

A ROBOTIC SYSTEM FOR UPPER-LIMB EXERCISES TO PROMOTE RECOVERY OF MOTOR FUNCTION FOLLOWING STROKE

Peter S. Lum^{1,2}, Machiel Van der Loos^{1,2}, Peggy Shor¹, Charles G. Burgar^{1,2}

¹Rehab R&D Center, VA Palo Alto HCS

²Dept. of Functional Restoration, Stanford University

Abstract

Our objective is to evaluate the therapeutic efficacy of robot-aided exercise for recovery of upper limb motor function following stroke. We have developed a robotic system which applies forces to the paretic limb during passive and active-assisted movements. A clinical trial is underway which compares robot-aided exercise with conventional NeuroDevelopmental Therapy (NDT). Preliminary data suggests robot-aided exercise has therapeutic benefits. Subjects who have completed a two month training protocol of robot-aided exercises have demonstrated improvements in active-constrained training tasks, free-reach kinematics, and the Fugl-Meyer assessment of motor function. Integration of robot-aided therapy into clinical exercise programs would allow repetitive, time-intensive exercises to be performed without one-on-one attention from a therapist.

Introduction

Disability resulting from stroke affects individuals, their families, and society. Each year 700,000 people in the United States suffer strokes, and the number of stroke survivors now

approaches two million. Stroke is the most common inpatient rehabilitation diagnosis and the resulting loss of upper limb motor function is often resistant to therapeutic efforts. Yet, methods that decrease the workload on clinical staff are needed. Integration of robot-aided therapy into clinical exercise programs would allow repetitive, time-intensive exercises to be performed efficiently.

We have developed a device which facilitates movement in the paretic limb. A Puma 560 robotic arm applies forces to the paretic limb that would normally be provided by a therapist. This system is capable of 4 modes of exercise, all patterned after exercises currently used in therapy. In passive mode, the subject relaxes as the robot moves the limb. In active-assisted mode, the subject triggers initiation of the movement with force in the direction of movement and then



"works with the robot" as it moves the limb. In active-constrained mode, the robot provides a viscous resistance in the direction of movement and spring-like loads in all other directions. In bilateral mode, the subject attempts bilateral mirror-image movements while the paretic limb is assisted by the robot. Movement of the contralateral limb is measured by a 6-DOF digitizer; the robot moves the paretic limb to the mirror-image position with minimal delay. A six-axis force-torque sensor measures the interaction forces and torques between the robot and the subject.



A clinical trial is underway to evaluate the therapeutic efficacy of robot-aided exercise for recovery of upper limb motor function relative to conventional NeuroDevelopmental Therapy (NDT). We report results from the first 5 subjects to complete the protocol.

Methods

Chronic stroke subjects (> 6 months post CVA) are randomly assigned to a robot or control group. Both groups receive 24 one-hour sessions over two months. A robot group typical session begins with 5

min of stretching, followed by tabletop tracing of circles and polygons, and a series of 3-dimensional reaching movements; all assisted by the robot. A control group typical session includes NDT-based therapy targeting upper-limb function incorporating stretching, weightbearing, games and activities (cone stacking, ball tossing, etc.), and 5 min of exposure to the robot with target tracking tasks. A single occupational therapist supervises all sessions.

All subjects are evaluated pre and post treatment with clinical and biomechanical measures. A blinded occupational therapist evaluates the level of motor function in the paretic limb with the Fugl-Meyer exam, and the disability level of the subjects with the Barthel ADL scale and the Functional Independence Measure (FIM). The biomechanical evaluations include measures of isometric strength and free-reach kinematics. Electromyograms (EMG) are recorded from several shoulder and elbow muscles during these evaluations.

Preliminary Results

Robot group subjects exhibited decreased resistance to some passive movements and improved performance of some active-constrained reaching movements post-treatment (Table 1). Decreased resistance to passive movement was indicated by increased total work. Improved performance of active-constrained movements was indicated by increased positive work,

Table 1. Improvements in performance metrics for three robot group subjects. Significant positive correlations ($p < 0.05$) between performance metric and session number indicated by "+" (shaded blocks indicate movement was not tested)

			#1 forward	#2 forward-up(should level)	#3 forward-up(eye level)	#4 forward-lateral	#5 forward-lateral-up(should level)	#6 forward-lateral-up(eye level)	#7 forward-medial	#8 forward-medial-up(should level)	#9 forward-medial-up(eye level)	#10 lateral (elbow extended)	#11 lateral (elbow flexed)	
Subject A	passive	work	+			+			+	+		+	+	
	active constrained	work	+	+	+	+	+	+	+	+	+	+	+	
		efficiency				+	+					+	+	+
		velocity	+	+		+	+	+	+	+	+	+	+	+
Subject B	passive	work	+	+	+	+						+		
	active constrained	work		+										
		efficiency	+	+	+	+		+	+	+	+	+		
		velocity		+									+	
Subject C	passive	work		+					+	+				
	active constrained	work	+	+					+	+		+		
		efficiency	+	+					+					
		% completed	+	+			+			+		+		

efficiency, % of movement completed, or average velocity (efficiency is defined as the positive work biased by the potential work that would have been done if the forces were directed perfectly toward the target).

