on walking, patients were allowed to walk freely in the room. However, it was not required. They can choose to walk, standstill or turn around in place to navigate the environment. All measurements were taken on the same day, after their program has finished. Figures 4, 5 and 6 show the summary of their baseline measures and the results after the testing period. Because the therapists were aware that other medical problems might arise from the users while using the system, their blood pressure was also monitored and they were frequently asked about their tolerance to the experience.

FIGURE 3 VR Therapy for the patient is given after their hospital therapy

For the Berg Balance Scale shown in Figure 4, both groups clearly indicated poor functional balance independence. However, at the end of the study, both groups showed improvement. The control group improved by 10.12% while the experimental group improved by 17.27%. While both groups started below the cut off score, both achieved an acceptable score after Week 4, noting also that the improvement of the experimental group was much higher.

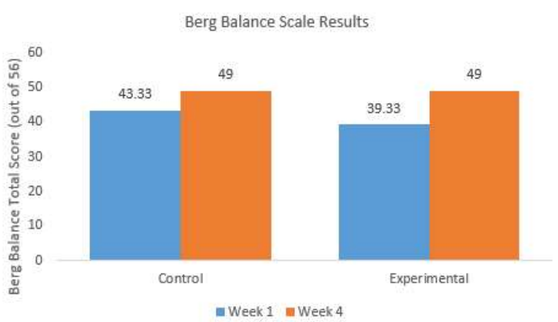

FIGURE 4 Results of the Berg Balance Scale showing the baseline measurements on Week 1 and the average measurement after Week 4.

The second test shown in Figure 5 also show improvement from both groups. However, the experimental group showed greater improvement in the four areas with 16.67%, 23.33%, 33.9% and 44.16% change from the baseline respectively. The control group showed improvement only on the third and fourth conditions with 27.77% and 18.07% change from the baseline respectively. Conditions three and four are of

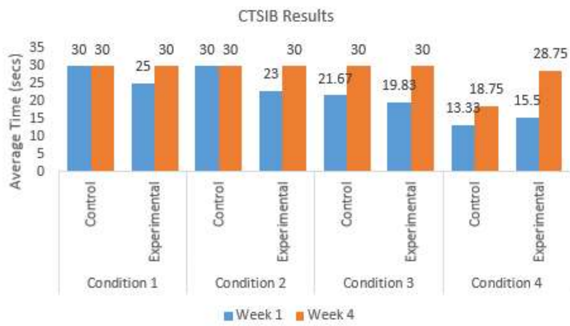

FIGURE 5 Baseline results and average results of the CTSIB Test for Conditions 1, 2, 3 and 4.

particular concern since when immersed in VR, all actual senses in the real world are compromised. However, in the virtual world, the user’s senses are still available. Immersing the user in an environment where s/he can virtually, say, freely walk, stimulates the brain’s cognition, perception and motor cortex by creating the illusion that user is actually moving. The participants reported a greater desire to move while in VR. Asking them to stand still while in Scene 1 where the character is walking, they reported that they actually wanted to walk while immersed in the environment than to stand still or just turn around to navigate. Because of the immersion, it created an impulse that made the brain aware of the desire and the necessity to move. From the results, we can conclude that immersive VR, while compromising actual real world sensory inputs, may be stimulating the brain to exercise these sensory inputs through cognition, neuroplasticity and motor imagery.

Lastly, for TUAG in Figure 6, a 10.38-second improvement for the control group and a 21.15-second improvement for the experimental group were recorded. While both of the group's improvement does not reach the cut off score, the results still show that the improvement can be related with immersing the patient in VR. Higher improvement rates were recorded with the experimental group. Direct observations from the participants' therapists also reported that some of their patients walked more confidently while in VR. Some walked faster and their posture and position while walking were better when in VR than when doing hospital rehabilitation while walking on command. At the end of the study, the experimental group also needed significantly lower assistance during both traditional and immersive VR rehabilitation. However, guidance was still continued due to the fact that they might bump into objects inside the hospital since there was a space limitation.

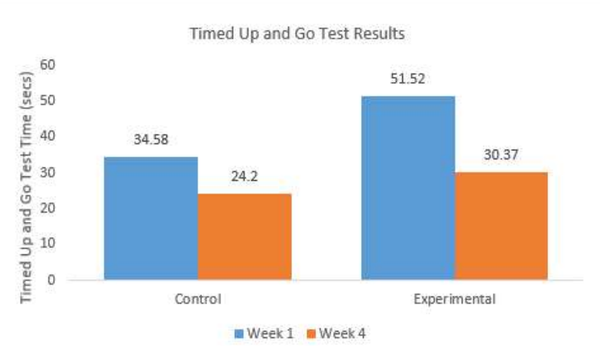

FIGURE 6 Baseline and average results of the TUAG test from Week 1 and Week 4.

To qualify the patient's needs and acceptability of the theoretical use of the immersive VR in rehabilitation, a trial test run was done and feedback from the patient as well as the therapists were queried on week 0. From their feedback and based on the user's experiences, the content and other functions were adjusted in the application. Initial contents used head gesture for walking. This meant that the character waits for patient input for them to start walking. However, older patients who have trouble understanding the instructions found it difficult to do so. To address the issue, the walking was made automatic for two minutes. It meant that the patient is walking virtually for the whole duration of Scene 1. Some barriers and obstacles were also removed from the scene for health reasons such as being elevated too much may cause nausea, or sudden collision with certain objects may cause a sudden increase in their blood pressure. For Scene 2, the only adjustment made was giving the ball more weight to make it more challenging to the users. Giving the ball more weight meant that the patient must tilt his/her head or body more which also requires more support from their limb muscles. In general, the participants did not report major dizziness, nausea and eye strain.

Some challenges were also encountered while administering the VR rehabilitation program. Since patients were older, and what is being administered to them is a new technology, making them understand the instructions on how a particular scene works was difficult. The first reason is because they were immediately immersed in the scene without prior exposure to it. The issue is a limitation of the Gear VR. While you can show a scene in VR using the phone's developer mode, actual gestures, head tracking, and other inputs do not work until the phone is mounted on the head gear. Because of the limitation, the patient is the only one who can see the scene and must be able to intuitively know what s/he should do. However, to address it, audio cues were also used to help the therapist administer the test. Also, since the patients had limited walking space, they needed assistance while immersed in Scene 1 which meant that the therapist must guide the patient to another direction when s/he will collide into objects in the real world.

While the sample size is very small for conclusive evidence that the system works however, the results show a good indication that the use of the system as a supplement in the traditional hospital rehabilitation affects the patients in terms of time, and quality of recovery. Since stroke cases, and the patient's function losses are different from individual to individual, another area to consider is making the application more variable by letting the user input their desired walking speed or desired ball weight.

VI. Conclusion and Recommendations

In the study, an immersive VR application was created to supplement stroke patients in their rehabilitation program. Since there is little information in the use of the technology specifically for stroke patients, findings were discussed in two ways: by first, qualifying its acceptability and testability to the users and secondly, by quantifying its use. The results showed challenges and limitations in terms of its testability and adjustments were made to make it more acceptable to users. The technology shows promising results in the motor rehabilitation of stroke patients by involving and stimulating a patient's cognitive functions and central nervous system more. Future works include the use of haptic feedback sensors for more involvement of the patient, and a larger testing group.

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