Design of a Low Cost Multiple User Virtual Environment for Rehabilitation (MUVER) of Patients with Stroke

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Abstract. We describe the development and preliminary testing of a low cost virtual reality system that patients with stroke or other neurological impairments could use independently in the home on a personal computer to improve upper extremity motor function, including hand and finger control. The system would help meet the needs of the rising number of patients with stroke with impaired hand function. We introduce the concept of a Multiple User Virtual Environment for Rehabilitation (MUVER). The MUVER has three components: the low cost P5 Glove (tracks arm, hand and finger movements), the open source Panda3D game engine, and laboratory created software. A unique aspect of the MUVER design is the system's capability for four types of multiple user interactions: competition, cooperation, counter-operative, and mixed. Such virtual interactions may help to increase patients' motivation to improve and possibly alleviate feelings of social isolation for those who remain homebound. Thus far, a proof of concept virtual environment that uses competitive interaction has been created and tested with six healthy subjects.

Keywords. Stroke, Rehabilitation, Virtual Reality, Upper Extremity, Hand Motor Training

1. Background

Stroke is the leading cause of disability among adults in the United States[1] with more than 700,00 people annually suffering a new or recurrent stroke [2]. Six months post stroke, 55-75% of survivors still have limitation of upper extremity (UE) function [3]. In cases with initial UE paralysis, complete motor recovery has been reported at <15% of cases [4]. A key component of this poor functional recovery is impaired use of the hand. Thus, there is a compelling need to improve available methods for UE rehabilitation in patients with stroke, and in particular, methods aimed at improved hand function. Many patients remain highly motivated to make further gains after standard rehabilitation has been completed, and studies have shown that these patients with chronic stroke do have the potential to improve [5,6].

A low cost device that patients could use independently in the home and that is designed to improve UE function especially that of the hand would be highly desirable for these patients. Such a device would also be useful as an adjunct to ongoing rehabilitation therapy, providing patients with an interesting and motivating way to perform a home exercise program. If designed appropriately, such a system could be used by a therapist to set up exercise programs that were adjustable in level of difficulty, and tailored to the patients interests. These features would likely increase patient motivation and compliance [7].

Designing this device to allow interactions with other users over the internet would make practice more fun and enhance motivation. Such virtual interactions may also help to alleviate feelings of social isolation in patients who remain homebound due to mobility problems [8].

Several other investigators have developed hand rehabilitation devices, but for the most part they are complex, expensive and not readily available to clinicians. The Rutgers Hand Master I and II has been used in combination with a Cyberglove™ (Immersion Technologies, San Jose, California 95131) to improve hand function in patients with stroke [9]. This system uses palm-mounted pneumatic pistons and virtual reality to train resisted finger flexion and non-resisted finger extension. A study utilizing the Howard Hand Robot found greater gains for stroke subjects who practiced with robotic assistance in virtual reality for all sessions during a 3 wk intervention vs those who had robotic assistance only in the last 1.5 wk. of training [10]. However, Fischer et al [11] found no difference in 3 groups of stroke subjects who trained on a reach to grasp task in virtual reality with and without 2 different types of robotic assistance to finger extension during the training. A pilot study performed with a new Finger Trainer robotic device found some improvements in active movement and less development of spasticity versus a control group who received bimanual therapy instead [12]. However, this Finger Trainer was designed to perform passive finger movement only.

Robotic devices that train the whole arm, such as the MIT-Manus have shown benefit for patients with stroke [13], and more recently the Bi-Manu-Track robotic arm trainer has been found to be equal in effectiveness to electrical stimulation training [14].

None of these devices meet the need for a low cost simple UE motor training device that patients could use easily in their homes, and potentially use with other patients over the internet. To meet these needs, we have created the concept of a Multiple User Virtual Environment for Rehabilitation (MUVER). This system will allow several patients to interact in virtual space with activities designed to enhance UE and skilled hand function.

2. Tools and Methods

2.1 System Design

The MUVER consists of three components**:** a P5 Glove™ (Essential Reality, 2002) used as the input device, Panda3D graphics engine, and laboratory developed software. These components are discussed in the subsequent sections.

