A Virtual Environment for Post-Stroke Motor Rehabilitation

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ABSTRACT
Current post-stroke motor rehabilitation is unable to significantly benefit the majority of stroke survivors, and is insufficient for the minority who are able to participate. Two components that could stimulate more motor redevelopment are increased motivation during extended therapy sessions (extended practice) and a patient perceiving normal arm movement which they control (action-observation). We are developing a 3D virtual environment that presents motivating rehabilitation tasks for patients to complete through movement of a virtual arm controlled by their own impaired arm. By creating a virtual environment that incorporates components not found in conventional therapy we hope to improve the extent survivors are able to recover normal arm movement after a stroke.

Keywords
Serious games, rehabilitation, stroke, virtual environment, Kinect

INTRODUCTION
Strokes kill or damage brain cells within the neural networks that control movement. In 85% of survivors the paralysis persists in the arm and wrist at four years post-stroke [1]. The brain can be stimulated to “re-learn” more normal movement in two ways: repetitive neural activity and the inclusion of action-observation when performing tasks.

Repetitive neural activity is repetition of a task such as reaching for an object. Studies have shown the benefit of practice-induced motor learning for increased neural reactivation in the regions of the brain that control movement [2-4].

Action-observation is observing expert completion of the task one is attempting to complete [5]. “Mirror neurons” respond to the observation of an action completed expertly while the individual is attempting to imitate that action. Observing the expert task completion stimulates more brain activity and can improve voluntary movement of the affected limb [6-8].

Conventional rehabilitation consists of sessions where a patient attempts to perform sets of repetitive tasks with the goal of stimulating neural activity that causes neural reorganization of the damaged area. While there is benefit to conventional therapy, the value of the rehabilitation is limited in several ways. Studies suggest that 300-1000 repetitions of tasks are needed daily to elicit neural reorganization [9], but in current rehabilitation sessions only 20-40 repetitions are completed.

Conventional tasks often lack motivation for the patient to complete the high number of repetitions needed to stimulate motor learning. Scaling the level of challenge to the level of the participant is important for engaging the participant and maintaining interest [10], but is difficult to do with conventional rehabilitation. In addition to these difficulties, only about 25% of survivors can participate in current rehabilitation due to the severity of elbow and wrist movement damage preventing them from performing the tasks [11].

To address the problems with current rehabilitation, we discuss our design of a virtual environment for hemiparetic (one-side) upper extremity (UE) rehabilitation that provides components of extended practice, motivation, and action-observation not found in conventional therapy. We also discuss the goal of a portable system to be used in-home.

RELATED WORK
Commercially available game controllers have been used in the design of physical therapy systems. Geurts et al. developed minigames for use with motor disabilities using Nintendo Wii remotes fitted to users and the Wii balance board [12]. The user studies highlighted the need for calibration to player ability and rehabilitation goals.

Burke et al. developed several prototype games for stroke rehabilitation using virtual reality, webcam, and Wii remotes as input devices [10]. They discuss the importance of various forms of feedback such as a virtual representation of the user’s arm, audio cues, and scoring systems to provide incentives for continued play, without which users are less likely to have an effective experience or continue with a rehabilitation game.

DESIGN AND IMPLEMENTATION
The goal of the system currently in development is a virtual game environment that provides extended practice, action-observation, and motivation in a package that could be used in-home. The system consists of a 3D game environment presented on a display positioned 5-6 feet in front of the user, and a Microsoft Kinect positioned on top of the display which provides skeletal tracking of the user. The user interacts with the system by using left hemiparetic arm movements to control a virtual model of a left arm that interacts with objects in the game.

Since many stroke survivors have very limited arm and hand use, the system needs to track impaired arm movement without attaching any sensors to the arm or hand that would inhibit movement or require setup by the user. The Microsoft (MS) Kinect is an inexpensive 3D depth camera that provides real-time, ready-made skeletal tracking without the need for any sensors to be placed on the user. Users simply sit in front of the Kinect to...
use the system, which both increases usability and allows for more natural interaction with the system.

Previous libraries that interfaced with the Kinect required a specific standing calibration pose for the system to recognize and track a user. The MS Kinect SDK, however, required no specific pose to begin tracking a user. Informal tests showed the Kinect capable of distinguishing arm movements to within 2-3 inches. This accuracy of measurement was adequate to accommodate restricted arm movement seen in more severe stroke damage.

The virtual environment currently being developed using Maya and Unity3D Pro will present game tasks to be completed by moving the impaired arm to control a virtual. In completing game tasks the users will perform practice tasks similar to conventional rehabilitation, with the important components of motivation, dynamic task difficulty and action-observation.

To achieve the “action-observation” effect in the virtual environment we needed to translate impaired physical reaching ability so the virtual arm has a full range of motion. For example, if a user could only extend their arm forward 4 inches, the system would translate the 4 inches of reaching movement into a full extension reach of the virtual arm. To measure how far the user can reach along each axis we designed a calibration stage (see figure 1) where the user sits at a physical table in front of the Kinect and views the game on the display. The user sees a virtual table that supports a grid of golf balls on golf tees with the goal of knocking as many golf balls off of the tees as possible using hemiparetic left arm movement. The system records the maximum and minimum values reached by the user’s wrist in each axis.

Figure 1: User interacting with virtual environment

CONCLUSION AND FUTURE WORK

We are currently working on a prototype game where users reach to knock down ducks presented in a vintage carnival theme “duck shoot” game. The game will incorporate movement scaling and provide rich visual and audio feedback for motivation. In early levels, the game will provide significant arm scaling based on the initial reach of the user. As the user regains reaching ability, however, the game will decrease virtual arm reach scaling to continue to provide a reaching challenge. Task difficulty will increase with successive levels of the game to maintain user engagement. Initially game tasks will consist of a simple forward reaching goal, but as the user progresses, lateral movement (side movement away from the body) will be introduced to continue to challenge the user.

A pilot study will be conducted at the Medical University of South Carolina Stroke center. The study will include approximately 20 patients suffering from hemiparetic left shoulder and elbow impairment. Both feasibility and treatment effect vs. conventional rehabilitation will be evaluated.

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REFERENCES


