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Home-Based System for Stroke Rehabilitation

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Abstract— **A system was developed for home-based stroke motor rehabilitation of the ankle. A study was conducted to test the hypothesis that moving while concentrating will lead to greater recovery than movement alone. Sixteen post-stroke subjects participated, one half in a tracking training group and the other have in a move group. The tracking training group tracked a target waveform by moving their ankle to control the tracking cursor while the move group moved their ankle approximately the same amount but without target following. Over four weeks subjects completed 3600 trials. The results showed that the Tracking group had more improvement in ankle dorsiflexion compared to the Move group. The remaining assessment criteria showed no significant differences between the groups.**

I. Introduction

APPROXIMATELY 800,000 people suffer a first or recurrent stroke each year and stroke is the third leading cause of death after heart disease and cancer [1]. On average, every 40 seconds, someone in the U.S. has a stroke. Stroke is the leading cause of serious, long-term disability. About 6.5 million stroke survivors are alive today, a number that is increasing because of improved acute care. In 1999, more than 1.1 million adults reported difficulty with functional limitations resulting from stroke. The direct and indirect cost of stroke in 2009 was $68.9 billion.

Partial paralysis of a limb is a common result of stroke, with an accompanying impairment of motor skills [2]. Stroke tends to affect function in distal muscles including those operating wrist, fingers and ankle joints, which means people with stroke often have difficulty manipulating objects with their hands or gait impairments. The goal of stroke motor rehabilitation is to regain those motor skills.

Recent research in motor learning and neuroplasticity and cell survival following an infarct have led to a scientific basis for motor retraining following stroke [3], [4]. Intensive use of the paretic limb, although beneficial, may not be optimal for rehabilitation as the research suggests that cognitively demanding motion is required rather than just motion. Studies have demonstrated that motor learning will only occur with voluntary motion where the patient engages the exercise task repeatedly and independently [5], [6]. Repetitive, simple motions are less likely to be effective than complex tasks that involve a high cognitive demand [7].

Traditional physical therapy to engage this cognitively demanding motion typically involves one-on-one interaction with a therapist for hours at a time several times a week. This is expensive and presents a barrier for patients who cannot or are not willing to travel to the clinic on a regular basis.

One solution is home-based, clinician-directed therapy that retains the cognitively challenging movement exercises, and takes advantage of internet communication for data forwarding and periodic consults between patient and clinician. Our group has been developing such a system.

The home stroke rehabilitation system is computer based and requires the subject to conduct a cursor tracking task where the cursor is controlled by the affected ankle joint. The system uses passive sensing of the joint and is simple, safe and low-cost, making it feasible to use at home without direct supervision.

Earlier, we reported on a system for wrist and finger motion that was tested in 24 subjects with stroke [8]. Here, we describe a system for rehabilitating the paretic ankle. We chose to study ankle dorsiflexion because it is commonly impaired following stroke [9] and can lead to increased tripping potential [10] and energy expenditure [11].

The study had two aims. The first aim was to determine if stroke rehabilitation can be effective when conducted at home by the patient without continuous interaction with a therapist. If motor therapy is home-based, it could lower the cost and raise the convenience and acceptance of rehabilitation.

The second aim was to determine whether increased recovery of ankle function and therefore improved gait would occur with cognitively demanding motion compared to motion alone, as predicted by the science. The study had a Track group that conducted cursor tracking tasks that were cognitively demanding, and a Move group that moved the limb but without cursor tracking.

II. Methods

A. Apparatus

The home stroke system consists of a potentiometer mounted on a brace to sense ankle motion, a laptop computer with the computer-based tracking task, a custom electronics package with an embedded microcontroller and a single button user interface that is the interface between the

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hardware and the computer, a cellular modem for internet communication and a webcam for video chatting with the therapist. The system architecture is shown in Fig. 1 and Fig. 2 shows the system in the home being used by a patient.

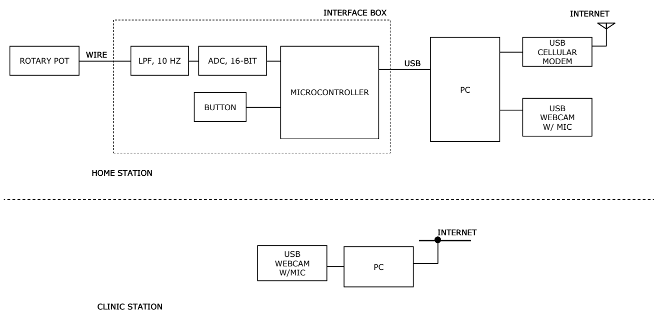


Fig. 1 Architecture for home-stroke rehabilitation system.