Improved performance of active-constrained movements in one robot subject was clearly due to improved muscle activation patterns. Pre and post-treatment data is displayed in Fig.1. for this subject during an active-constrained forward-lateral-up(shoulder level) reach. Pre-treatment, no movement was possible. Post-treatment, half the movement could be completed. Pre-treatment, only biceps (antagonist) was strongly activated. Post-treatment, triceps (agonist) was activated while

activation of biceps was suppressed. In addition, several shoulder agonists were silent pre-treatment, and were subsequently activated post-treatment.

The ability to free-reach toward targets increased post-treatment. The kinematics of unconstrained reaching were measured pre and post-treatment. Table 2. illustrates the cases of significant increases ($p < 0.05$) in the extent of reach (indicated by "+"). Shaded squares indicate the reach could be completed pre-treatment.

While there were no significant changes in the Barthel ADL scale or the FIM, all subjects tested to date have exhibited some improvements in motor function. Improvements in the Fugl-Meyer assessment of motor function in all robot (diamonds) and

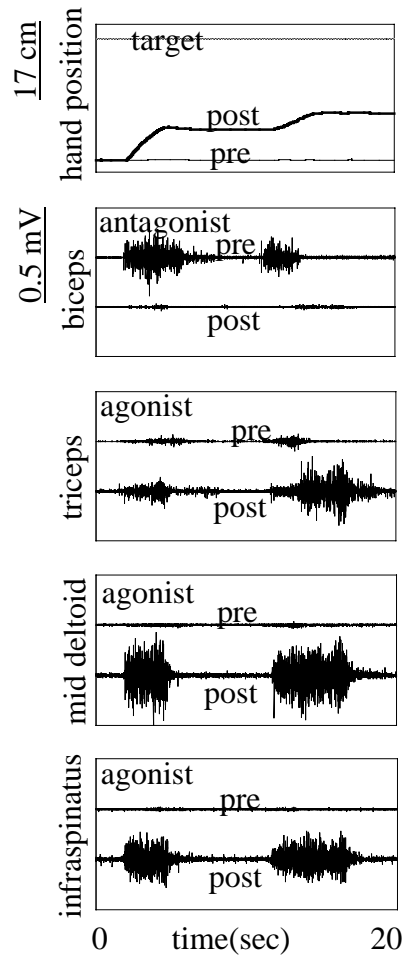


Fig. 1. Kinematics and EMG for an active-constrained forward-lateral-up(shoulder level) reach in one robot group subject.

control subjects (circles) is illustrated in Fig. 2.

Table 2. Improvements in the extent of free reaches post treatment. Subjects A,B,C are robot, and subjects D&E are controls.

	#1 forward	#2 forward-up(shoulder level)	#3 forward-up(eye level)	#4 forward-lateral	#5 forward-lateral-up(shoulder level)	#6 forward-lateral-up(eye level)	#7 forward-medial	#8 forward-medial-up(shoulder level)	#9 forward-medial-up(eye level)
Subject A				+	+	+			
Subject B									
Subject C		+		+	+			+	
Subject D	+			+					
Subject E									

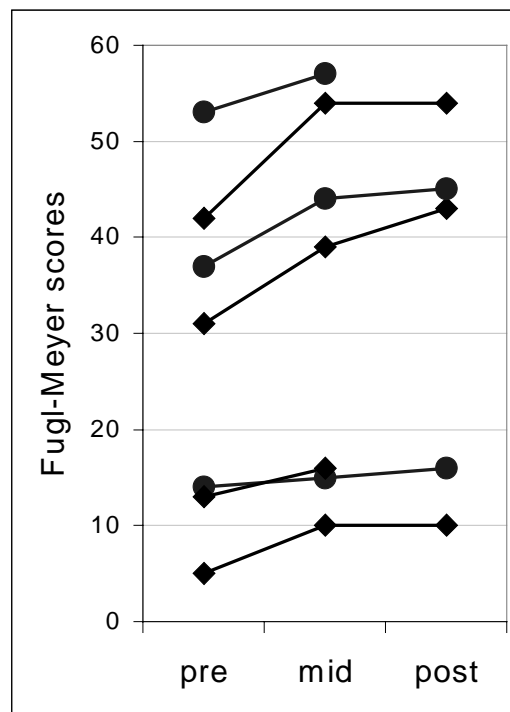


Fig. 2. Fugl-Meyer scores pre, mid and post-treatment. Circles are the robot group subjects and diamonds are the controls.

Conclusions

Preliminary data from this ongoing clinical trial suggests robot-aided exercise has therapeutic benefits. Improvements have been demonstrated in active-constrained training tasks, free-reaching, and the Fugl-Meyer assessment of motor function. It will be possible to determine the efficacy of robot-aided therapy relative to NDT-based therapy after more subjects are tested.

Acknowledgements

Doug Schwandt, MSME, Jim Anderson, JEM, Matra Majmundar, OTR

Funded by VA RR&D Merit Review project B2056RA