

Home Stroke Telerehabilitation System to Train Recovery of Hand Function

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Abstract—Over four million Americans are affected by stroke. Current theories of stroke rehabilitation point towards paradigms of intense, concentrated use of the afflicted limb as a means for motor program reorganization and partial function restoration. A home system for stroke rehabilitation to train recovery of hand function has been designed and deployed in a research study. The system measures finger and wrist flexion and extension motions on both hands. Patients use joint motion to control the cursor on a screen in a concentrated tracking task for several hours each day over the course of 10 days. A tele component was added so that a therapist can check in with the patient and monitor progress. Fifteen patients have used the system in their homes. The equipment has been reliable and patients have generally responded that the system is easy to use.

I. INTRODUCTION

THIS project combines principles of motor learning and neuroscience with information technology to create a home based application for stroke rehabilitation. One of the most debilitating problems associated with stroke is paralysis of the hand [1], [2]. Often, the individual will be able to close the fingers into a fist but cannot open the fingers because of extremely weak finger extensor muscles and spastic tone in the antagonistic flexor muscles. As a result, the person cannot manipulate objects which impairs feeding, dressing, handwriting, and occupational skills.

The Home Stroke Rehabilitation System was designed determine whether the improved function and brain reorganization accomplished in an earlier stroke rehabilitation study [3], [4] applied in the clinical environment could be replicated in the patient's home environment, and whether the improved function and brain reorganization stem from the repetitive movement or from the cognitive processing associated with learning how to move the finger accurately. This could help for understanding why complex tasks such as tracking that require cognitive processing, appear to promote greater neuroplastic change than simple tasks [5].

A pilot study used a finger movement tracking program

where subjects with stroke received 18-20 one-hour rehabilitation training sessions using their paretic index finger to track target waveforms displayed on a computer screen under variable conditions [3]. This treatment was done in a clinic with a physical therapist supervising. Pre and post training treatment functional magnetic resonance imaging (fMRI) was used to determine which parts of the brain were activated when the subject was performing the finger tracking activity. A limitation of the pilot study was that subjects were required to come to the clinic for training sessions. This was physically difficult and time demanding for the subjects. Further, in-clinic sessions could last no more than 60 minutes while current massed practice rehabilitation theory points to the benefit of longer training sessions. In light of the promising results of the pilot study, the Home Stroke Rehabilitation system was developed to enable tracking training sessions in the subjects' homes without a therapist present.

The system required the patient to move his or her hand and wrist in a tracking task that required concentration, an essential factor to accomplish motor relearning. The major design requirement was ease of use so that the system could be operated autonomously at home without requiring technical expertise. In addition, the system needed a telecommunication mechanism for periodic real time interaction with a remote physical therapist to monitor, assist, and motivate the patient's progress. The basics of the tracking task were established in the pilot study. The challenge in this project was to transfer the task to a home-based system that could be operated without a therapist present.

The purpose of this paper is to describe the Home Stroke Rehabilitation system technology and to report on what was learned from having subjects use the system at home. The study is in progress and clinical results will be published at a later date.

II. APPARATUS

A. Overview

The home tracking system consists of a laptop computer, a sensing device worn on each hand to measure finger and wrist flexion and extension motions, a sensor box that interfaces between the hand sensor and the computer, a web cam, a telephone line switch box, and a cellular telephone. The computer is treated as an appliance with the patient

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never having to use the keyboard or mouse which avoided issues of hand dexterity and assumptions about familiarity with standard computer input devices. On power-up the computer boots into the tracking program and all interaction by the patient is done with a single button on the sensor interface box. While the system has many individual components, it is still relatively compact and fits easily on a desktop or table without being an overly obtrusive presence in the patient's home (Fig. 1).

B. Hand Sensors

The hand sensor measures flexion and extension of the wrist joint and flexion and extension of the first MCP joint (Fig. 2). The sensor and skeletal links form two four-bar mechanisms that transfer finger and wrist joint motion to two potentiometers located on the sensor platforms. This design does not require precise placement on the body, an essential characteristic as the device is self-donned by the patient.

Two slap bracelets (metal strips that lie flat when bent in one direction and self-assemble into a circle when a small amount of pressure is applied in the opposite direction) were used for anchoring the proximal sensor platform to the forearm. Velcro straps anchor the palm and distal finger platforms.

