Virtual Reality Environment Assisting Post Stroke Hand Rehabilitation: Case Report

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Abstract. We describe a novel art-empowered Virtual Reality (VR) system designed for hand rehabilitation therapy following stroke. The system was developed by an interdisciplinary team of engineers, art therapists, occupational therapists, and VR artist to improve patient's motivation and engagement. We describe system design, development, and user testing for efficiency, subject's satisfaction and clinical feasibility. We report initial results following use of the system on the first four subjects from the ongoing clinical efficacy trials as measured by standard clinical tests for upper extremity function. These cases demonstrate that the system is operational and can facilitate therapy for post stroke patients with upper extremity impairment.

Keywords. Stroke rehabilitation, virtual reality, interactive environments, 3D art, occupational therapy, engineering

Introduction

According to the National Stroke Association "Stroke is the third leading cause of death, killing about 137,000 people each year, and a leading cause of serious, long-term adult disability" in the US [1]. The traumatic loss of upper extremity function following stroke requires extensive therapeutic treatment to regain even the most basic daily activity skills. Repetitive practice of stretching, increasing range of motion and strengthening exercises, and activities of daily living (ADLs) are crucial to maximize the therapeutic benefits. Patient's adherence and compliance with prescribed conventional occupational therapy protocol can decrease as the repetitive therapy regimen becomes monotonous and arduous [2, 3]. Over the last decade VR technology has been increasingly used in stroke rehabilitation as a way to maximize the potential of physical rehabilitation. Many studies demonstrated encouraging results [4, 5, 6, 7]. One of the challenges is how to maintain motivation and increased interaction in the VR for people undergoing therapy. Recent studies show that games may be an effective way of addressing the problem of engagement [8, 9]. However, engineers and scientists without art or design skills created most of these VR systems, and as a result their

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environments often are not sufficiently inspiring to engage the user for longer periods of time.

Therefore, we developed a novel art-empowered virtual rehabilitation system in order to increase motivation, and promote intensive individualized repetitive practice. The objective was to maintain the user's interest longer than in standard protocols by creating appealing computer graphics, aesthetics and engaging interaction to ultimately improve compliance. Our aim was to carefully design 3D graphics and aesthetics of virtual environment to maximize their potential impact on motivation. An interdisciplinary team of researchers that included occupational therapists, engineers, scientists, VR artists and art therapist has developed an immersive, 3D representation of the March Hare's home. The system has been conceived and developed in the Hand Rehabilitation Laboratory at the Rehabilitation Institute of Chicago (RIC), a rehabilitation institute with a flagship hospital located in downtown Chicago. RIC represents a strong formal collaboration between innovative research and inpatient/outpatient services. Researchers and therapists collaborate on the design and implementation of state of the art rehabilitation systems and interventions. The therapists provided valuable comments and feedback based on their daily work with patients during the design and development of our system. As a result, the system is a genuine teamwork product bridging VR, healthcare and arts.

Figure 1. System and interaction with the VR environment. User wears a custom pneumatic glove, which assists finger extension. Magnetic trackers provide information regarding head orientation and hand location; the virtual scene is updated accordingly.

Our current system consists of two large 30-inch LCD displays positioned at a 150-degree angle to support an observational view of the scene, a tracking system of head and arm, and a pneumatically actuated glove, the PneuGlove previously developed at RIC [10, 11], to support finger extension and provide tactile sense of grabbing the target object (Fig. 1). We report on the system design, development, pilot testing for efficiency, subject's satisfaction and clinical feasibility. Last year we completed the qualitative, pre-clinical pilot study to evaluate the extent to which a sample group (n=14) of stroke survivors with chronic hemiparesis found the system and peripherals appropriate and engaging for therapy. We used a 15-item anonymous survey questionnaire relating to the participant's experience with the technology to ascertain the subject's understanding, comfort, and engagement in this VR environment.

The survey contained two different types of questions; 11 structured multiple-choice questions including 6 in Likert scale format, and 4 non-structured questions where the participants were encouraged to reply at length to provide their comments and feedback. The results from the completed surveys showed that post-stroke patients with impaired hand functioning find the system fun, engaging and motivating. No one conveyed that the system was boring (0% reported). Most of the participants reported that the exercises were difficult and they were tired (Tiring: 35.7%), but they liked it because it allowed them to work their impaired arm. Participants stated that they were highly satisfied with the VR environment, and rehabilitation task variety and difficulty. The data from these questionnaires, along with observations by the researchers and therapists, were used to assess the comfort and functionality of the hardware and software components of this protocol and to make improvements prior to bringing the system forward to the next phase of formal trials for clinical effectiveness. Following the result of our pilot studies, we had to retire the HMD component due to its side effects (29% of our subjects reported unpleasant side effects such as dizziness, eyestrain, and nausea). The HMD was replaced with two large 30-inch LCD displays (1360x1024 pixel resolution, 60 Hz) positioned at a 150-degree angle forming 120 degree horizontal FOV to support an observational view of the scene. Recently, we have begun an IRB-approved clinical efficacy study investigating the use of our system within a rehabilitation protocol. So far four stroke survivors completed the eighteen-session protocol over the course of four months and found that system can facilitate therapy for upper extremity. Here we report these methods, procedures and results.

