A Mixed Reality-Based Exercise Program for Upper-Limb Post-Stroke Rehabilitation

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Abstract
This paper describes a proposal of exercises for post-stroke rehabilitation of the upper-limb movements using mixed reality combined with mental practice. Physiotherapists induce patients' mental practices so that they execute the assigned tasks in the mixed reality environment. In the mixed reality environment, patients can visualize themselves and their surroundings, just like in a mirror. However, a virtual upper-limb is superimposed over their real paralyzed upper-limb. The set of proposed exercises include low complexity movements as shoulder infection, shoulder abduction, shoulder adduction, fist extension, and hand grasping as well as high complexity movements like reach and grasp a ball, drag it to the desired position and release it. We believe that the proposed system can be used to verify the effectiveness of visual stimuli for post-stroke rehabilitation. The system will allow post-stroke patients and their caregivers to perform the rehabilitation exercises at home. Also, this system will provide physiotherapy students the possibility to repeat medical training.

1. Introduction
In Brazil, about 167,199 people 40 years old and up, had a stroke during 2005 [1]. Each year, in the United States, approximately 700,000 people sustain a stroke. Strokes are a leading cause of physical disability. Because of this, there is a great variety of therapeutic interventions to improve motor recovery following strokes. At this time, existing physical and occupational therapy interventions are the foundation of post-stroke treatments [6].

Upper-limb hemiparesis is one of the most debilitating effects of stroke, and it is the primary impairment underlying functional disability following stroke [9].

During the subacute phase, at most one year post-stroke, patients learn or relearn competencies necessary to perform daily life activities. Frequent practice of skills enhances motor learning and skill acquisition. However, most of the rehabilitation treatments are stopped one year after post-stroke, during the chronic phase [9].

Several researchers have shown in both animal and human studies that important variables in re-learning motor skills and in changing the underlying neural architecture are the quantity, duration and intensity of training sessions. Focal ischemic lesions in monkeys, similar to what occurs in a stroke, usually result in a loss of cortical territory in the motor area adjacent to the infarcted region. However, three-four weeks of intensive, repetitive, hand training prevented this loss and in some instances led to an expansion of this cortical region [4].

Mental practice, also known as “imagery”, is a rehabilitation tool that can stimulate motor image [7].

In this paper, we propose a set of exercises to be used in a mixed reality environment that promote the recovery of upper-limb motor skills in chronic stroke patients, who had a stroke more than one year before, and who exhibit upper-limb hemiparesis. The exercises are intended to provide chronic stroke patients the visuospatial information to induce a third person perspective motor image.

The rest of the paper is organized as follows: Section 2 briefly presents related work. Section 3 reviews Mental Practice. The design and results of the experiments are then discussed in Section 4. Preliminary conclusions and future works are summarized in Section 5.

2. Related work
A related work was presented in [6] and [4]. The researchers provided a virtual reality training of the hemiparetic hand of post-stroke patients. The paper [4] presents the virtual reality-based exercise program and preliminary studies performed on users with no hand deficits and with a user who had suffered a stroke but had nearly normal hand function. On the other hand,
the paper [6] presents a study performed on eight subjects, 6 males and 2 females, with hemiparesis resulting from a stroke, using the virtual reality training system proposed in [4]. The conclusion of this work was that computerized exercise systems may be a way to maximize both the patients' and the clinicians' time because they can provide the intensity of practice that appears to be needed to effect neural reorganization and functional post-stroke changes. The system used two instrumented gloves. The subjects sat in front of the computer screen and interacted with the virtual world wearing one of the two instrumented gloves. Four virtual reality exercise programs were developed. Each exercise took the form of a simple game where the patient performed a number of trials of a particular task. If a certain performance target was reached, then the patient achieved the goal. These target-based exercises required an initial test to evaluate three parameters of range, speed and fractionation of the patients' movements.

In [2] was examined the potential of using computer-enhanced mental practice in the rehabilitation of upper extremity function after cerebrovascular accident. The treatment protocol consisted of one daily session, 3 days a week, for 8 consecutive weeks. Patients used the visualization prototype, which consists of the following components: a retro-projected horizontal screen incorporated in a wooden table; an LCD projector with parallax correction; a mirror that reflects the projector beam onto the horizontal screen; two movement tracker sensors; and a personal computer equipped with a graphics accelerator. The training procedure consisted of the following steps. First, therapist shows the patient how to perform the movement with the unaffected arm. When the patient performs the task, the system registers the movement and generates its mirrored 3-D simulation. Next, the patient is asked to mentally rehearse the same movement using the paretic limb. System shows the 3-D simulation superimposed over the (unseen) paretic limb, so that the patient can observe a model of the movement to be imagined.