C. Interface box

The sensor interface box converts the potentiometer reading into a digital signal that is transmitted to the laptop through its serial port. The interface box contains analog signal conditioning circuitry including programmable gain and offset, a 20 Hz, two-pole low pass filter, and a programmable multiplexer that selects which of the four channels to digitize. Signals are digitized at 100 Hz with a 10-bit analog-to-digital converter. Software on a PIC16F873 microcontroller controls the peripherals, creates the real-time sampling loop, and sends the serialized signal to a level converter for transmission to the PC. The host program running on the PC communicates with the microcontroller to enable and inhibit sampling, and to set current channel, gain and offset. The sensor interface box has a large red button on the top cover, a small black button on the back, and two color coded jacks for the left and right hand sensors on the front. The red button is the only control the user needs to operate the program. Through prompts on the computer display, the red button is used to start the treatment, pause the treatment, calibrate the hand sensors, and end the treatment. The black button is used for unusual circumstances to abort the program and immediately shutdown the computer.

D. Software

The tracking software running on the host PC was written in Microsoft Visual Basic 6.0. A series of startup screens take the patient through a simple calibration procedure involving maximal voluntary flexion and extension of the joints, then moves to the therapeutic tracking task. Each

tracking trial is repeated three times in succession to form a block. Sixty blocks forms one session and the subject is expected to complete one session each day. The entire treatment program is 10 sessions or 1800 trials.

Trials are preceded by a screen that cues that subject on which hand, joint and posture to use for the trial (Fig. 3). At the same time one of the two LEDs on the sensor blinks to indicate the proper joint. A countdown clock indicates the time remaining until the next tracking task begins.

The next screen is the actual tracking task (Fig. 4). A green ball is displayed on the far left of the box. Joint movement controls the vertical motion of the ball. After the one second delay, a chime sound is played and the ball moves horizontally across the screen at a fixed rate. The patient attempts to make the green ball follow the blue target wave by moving the specified joint up and down. The ball leaves a red trail behind it for visual feedback. Trials vary in wave shape, duration, frequency, hand, joint, and forearm posture. In some trials, the ball and red trail are replaced by a vertical hairline cursor that sweeps across to show timing but provides no feedback on joint location. The variations are important to keep the patient concentrated on the task.

A post trial screen shows a tracking score derived from the RMS tracking error with higher scores indicating better tracking. For some trials, the screen also displays text providing additional feedback on performance. This feedback alerts the patient to areas in which his performance is weak, such as wrist or finger extension, or alerts the patient to excessive or insufficient frequency of movement.

The program informs the patient when the day's session is complete and automatically shuts down the computer. The automatic shutdown helps regulate the rate of rehabilitation to the prescribed regime of one session each day.

E. Telecommunication

Periodic contact between the patient and therapist is necessary to monitor progress, answer questions and provide encouragement when needed. The Home Stroke Rehabilitation System includes telecommunication to allow the remote therapist to interact by voice and video with the patient, and to download tracking files from the home computer to the remote computer in the clinic. It was assumed that every patient's home had a land line telephone and cellular phone coverage, but no broadband internet access. The telecommunication system uses a modem connection to the internet over the home's normal telephone line transmitting data files, low quality web cameras on the patient and therapist ends for two-way video, and a cell phone on the patient side for high quality audio. The assumption was that high quality audio was important for effective communication, but that low quality video (color, 128x96, 3fps) was adequate.

In a tele-session, the home computer automatically dials an internet service provider then establishes a network socket connection to the clinic computer. The rest of the session is controlled remotely by the therapist who can launch the web cam system for a video connection and

transfer file information from the home computer to the clinic. During the session, audio communication is over the cell phone. At the end of the session, the therapist can remotely shut down the home computer.

III. RESULTS

Fifteen subjects with stroke have used the home tracking system. In some cases, after being instructed in the clinic, the subjects were sent home with the system which they were able to install by themselves. Most required a home visit by the therapist to install the system. Patients took between 10 and 14 days to complete the 1800 trials. Tele-sessions occurred every second day. Two in-home visits were needed for minor repairs. In a telephone interview survey of 13 subjects, all said the computer was easy to use. Nine of 13 were able to don and doff the sensors independently. Twelve of 13 found it easy to communicate with the therapist during the tele-sessions. Nine found the scores and feedback comments after tracking trails to be helpful. One thought the equipment in the home interfered with daily life.