1. Methods & Materials

The therapy sessions take place within a virtual reality environment (VRE) whose acceptance by patients has been evaluated in a preliminary pilot study. The VRE program is based on the narrative of a tea party at the cottage of the March Hare from the classic story of Alice in Wonderland (Fig. 2).

Figure 2. Virtual reality scene: tea party at the March Hare's cottage. The March Hare avatar moves and speaks to the user. The user is able to interact with a number of objects shown on the table.

After discussing several possible narratives in detail with therapists, patients, engineers and artists, an Alice in Wonderland story proved to appeal to the majority of the adult target group. By building upon this well-known story, we anticipated that users could more quickly engage in the narrative without a lengthy introduction. In addition, we visited a collection of miniature rooms at the Art Institute of Chicago to obtain historical references for our 3D architectural design and utilitarian objects. Begun as a simple watercolor sketch, the cottage was fully developed and realized with appealing colors, realistic textures, and charming objects. Seated at the virtual dining room table, the patient can turn to get a 360° view of the room that includes a crackling fireplace a vista through the window to a nearby forest.

In this narrative, a series of tabletop activities of daily living are introduced but with a "mad tea party" twist that creates the opportunity for inventive repetitions of rehabilitation tasks. A virtual therapist (the March Hare avatar) guides and encourages the participant through a series of exercises. The patient can see a virtual hand replicating his real hand movements and interacting with virtual object. To explicitly promote practice of reach-touch, grasp-transport-release, and finger individuation tasks requiring hand and arm coordination for upper extremity rehabilitation we designed ten specific exercises for the users:

- Cookies morph into crabs and scurry away from the participants,
- Bluebirds fly from the china pattern and hover above the table,
- Flowers needed to be cut with shears,
- Sugar cubes jump out of the sugar bowl,
- Teacup empties itself,
- Cream pitchers contain various colors for finger painting in the air,
- Napkin fly above the table,
- Wine glass refills itself with sherry,
- A ticklish teapot giggles as it pours tea,
- Spoons melt down in the hot tea.

In many exercises users must employ reach-to-grasp movements; to grab the crabs, catch the birds, use individual fingers for finger painting, or rotate their arm to pour the tea, etc. Consequently, movement practice is encouraged, albeit indirectly, as the motivation for participation comes from the patient's engagement with the narrative and the environment. Feedback on the various grasps is provided through special effects. The virtual objects drop down and break/splash/shatter when the patient's grasp is too loose; when the grasp is too tight, the virtual objects explode. As long as the correct grip and pinch strengths are maintained to hold objects, the participant can proceed with the exercise task. If participant drops or smashes the objects, he needs to redo the repetition again.

We have also implemented a score system, which at the moment measures the time spent on each exercise in some arbitrary units. The score is displayed on the score panel in front of the table so that participant can have a visual feedback on their progress and incentive for competition. The score system serves as an additional powerful motivator as participants remember their previous score in the tasks and try to score better in the next repetition.

1.1. *System architecture and technology*

Our system incorporates two computers connected with each other (therapist and patient). The therapist computer (PC Workstation, Dell Dimension™ DIM 4600, Intel® Pentium™ 4 CPU 2.80 GHz, 512 MB RAM, Intel® 82865G Graphics Controller) serves as the master controller, determining which exercise will be performed, criteria for success or failure for the exercise, and the amount of hand opening assistance to be provided utilizing the graphical therapist interface. The client's station (PC Workstation, Dell Precision™ PWS 67, Intel® Xeon® CPU, 3.40 GHz, 2.00 GB RAM, AMD ATI Radeon™ HD 5800 graphics Chipset) is responsible for controlling the virtual scene through the software 3DVIAVirtools (Dassault Systemes, France). The VRE updates the view according to the orientation of the head, as measured with a magnetic tracker (Flock of Birds by Ascension Technologies). Hand position and orientation are tracked with another Flock-of-Birds magnetic tracker, and finger joint angles are measured with an instrumented pneumatic glove, PneuGlove, which was previously developed in the lab. In addition to measuring finger joint angles, PneuGlove also assist with independent finger extension through air bladders on the palmar side, which are inflated when the subject is unable to reach predefined target angles.