2.1.1 P5 Glove

The P5 Glove was released from Essential Reality in 2002 as a home personal computer (PC) input device aimed at the video game market. The device monitors 6 DOF hand position (x, y, z, roll, pitch, and yaw) via an infrared (IR) tracker, and 5 finger flexion/ extension via piezoelectric bend sensors. The P5 connects to the PC via a USB connection from the IR tower that is tethered both to the PC and the glove. The P5 glove was chosen because it is a low cost, off the shelf device that would be suitable for home use.

2.1.2 Panda 3D Game Engine

The Panda3D graphics engine [15] was created by Disney and is currently owned by Carnegie Mellon University. All of the software in the engine is open source and free to download. The engine is written in C++ libraries and modules and is controlled by scripts written in python. Panda 3D also has comprehensive support for networking that would allow for rich virtual interactions between users.

2.1.3 Laboratory Developed Software

One proof of concept virtual environment (VE) training scene has been developed to date. Figure 1 below shows our VE scene, which will be used for competitive virtual interaction between two users. This scene is designed to allow practice of active grasp (pincer, 2-5 fingers with thumb) and release and maintained grasp with active supination (hand turning toward palm up). These movements are essential to improved hand function in patients with stroke. In this scene, the user must first grasp the lid (at the correct grasping position the lid turns blue, once grasped the lid turns green), next s/he turns the lid (hand supination) while maintaining grasp and transports the lid to the right. Upon successful grasp plus supination and transport, the lid turns red. If the user looses grasp while turning, the lid drops back to the start position on the pot and returns to the neutral grey color. Supination threshold for success is currently set to 45 degrees, but is adjustable. Finally, the user pronates and transports the lid back to the pot and releases the grasp by extending the fingers, at which point the lid turns grey, and the trial is counted as a ‘success’.

We divided the movement into phases which could be timed and counted separately, in order to provide more feedback to subjects about their performance if the entire trial was not successful. These phases were 1) start position to grasp of lid; 2) grasp plus supination to threshold value and transport toward right side of screen; 3) pronation, transport back to left to position lid on pot, then release of fingers (finger extension to a threshold value). The ability to count successful phases and trials and record time for each was incorporated in the design for the scoring function. Each element can be displayed separately to subjects to provide feedback about performance either during the session or after. These elements are 1) count for number of successes for each phase; 2) count for number of successful trials (all 3 phases completed); 3) time for each phase, and 4) time for each trial. Time can also be displayed as a mean for block of trials, with the number in block adjustable.

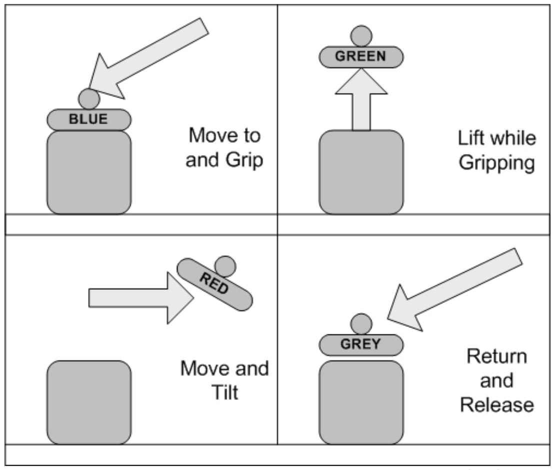

Figure 1. Virtual Reality Scene Flow Diagram, see section 2.1.3 for full description

Figure 2 shows the design for four types of multiple user interactions: Competitive, cooperative, counteroperative, and mixed. Competitive interaction means users complete the same goals for a competitive score, without any direct interaction between the players. Counteroperative interaction means one user works against another for a common goal only one can obtain. Cooperative interaction means two or more players work together to complete a common goal. Mixed interaction means users work together to complete a common goal but are scored competitively or using combinations of the other types of interactions. Often more than one interaction is used in virtual environments.