4. Exercises Overview

We designed a set of six exercises to be performed by the virtual arm. This approach was suggested by a physiotherapist.

The finite state automata, shown in Figure 1, describes the six exercises available in our system. S1 indicates the initial state where the animation has not started yet. There are five low complexity exercises and one high complexity exercise. Low complexity exercises are S2, S3, S4, S5 and S6. All of them are final states. State S2 is the shoulder abduction, S3 is grasping, state S4 indicates shoulder extension, S5 defines fingers extension and S6 designates shoulder adduction.

A high complexity exercise of reach-grasp-release is available. If the target is put in front of the patient, the reach-grasp-release exercise consists in the following sequence of states: S1-S4-S3-S5-S6. Otherwise, if the target is put beside the patient's aected limb, the sequence is S1-S2-S3-S5-S6. The automata set of input symbols consists of the type of exercise to be performed and the target's relative position to the patient's plegic arm. Incoming arcs activate S2, S3, S4,
S5 and S6 when an intervention occurred and sleep time reached 300 ms.

As cited in [5] main upper-limb movements for rehabilitation include shoulder abduction, shoulder adduction, shoulder flexion, fingers’ extension and hand grasping.

Shoulder abduction is a movement which draws a limb away from the sagittal plane of the body. It ranges from 0 -180 degrees.

Shoulder adduction moves the arm in front of the body, with backhand facing down. It ranges from 0 to 40 degrees.

The shoulder flexion is gained moving the arm in the forward direction, putting the backhand parallel to the body’s sagittal plane. This movement ranges from 0 to 180 degrees.

The fingers’ extension opens simultaneously all the fingers. Metacarpophalangeal joints bend from 0 to 90 degrees.

The four movements, which we selected for our simulation, are presented in the Figure 2. Figure 2(a) shows shoulder abduction, Figure 2(b) presents shoulder adduction, Figure 2(c) is an example of fingers’ extension and Figure 2 (d) illustrates shoulder flexion movement. The grasping movement closes simultaneously all the fingers. Interphalangeal joints range from 0 to 100 degrees.

5. Results

To date, we have implemented all proximal low complexity exercises: shoulder adduction, shoulder abduction and shoulder flexion.

We chose Cal3D format for our 3D model of the human arm. Cal3D format stores meshes and skeleton (bones and joints). We attached a marker on the patient’s shoulder joint plegic arm. We built our system using the computer vision ARToolkit library to track the marker and OpenGL library for graphics.

Figure 3, Figure 4 and Figure 5 present different angles’ screenshots of our simulation.

The method effectiveness will be evaluated using two treatment protocols during a time period. The subjects will be randomly assigned in two groups: control intervention group and virtual intervention group. Patients in the control group will receive the same motor and mental practice therapy as those in the NeuroR group. We will apply pretreatment and posttreatment measures using Action Research Arm Test (ARA) and Jebsen Test of Hand Function in both groups. The Action Research Arm Test is an outcome...
measure designed specically for use with patients with stroke. Jebsen Test of Hand Function is a timed test developed to assess hand function and dnger dexterity in both the dominant and nondominant hands.

6. Preliminary Conclusions and Future Work

We believe that our system will provide a method to investigate the eficiency of a mental practice protocol combined with visual feedback in motor rehabilitation of chronic stroke patients. Therefore, the system could be used to promote upper-limb rehabilitation for additional treatment past the traditional period of patient hospitalization and rehabilitation.

Also, this system will allow the rehabilitation stations to be set up in a patient’s home or locations other than the rehabilitation center. The simulation of the exercises will help post-stroke patients and their care givers to perform the rehabilitation exercises in different settings and they will visualize the simulation for the training of motor tasks before performing it.

In the same way, our system will allow to physiotherapist’s students learn about how to perform the main upper-limb motor rehabilitation exercises.

Currently we are implementing the algorithm to remove the real paralyzed upper-limb from the image and blend the resulting real image with the virtual arm. Also, a physical therapist is going to evaluate the system.

7. References


