33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

A telerehabilitation platform for home-based automated therapy of arm function

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Abstract—**Constraint-Induced Movement Therapy (CI therapy) has been shown to be an effective approach for improving arm function in stroke survivors with mild to severe hemiparesis. Given the time-intensive nature of the intervention, and the inherent costs and travel required to receive in-clinic treatment, the accessibility and availability of CI therapy is limited. To facilitate home-based CI therapy, a telerehabilitation platform has been developed. It consists of a table-top workstation configured with a range of physical task devices (e.g. pegboard, object flipping, threading, vertical reaching). A desktop PC is used to acquire data from sensors embedded in the task devices; display visual instructions, stimuli, and feedback to the patient during tasks; and provide videoconferencing and remote connection capabilities so the therapist can interact with and monitor the patient during at-home therapy sessions. This system has potential to greatly expand access to CI therapy and make it a more realistic option for a larger number of stroke survivors with upper extremity impairment.**

Keywords— **Rehabilitation, stroke, upper extremity, telemedicine, telerehabilitation, videoconferencing, CI therapy**

I. Background and Rationale

Stroke is a leading cause of serious, long-term disability in the United States. Each year about 795,000 people experience a new (600k) or recurrent (195k) stroke. On average, a stroke occurs every 40 seconds in the United States, with the direct and indirect cost of stroke estimated to be $73.7 billion in 2010 [1].

Hemiparesis is one of the most frequent effects of stroke, often resulting in limitations in self-care skills and Activities of Daily Living (e.g. bathing, dressing, toileting, feeding, and other reaching/prehension tasks). Beyond physical limitations, hemiparesis also has a significant negative impact on quality of life attributed to an increased dependence on caregivers, an inability to live independently, and reduced employment opportunities [2].

Constraint-Induced Movement therapy (CI therapy) is one method targeted to help stroke patients regain the use of affected limbs. CI therapy has been shown in controlled, randomized studies to substantially reduce incapacitating upper extremity motor deficits in patients with mild to severe chronic strokes [3-7]. It consists of forced use and massed practice of the affected limb with constraint of the unaffected limb and use of a 'transfer package' of behavioral techniques to promote generalization of whatever gains occur in the training session to spontaneous use of the more affected extremity in the everyday life situation. CI therapy typically lasts from 2 to 3 weeks, with daily training sessions (5 times per week) of up to 4 hours per day.

To address the time- and subsequent cost-intensive nature of CI therapy, past efforts led to development of an automated system to aid in the administration of in-clinic CI therapy. The AutoCITE (Automated CI Therapy Extender) workstation incorporates 8 therapy task devices with sensors used to measure key performance variables (e.g. counts of task repetition, performance time). A customized software program guides the patient user through an automated CI therapy session by displaying task instructions and providing feedback on performance. The AutoCITE workstation was found to be as effective as standard CI therapy, while substantially decreasing the amount of active involvement required of the therapist [8].

To investigate the potential of delivering CI therapy remotely, AutoCITE training was evaluated with reduced therapist supervision [9] as well as in a simulated telerehabilitation setting (with 'remote' therapist 4 rooms away in the clinic monitoring patients via video and intercom) [10]. In both cases, training was found to be as effective as standard one-on-one CI therapy.

Although the AutoCITE system was able to facilitate delivery of remote CI therapy, the system itself had several limitations and shortcomings that would need to be addressed to improve its viability as a telerehabilitation tool. Most notably, the ability to interact with and monitor the patient during a remote session would have to be greatly enhanced, as would the ability to control and modify the CI therapy training regimen.

II. Objective

Building on the prior work, the objective of this project was to develop *teleAutoCITE*, a telerehabilitation-enabled

Manuscript received March 26, 2010. This work was supported by National Institutes of Health Grant R01HD053750

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automated platform for delivering CI therapy to stroke patients in their homes. The motivation for this approach was to improve the accessibility of CI therapy and make it a more realistic and cost-effective option for a larger number of stroke survivors with upper extremity impairment.

III. Design Goals

The conceptual model for the development (Figure 1) combines individual components, each providing specific functionality that together facilitate the overall system aims:

1. Patients are able to receive CI therapy at home, reducing their need to travel.
2. The remote supervising therapist can monitor a patient during training with live audio and video feeds that allow immediate interaction should difficulties or problems occur.