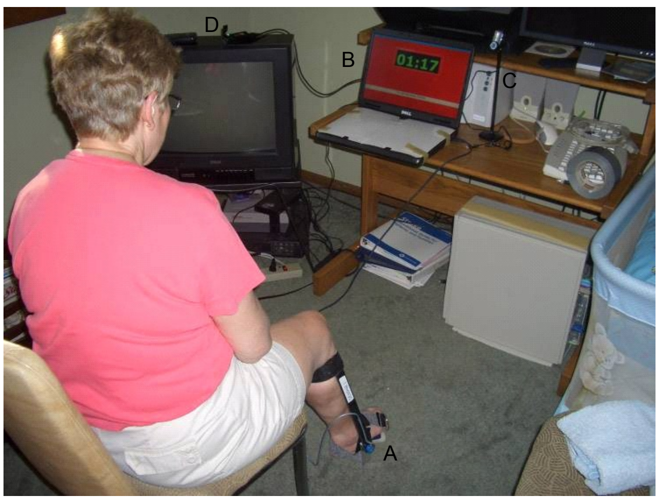


Fig. 2. System in use at home. A ankle sensor, B computer station, C webcam, D cellular modem.

B. Subjects

Nineteen subjects were enrolled in the study and randomly assigned to a Track or a Move group. Sixteen subjects completed the study, eight in each group. Inclusion criteria were cortical or subcortical stroke occurring between 0.5 and 10 years before enrollment, at least 10 degrees of ankle dorsi/plantarflexion, ability to walk at least 30 m and Mini-Mental exam score more than 24. Exclusion criteria were indwelling metals or medical devices incompatible with MRI or currently receiving stroke rehabilitation therapy. Subject average age was 54±12 and average post-stroke duration was 43±39 months. The study was approved by the University of Minnesota IRB.

C. Study Protocol

Fig. 3 illustrates the study protocol. Subjects came to the university for training in how to setup and use the rehabilitation system and for pre-test assessment. Subjects then completed the four-week treatment or control protocol at home and returned to the university for post-test.

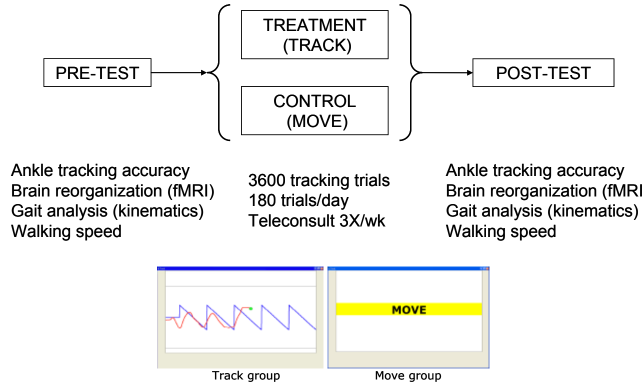
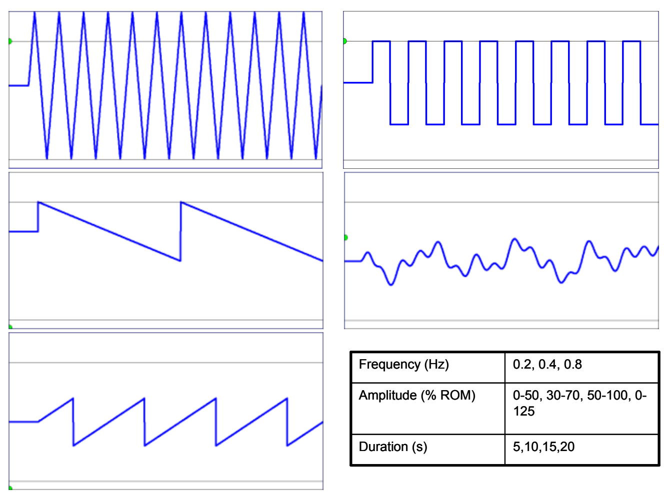


Fig. 3. Study protocol.

D. Treatment

Both groups performed 180 ankle movement trials each day, five days each week for a total of 3600 trials. The Track group followed a target waveform for each trial. Every third trial the target changed with the new target selected from a set of shapes, amplitude (normalized to that day's ROM), frequencies and duration (Fig. 4). For some trials, cursor direction was reversed with a dorsiflexion motion driving the cursor down. Subject position was selected from four possible postures (Fig. 5). The reason for the variety was to keep the task cognitively demanding. Following each trial, subjects received a score that indicated how closely they tracked the target.