IV. DISCUSSION

The Home Stroke Rehabilitation System proved to be reliable and effective for conducting the study of tracking training for stroke recovery. The system could be set up in all homes and all homes could establish tele-session links to the clinic. The tele-sessions allowed the therapist to see and diagnosis problems and lead the subject through a solution.

A better system would completely eliminate the need for a therapist to travel to a patient's home for system setup and retrieval. This will require reducing and simplifying system components.

Most subjects liked, or at the very least tolerated the system. Some commented on the convenience of working at home. Subjects liked to beat their own score demonstrating the power of immediate feedback. One third of the subjects found the hand sensors hard to don and doff which could be correlated to their level of paralysis. A next generation system will require improved sensor mounting.

The telephone modem had a barely adequate bandwidth for video conferencing. A broadband connection is clearly preferable, but broadband access is not available in all residential areas and the installation and continuing charges for broadband are high. The next generation system should make use of a broadband connection should it already be installed in the home.

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FIGURES



Figure 1: Home tracking system



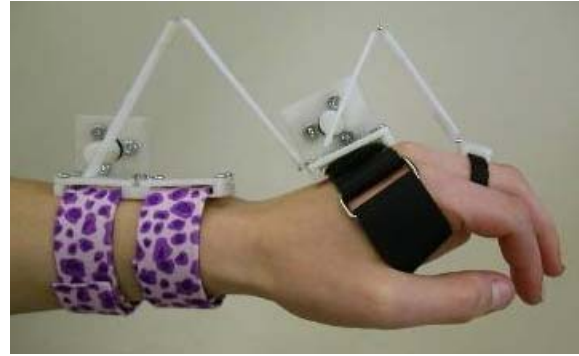
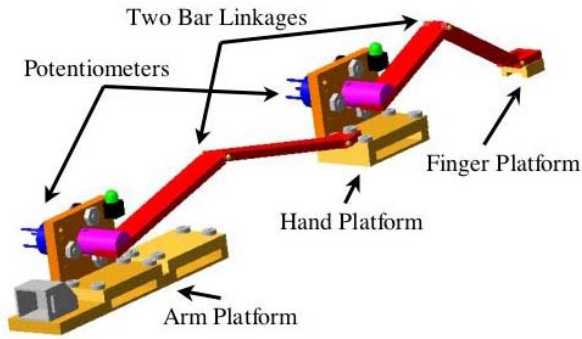


Figure 2: Hand sensor.



Figure 3: Pre-trial screen.

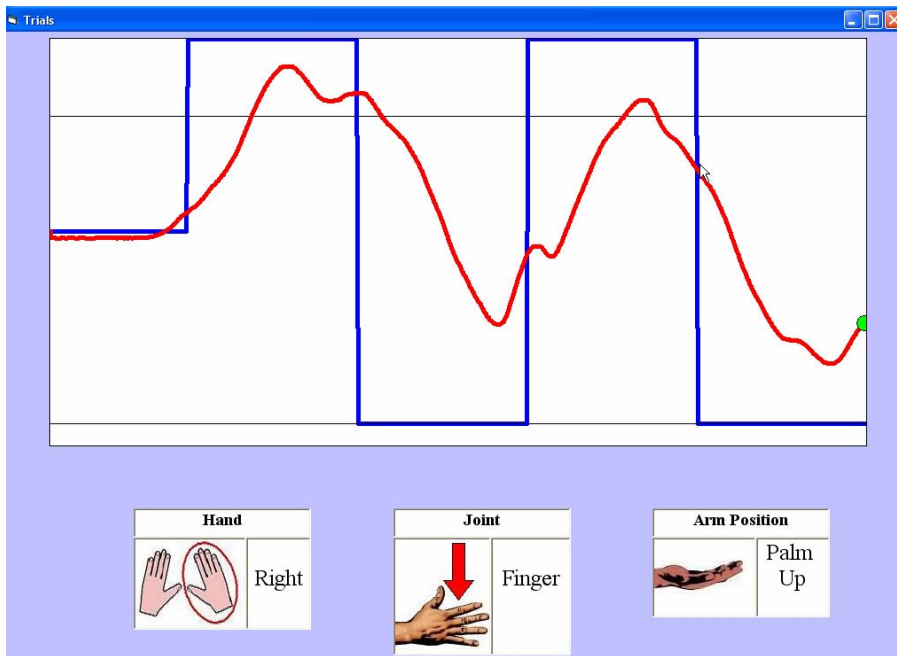


Figure 4: Tracking trial screen