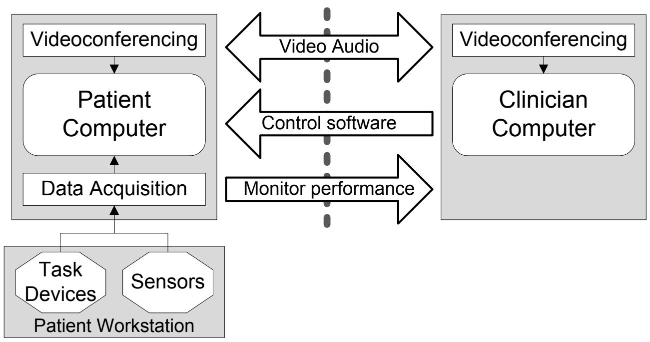

Fig.1. *teleAutoCITE* Conceptual Model

The *teleAutoCITE* is comprised of one system used by the patient and a second used by the clinician. Each system operates from a standard Windows PC, running the *teleAutoCITE* software which manages videoconferencing, data transfer/storage, and remote monitoring functions. The patient system also includes all of the hardware which enables the CI therapy: patient workstation, task devices, sensors, and data acquisition tools.

IV. System Specifications

A. Patient Workstation

The workstation (Figure 2) was designed to meet the following criteria:

- Hold task devices in a fixed location so that each would be within reach of a patient during training
- Be able to be adapted for right- or left-handed training
- Provide comfortable and height-adjustable seating, allowing for chair to rotate and lock into place
- Be easy to transport and install in a patient home (i.e. fit into a minivan or SUV and carried by one person)

The workstation was prototyped using Solidworks 2007 3D Design Software (SolidWorks Corporation, Concord, MA). Prototypes were evaluated on the above design criteria and in consultation with the CI therapy laboratory team. The final workstation design consists of a 42" x 42" L-shaped table, with a semicircular profile. In this configuration, the patient is able to swivel to the right and left, without moving the location of the chair, so that each task device is within reach throughout a training session

The tabletop was cut from two layers of ¾" thick medium-density fibreboard. The top layer was milled with cutouts matched to the footprint of each task device (described below), and secured to the bottom layer using thumbscrews. This allows for the top layer to be flipped accommodating training on the patient's hemiparetic side. Folding legs enable the table to be collapsed for transport.

A standard, high-backed leather office chair was modified for the workstation, with the existing swivel base replaced by a lockable hydraulic 'barber-shop' style base. The patient is seated in the center of the table configuration, with the rotation of the chair able to be fixed in front of each task device. A 20" LCD capacitive touchscreen monitor (ELO TouchSystems, Menlo Park, CA) is used for display as well as for tracing and reaching tasks. It is mounted on a sliding track so that the distance between patient and screen can be adjusted and set at fixed locations during training.

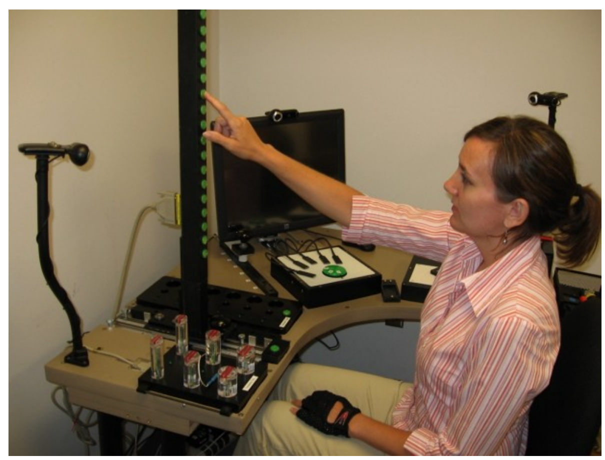

Fig.2. User seated at the *teleAutoCITE* workstation, demonstrating the 'Raising Arm' task

B. Task Devices and Sensors

The *teleAutoCITE* task devices were based on those from the original AutoCITE system. Each device is targeted to require the user to perform specific upper extremity action(s) that focus differentially on shoulder, wrist, elbow, hand, and finger use for different tasks. In CI therapy, the difficulty of a training task is set by shaping parameters, which relate to the 'difficulty' or 'extent' of a task (e.g. the range over which the patient must make a movement).