1.2. *Studies*

We have begun an IRB-approved clinical efficacy study to investigate the use of our system within a rehabilitation protocol. In our study, 9 patients with chronic right-side hemiparesis following stroke participate in 3 one-hour therapy sessions per week for 6 weeks. A therapist evaluates the subjects in separate sessions immediately before the beginning of therapy (pre evaluation), right after the completion of therapy (post evaluation), and one month after the completion of therapy (one month follow up). By the end of the study, each subject will have completed 18 therapy sessions within 6 weeks. The inclusion criteria are moderate chronic right hand impairment rated by a team of occupational therapists to be at Stage 4 through Stage 6 (ordinal scale runs from 1 – 7) on the Stage of Hand section of the Chedoke-McMaster Stroke Assessment scale. Subjects at these Stages exhibit voluntary finger flexion but have some difficulty with finger extension, individuation and coordination with fine motor tasks. Participants have experienced stroke for at least 6 months before enrolment in the study and have no contracture or pain in the digits.

So far, four patients have completed eighteen 60-minute sessions in the Coleman Hand Rehabilitation Laboratory within RIC. Each session began with a PneuGlove donning and calibration and positioning magnetic trackers of head and arm. Once calibrated and equipped, the subject was then guided through a series of VR exercises and the therapist helped with some of the most difficult VR rehabilitation tasks. Each training session was guided by an occupational therapist and consisted of one or two cycles of the 10 exercises listed above. Ratings were performed by another occupational therapist, who was not involved in the therapy sessions. We anticipate to complete the study with all subjects (n=9) followed up by one-month post evaluations by February of 2013.

Seven primary types of measures were used for evaluation as follows; motor recovery status of the involved upper extremity was measured using the Fugl-Meyer Motor Assessment, physical impairment and disability of the involved upper extremity was measured with the Chedoke-McMaster Scale, upper-extremity functional limitation of the affected upper extremity was measured using the Action Research Arm Test (ARAT) test, grip, palmar and lateral strengths were measured with Grip and Pinch tests.

2. Results

At this time, only 4 stroke patients have completed the protocol.The lateral pinch strength tends to improve right after therapy. Subjects 1, 2, and 4 showed palmar pinch increase., and subject 2 additionally showed grip strength increase. We also found a minimal progressive reduction in the Fugl-Meyer hand score in the subjects 1, 3 and 4 (subject 2 did not change); for subjects 1, 2, and 3 in the Box & Blocks tests. However subject 4 showed increase in this test. Scores for ARAT tests stayed the same for subjects 2 and 4, increased in 3 and decreased for subject 1. Most of the above changes were not confirmed within a month post completion. However, with only four of the nine subjects having completed the study, statistical analysis is premature. We anticipate completing the study by February of 2013 to be added by the time of the conference.

At this point we noticed that participants complete exercises more quickly in the later sessions. Instead of just one cycle of 10 exercises they can do two cycles and even repeat some of the exercises a few additional times. As participants practice grasp and release repetitions, they can control and maintain their grip and pinch strengths better as well as faster articulate their arm and fingers. Therefore they were able to do more movements/exercises over the course of later training sessions.

Overall, the performance of the system has been stable. Despite the retentiveness of the regiment of exercises the subjects stayed highly engaged in the VR environment, which was customized for each subject by the attending therapist. The kind of engagement, however, changed with time. Patients became irritated–but never bored– by the always-repeating comments the avatar made. Some patients requested the avatar to be muted in later sessions. With the continuation of the study more data will become available allowing us to address the clinical efficacy.

3. Discussion

A novel, art-based virtual rehabilitation system has been developed and is being tested for use within an 18-session rehabilitation protocol. At this point, four stroke survivors have completed the protocol. They have been pre- and post- evaluated and had a one- month-follow-up tests as measured by standard clinical tests for upper extremity function. Clinical assessment and outcome measures demonstrated some improvements of the grip and pinch. We are still assessing the clinical efficacy of the protocol with other patients. All patients we have tested so far were able to perform an increased number of movements over the course of the training sessions (1-18). We plan to replace the magnetic tracking with the Microsoft Kinect wireless tracking system. This relatively inexpensive and robust instrument affords sufficient precision for this application. A home therapy project is also underway in which participant and therapist will collaborate remotely in the virtual environment.

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