Frequency (Hz)	0.2, 0.4, 0.8
Amplitude (% ROM)	0-50, 30-70, 50-100, 0-125
Duration (s)	5,10,15,20

Fig. 4. Tracking waveform variations

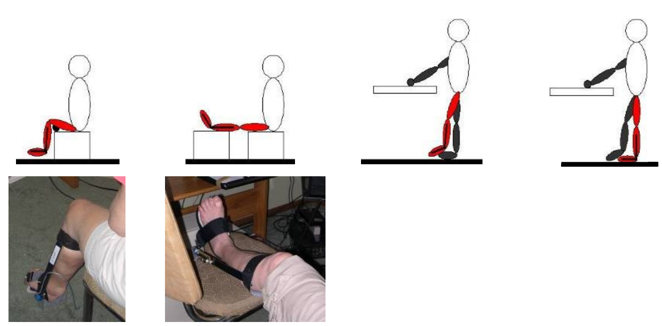


Fig. 5. Posture variations

The Move group had the same number of trials with the same trial duration but only saw the word “Move” on the screen with no target, no cursor and no post-trial score. The Move subjects were instructed to move their ankle up and down through their full range at a comfortable, self-selected frequency. The intent was for the Track and Move groups to have equal ankle motion with the cognitive demands eliminated from the Move group.

E. Telecommunication

Each night, the day’s tracking session was automatically uploaded to the clinic server for review by the therapist. Every three days the therapist conducted a tele-consult with the subject to answer questions and provide motivation to complete the treatment (Fig. 6). Skype was used for the video chat. A typical call lasted 15 minutes and served mainly to motivate the subject to continue with the treatment. Occasionally the therapist would conduct a rudimentary range of motion assessment by having the subject point their webcam at their impaired ankle while moving the ankle.

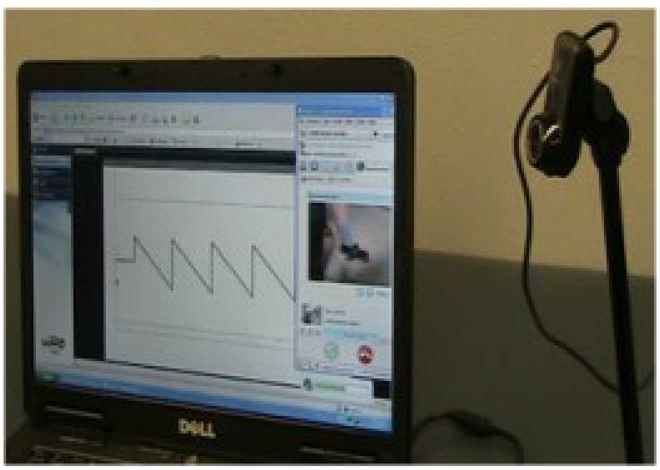


Fig. 6. Tele-consult, clinician’s station.

F. Assessments

A set of assessments were performed pre and post treatment for Track and Move groups. Quantitative gait kinematic parameters were estimated using an 8-camera Vicon motion capture system. Subjects were told to walk at their self-selected speed down the walkway and ten gait cycles were averaged and analyzed. Gait parameters included ankle DF/PF angle, toe clearance, gait temporal symmetry ratio and stride length. Subjects also did two trials of a 10-meter walk at their self-selected comfortable speed and then two trials at maximum speed.

Cortical activation was measured using functional magnetic resonance imaging (fMRI) in a 3-Tesla magnet while the subject performed a seven minute task alternating every minute between ankle tracking a 0.4 Hz target sine wave and rest (Fig. 7). MR images of the blood oxygen-level dependent (BOLD) signal were obtained in the transverse plane for 3 mm slice thickness. The analysis created an activation map showing voxels with significantly different brain activity between sine tracking and rest conditions.

After completing the post-tests, subjects were given a questionnaire and interviewed about their experiences.

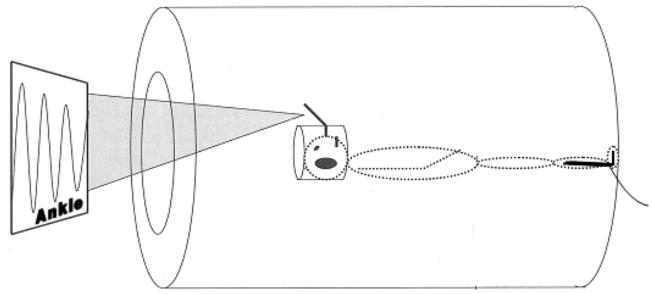


Fig. 7. Subject setup for performing ankle tracking in fMRI magnet. Subject is supine and views the tracking display, located outside the magnet, through a mirror.

III. RESULTS

The mean peak ankle DF during gait for the Track group increased from 6.75 deg at pre-test to 12.86 deg at post-test ($p=0.08$). The Move group increased from 6.61 deg pre-test to 8.99 deg post-test but the change was not significant ($p=0.055$). While there were no significant changes in toe clearance for either group, the toe clearance variance for the Track group decreased from 0.48 mm pre-test to 0.29 mm post-test ($p=0.014$) and showed no significant change for the Move group. Gait symmetry and median stride length improved significantly for both groups. There were no significant changes in either 10-meter walk tests for either group.