Prior to fabrication, each of the devices was prototyped using Solidworks, then evaluated and subsequently refined in consultation with the clinical CI therapy staff. To track patient performance during training, each of the devices is equipped with an array of sensors used to measure repetitions during a task as well as to indicate the shaping parameter settings on the device (Table 1).

Each device is equipped with a single DB-style connector through which all sensors are wired. To aid in installation at the patient home, each device has a unique configuration of gender/number of pins. A data acquisition junction box, mounted to the underside of the workstation, serves to route the wires from each task device to the data acquisition hardware. As sensors used in the system are all detecting basic on/off data, acquisition occurs through digital I/O boards (Measurement Computing Corporation, Norton, MA), connected to the computer via USB.

TABLE I
SENSORS AND SHAPING PARAMETERS FOR EACH TASK

Task	Sensors Used	Shaping Parameters
Threading	· Magnetic reed switch	· Target Row · Thread Direction
Raising Arm	· Magnetic reed switch · Pushbutton switch	· Tower Position · Target Height
Tapping Finger	· Magnetic reed switch · Capacitive touch	· Palm Height · Finger to Tap
Flipping Bars	· Magnetometer · RFID	· Object Size
Turning Hand	· Tactile switch	· Angle Left · Angle Right
Pegboard	· Magnetic reed switch · Pushbutton switch	· Peg Size · Target Row Far · Target Row Near
Tracing *	· Touchscreen · Magnetic reed switch	· Monitor Position · Path to Trace · Path Thickness
Reaching *	· Touchscreen · Magnetic reed switch · Momentary switch	· Monitor Position · Target Size · Target Location

* These tasks did not require a custom device, as they utilized the workstation touchscreen as a user interface

For the Flipping Bars task, in which patients are required to hold and flip over rectangular bars of different widths, a USB-RFID reader (Parallax Inc., Rocklin, CA) is used to identify the bar being used and a magnetometer detects its orientation.

In addition to task-specific sensors, other sensors are integrated into the system to provide additional data on the patient's status and performance during training. A diffuse reflective proximity sensor (Eaton Cutler-Hammer, Columbus, Ohio), mounted to the back of the chair, is used to detect if the patient was within range and seated in a proper upright position. This sensor provides digital output and is wired to the data acquisition box. A Bluetooth tri-axis accelerometer (Sparkfun Electronics, Boulder CO) (placed in a pouch on a patient-worn vest) is used to collect data on torso position (e.g. leaning fore/aft or side/side). A Bluetooth fingertip pulse oximeter (Nonin Medical Inc., Plymouth, MN) is used to measure patient blood-oxygen saturation and heart rate.

C. Software

The *teleAutoCITE* software was developed in C#.NET 2007 (Microsoft, Redmond, WA) and integrates several different components: videoconferencing, delivery of CI therapy, and remote monitoring of patient performance. Different user interfaces were developed for the patient- and clinician-facing software.

The patient-facing interface was designed to be as simple as possible, in accordance with telerehabilitation human factors considerations [11]. The patient is not required to interact with the software; rather it only serves as an information display to guide him through the CI therapy. During a remote session the clinician controls all aspects of the software on both sides of the connection. The clinician initiates the call to start treatment, adjusts the quality of the audio and video signals, and controls the delivery of the CI therapy.

The videoconferencing capabilities are supported through the use of the HDDK Developers Kit (Emblaze VCON, Israel), which allows for the integration of audio and video OCX controls directly into the *teleAutoCITE* software. The system utilizes the H.323 IP-based videoconferencing standard with security provided via H.235 AES encryption. Hands-free noise cancellation microphones and speakers at both sites allow the patient and clinician to speak to and hear each other clearly.

In order to monitor the patient beyond live audio and video feeds, *teleAutoCITE* utilizes remote desktop sharing to provide a real-time view of the patient's computer. This allows the clinician to 'see what the patient sees' during training. Data from the chair sensor, torso position sensor, and pulse oximeter are also streamed in real-time to the clinician to provide additional insight into patient status.