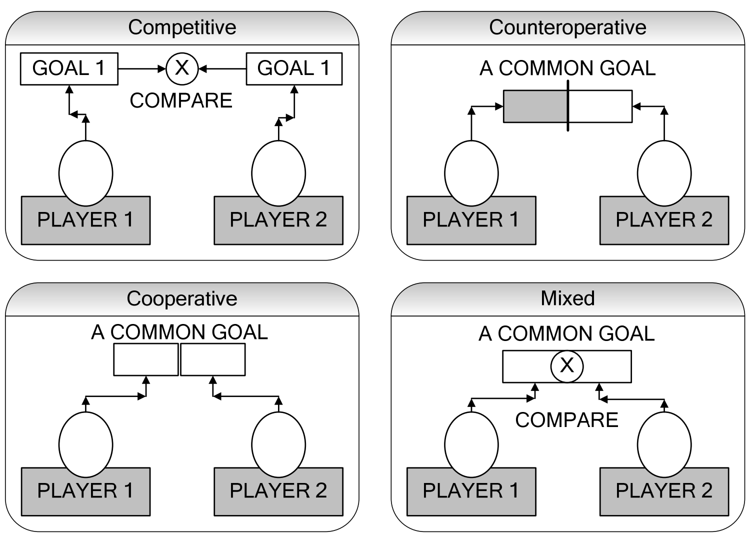

Figure 2. Multiple User Interactions, see section 2.1.3 for full description

2.2 System Testing

Six healthy subjects (4 males, 2 females; 5 R handed, 1 ambidextrous) performed competitive interaction using the MUVER scene shown in Figure 1. Each user donned and calibrated the P5 glove, and was instructed in the hand rehabilitation movement, and given up to 5 minutes to practice and become accustomed to working in the virtual environment. Next, subjects were asked to complete 10 movements as rapidly as possible. A short rest was given between each trial. Total time and time for each phase was recorded for each trial and each subject.

3. Results

Mean duration ± standard deviations across blocks and subjects are shown for each subphase of the movement task, and for the total task in Figure 3 below. Phase 1, Start to completion of grasping lid, averaged 1.6 ± 0.7 sec; Phase 2, Grasp with turn and transport to right, averaged 1.8 ± 0.6 sec; Phase 3, pronation, lid return, finger extension to release grasp, averaged 2.1 ± 0.9 sec. Mean time for the total task was 5.5 ± 1.6 sec.

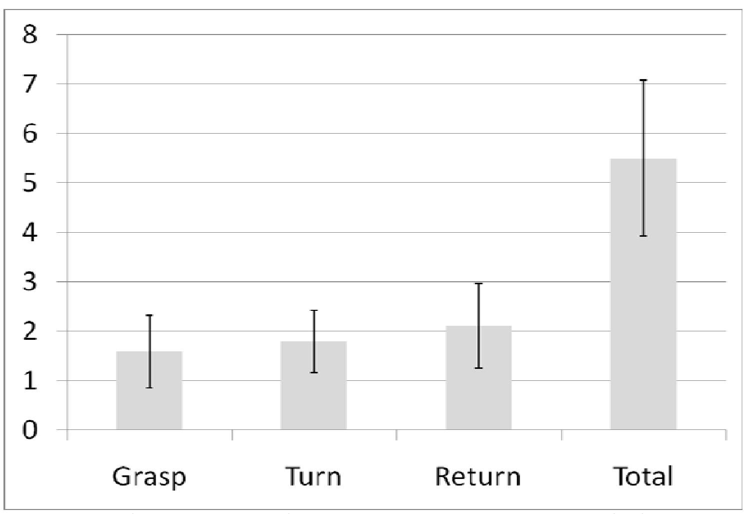

Figure 3. Chart of the 4 Subphases of the Virtual Environment, see section 3 for full description

4. Discussion

Both experimenters and subjects noted that the mapping of real world to virtual movements was not completely accurate, which probably accounts for times that are somewhat slower than expected in healthy subjects. This inaccuracy could be due to a hardware problem in the glove position detection or to the software that maps position and orientation data to the virtual scene elements. This issue will need to be resolved prior to testing the device with a patient population. On the other hand, all subjects tested were relatively close together in performance for each phase and for total time, so the errors that are present appear to be relatively stable ones that should be fixable.

Despite these difficulties with system accuracy, the basic scene worked as intended, and the phasing feature looks promising as a useful way to provide additional feedback to subjects about performance.

5. Conclusion

The MUVER design shows promise as a potential low cost hand rehabilitation device for home use. Further enhancement to improve system accuracy and mapping of virtual to real world motion will be required along with implementing the multiple user virtual interactions prior to testing the feasibility of the system with patients.

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