The mean number of movement repetitions per trial for the 3600 training trials in the Track group was 7.64 (±1.36) compared to 11.61 (±2.80) for the Move group ($p=0.003$). The peak-to-peak amplitude movements averaged 89.79 (±0.69) deg for the Track group compared to 93.62 (±1.25) for the Move group ($p=0.018$).

The sine wave tracking score improved from 18.95% pre-test to 39.92% post-test for the Track group ($p=0.041$) and from 34.37% pre-test to 53.58% post-test for the Move group (NS).

Sample fMRI data is shown in Fig. 8. None of the fMRI indices showed significant differences pre and post-test for either group.

Sixteen of the 19 enrolled subjects completed all 3600 trials, as confirmed by the data records uploaded nightly to the clinic. Three subjects dropped out citing fatigue during the training. All subjects were able to set up the apparatus at home independently and all subjects were generally favorable about home-based rehabilitation. Several subjects had difficulty donning the ankle sensor and some required assistance from the primary caregiver. Video chat consults were successful except for four subjects whose wireless link was insufficient to carry a video chat forcing the tele-consults to be done by telephone.

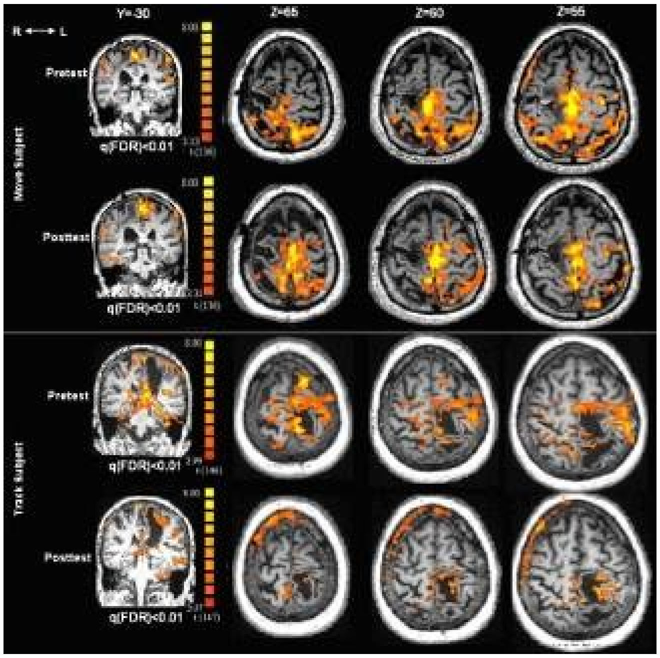


Fig. 8. Sample fMRI results. Cortical activation at one coronal slice and three transverse slices for one participant in the Move group with right hemisphere stroke while tracking with paretic left ankle and one participant in the Track group with left hemisphere stroke while tracking with paretic right ankle. Pre-test to post-test shows less activation with greater focus in the lesioned left hemisphere for the Track participant compared to the lesioned right hemisphere for the Move participant. R=right, L=left

IV. Discussion

Two important results came from the study: (1) home-based rehabilitation with periodic therapist contact is feasible for people with stroke, and (2) movement with cognitive demands (Track group) resulted in greater improvement in ankle DF compared to movement without cognitive demands (Move group). The latter is particularly interesting as the Track group had fewer movement repetitions per trial than the Move group. The Track group also had a significantly improvement in ankle target tracking with both results indicating that tracking training promoted motor learning.

A previous study by our group using Track and Move groups to investigate motor relearning in the wrist and finger found no differences between the groups [8]. In that study, training was two weeks while in the present study, training was four weeks and twice as many movement trials, which indicates the importance of duration for stroke motor rehabilitation. This brings out an important advantage of low-cost home-based rehabilitation, which is that treatment durations can be extended, limited only by the patience and perseverance of the patient.

Home-based treatments are not intended to replace the intensive, one-on-one therapy that has proven effective immediately post-stroke, but rather is targeted to a later stage of rehabilitation where repetitive movement could lead to further recovery. The home-based system described here provides this type of therapy in a convenient format with only periodic guidance from the clinician.

Further progress requires a multi-center clinical study with a larger number of subjects. Because the Track treatment is at least as good as and likely better than the Move treatment, the clinical trial should compare home-based Move treatment to another standard of care for stroke motor rehabilitation, for example, to clinic-based constraint-induced movement therapy. A positive outcome of the study is that sophisticated, home-based therapy is feasible, which is encouraging for the future of telerehabilitation.

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