There are three primary modes within the system, each of which has a specific on-screen layout for the patient and clinician software user interfaces:

- In 'conversation' mode, patient and clinician see each other in full-size video windows.
- In 'data sharing' mode the video window is reduced in size to accommodate a shared data window, within which the patient and clinician can share survey forms, activity logs, and home skill assignment checklists.
- In 'AutoCITE' mode, the patient display is devoted entirely to the CI therapy tasks. During training, basic in-task feedback is displayed on-screen to the patient in the form of a countdown timer and number of repetitions. Between trials and tasks, on-screen motivational messages offer encouragement and performance feedback is given through bar graphs and display of average and best effort scores. A 'Call Therapist' button is displayed on-screen at all times should the patient require assistance (it triggers a loud tone and displays a message box on the clinician's screen).

The *teleAutoCITE* system is designed to deliver automated CI therapy to the patient by presenting training tasks according to a prescribed interval and sequence, with pre-determined training parameters. The remote clinician is able to adjust these settings at any time before or during a training session, in accordance with standard CI therapy clinical practice. While the patient is training, the clinician's screen in 'AutoCITE' mode (Figure 3) is divided into 4 panels, each devoted to a different aspect of the software:

- Live remote video of the patient (patient workstation is equipped with three USB web cameras - Right Side, Face, Left Side).
- Live remote desktop view of patient's screen
- Live display of data from patient sensors
- CI therapy task settings and controls

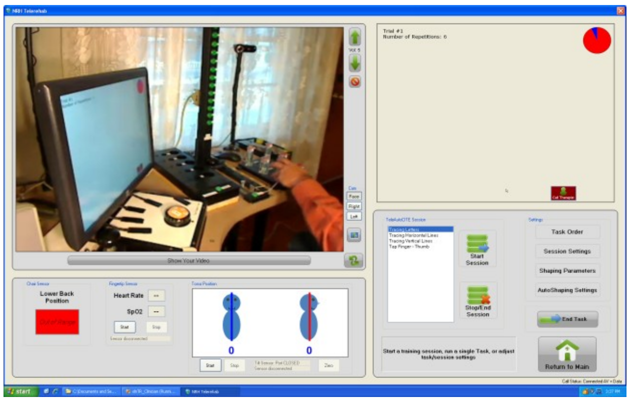

Fig.3. Clinician software in ‘AutoCITE’ mode during patient training. Clockwise, from top-left: video of patient from Left camera, remote desktop view of patient's screen, CI therapy controls, display of patient sensor data

A database is used to record and track patient performance on each task as well as data from the sensors. The clinician can review these data prior to initiation of a training session so as to modify training parameters for tasks as needed. System activity logs are also recorded to detail and describe the operation of the *teleAutoCITE* software, track errors or faults with the system, and monitor other operational characteristics of the patient and clinician computers.

V. PILOT TESTIING

Upon completion of development, the system was installed in the CI therapy clinical laboratory at the University of Alabama at Birmingham and evaluated by clinicians and other members of the project team. Through informal and structured evaluation with both patient and clinician users, areas for revision were suggested and the system was modified in response. The majority of these changes related to the automation of the CI therapy and on-screen display of information.

Pilot testing was performed with 3 patients (all > 1-year with mild to moderate upper-extremity hemiparesis) in the laboratory in a simulated remote environment. The user interface was found to offer easy-to-understand feedback and instructions to the patient, and the training tasks were appropriately challenging.

In-home pilot testing with patients is currently underway. Preliminary findings indicate the *teleAutoCITE* system can provide the appropriate level of patient monitoring to enable home-based CI therapy. While the system is able to connect using 3G wireless Internet, it was determined that for call stability, a wired (e.g. DSL or cable) high-speed connection would yield better performance.

VI. CONCLUSION

In order to facilitate in-home delivery of upper extremity CI therapy, the existing AutoCITE system was re-envisioned. The *teleAutoCITE* consists of a patient workstation, designed to provide access to CI therapy task devices, and software that combines videoconferencing with live data sharing. This approach facilitates the dynamic interaction and performance monitoring required to deliver home-based CI therapy.

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