Evaluation of the Harmony Exoskeleton as an Upper Extremity Rehabilitation Tool after Stroke

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***Abstract*—We carried out an exploratory study to evaluate the safety of the Harmony upper body exoskeleton during stroke rehabilitation in a clinical setting. This robot contains a novel arrangement of active degrees of freedom about the shoulder complex that should be evaluated for safe interaction before assessing clinical efficacy. This study was performed with a fifty-eight year old male and began twenty-seven months after ischemic stroke. The subject's shoulder girdle motion, glenohumeral subluxation, and muscle status were monitored over twenty-two sessions. Glenohumeral subluxation was successfully avoided throughout arm motion, and palpated scapular motion was deemed satisfactory. Active range of motion and effort duration measurements showed slight changes between early and late sessions, but no significant improvement in daily function was anticipated. Nevertheless the Harmony exoskeleton was capable of maintaining glenohumeral joint closure and proper coordination of shoulder girdle motion during several multi-joint movements in a chronic stroke subject.**

I. Introduction

IN recent years, robotic therapy has been increasingly considered as an additional method for assessing patient progress and supplying repetitive motion during upper limb stroke rehabilitation [1]. To date, these devices have been shown to produce statistically significant improvements in ADL and arm function [2]. One symptom of stroke is impairment of coordinated motion within the shoulder complex, which is called scapulohumeral rhythm (SHR). Most robots that have undergone clinical testing are unable to actively control the full movement of the shoulder girdle (e.g., [3]), and systems that are capable of this do not describe any methods of enforcing coordinated shoulder motion (e.g., [4]).

We have developed an upper body exoskeleton, Harmony, for assisting in post-stroke rehabilitation [5]. Each arm of the robot contains a five degree-of-freedom shoulder arrangement that can actively control both elevation-depression and protraction-retraction of the shoulder girdle. The exoskeletal design allows us to control both single and multi-joint motions during therapy, including SHR.

We present results from an initial study with a single chronic stroke subject. We evaluated the robot's capacity to work with the subject for passive stretching and focused resistance training. We also assessed the robot's ability to mobilize the shoulder complex during these motions without jeopardizing glenohumeral (GH) stability.

This work was supported by National Science Foundation, Walter Oil and Gas Corporation, a NASA Space Technology Research Fellowship, and Mission Connect/TIRR Foundation.

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II. Material and Methods

We used an inverse dynamic model with a recursive Newton-Euler algorithm to compensate for the weight of the robot arms. Vertical forces were added at the humeral and wrist attachment points to provide approximate compensation for the subject's arm. Shoulder coupling torques to promote SHR were added around the shoulder girdle mechanism [6]. The coefficients of this coupling were tuned for kinematic compatibility with a young adult male without neuromuscular impairment.

This controller was supplemented with six arm trajectories that were based on functional therapeutic exercises: 1) forward reaching in a parasagittal plane; 2) proprioceptive neuromuscular facilitation (PNF) D2 pattern for the upper extremity [7]; 3) PNF D1 pattern; 4) scapular plane elevation (scaption); 5) elbow extension with forearm pronation; and 6) internal-external (I-E) humeral rotation near the open packed position of the GH joint. These movements were recommended by clinicians to target the subject's difficulty with voluntary extension and lateral movements. These movements were used as the reference trajectory of an impedance control scheme in robot joint space.

A 58 year old male subject participated in this study and began 27 months after right hemispheric ischemic stroke. The subject's primary deficits were spastic left hemiparesis and partial hemisensory loss; the subject had a NIH Stroke Scale score of 5. The subject participated in twenty-two one hour sessions over six weeks, and a nurse and at least one clinician were present for all sessions.

Each session contained three to four sets of eight repetitions of each of the six movements. These sets included multiple types of interaction with the device, including therapist-driven movement, robot-driven movement with the subject passive, and robot-driven movement with the subject active during phases of extension, excluding elevation during scaption. The clinicians occasionally palpated the targeted muscles to

TABLE I

CHANGE IN ACTIVE RANGE OF MOTION SCORES

	Primary		Secondary	
Motion	Day 2	Day 20	Day 2	Day 20
Reaching	1.04	1.03	2.10	1.73
PNF D2	1.09	1.07	2.98	2.33
PNF D1	0.96	1.01	3.49	2.43
Scaption	1.06	1.13	2.85	2.61
Elbow	0.94	0.91	1.46	2.37
I-E Rotation	0.99	0.98	3.94	3.93

TABLE II

CHANGE IN EFFORT DURATION SCORES

	Primary		Secondary	
Motion	Day 2	Day 20	Day 2	Day 20
Reaching	0.22	0.20	0.56	0.46
PNF D2	0.42	0.39	0.98	0.98
PNF D1	0.36	0.35	0.62	0.25
Scaption	0.36	0.74	0.21	0.27
Elbow	0.19	0.47	0.93	0.98
I-E Rotation	0.05	0.08	0.99	0.99

evaluate recruitment as well as around the scapula and GH joint to assess scapular motion and joint stability.

Robot joint angles were measured during subject activity to estimate active range of motion and duration of sufficient effort. These quantities were normalized by the angle ranges of the reference trajectory and the duration of extension movements, respectively. Joints that were associated with key motion components were classified as *primary*, while joints that contained unimportant or potentially compensatory movements were defined as *secondary*.

III. RESULTS

The clinicians and subject perceived a general reduction of abnormal tone in the affected arm after each session. The clinicians inferred increased use of posterior deltoid, triceps, and supraspinatus during the active phases of movement.

The robot was able to properly mobilize the subject's shoulder complex during these motions. Palpation during the exercises showed that the scapula was moving with satisfactory. After manually reversing the GH subluxation during the donning procedure, the robot was able to maintain this reduced joint displacement throughout the movements.

The subject's active range of motion scores (Table 1) showed minor decreases in most movements for both primary and secondary joints. While the improvements in the secondary joints appear larger, this is partially due to the relatively small desired amplitude of secondary motion. The effort duration scores (Table II) generally show similar trends, excluding the increase in extensor effort during elbow extension. Although brachioradialis tone appeared to be suppressed in later sessions, this may not be the sole source of this change.

IV. DISCUSSION

The SHR controller was able to mobilize the shoulder girdle during each of the movements. A simplistic implementation of this assistance still produced acceptable motion, which suggests that highly specific tuning of SHR gains may not be necessary for safe motion during mobilization exercises with impedance control. Still, the dependence of subject performance on these parameters and applicability to other subjects remain uncertain.

The continuous support of the GH joint was an encouraging observation. The robot was able to maintain this closure regardless of the guidance method or subject activity, which is valuable when working with conditions that require active control of GH joint integrity. In addition, the potential to evoke activity in the supraspinatus and posterior deltoid, which have been associated with maintaining GH stability [8], suggests that the device may be useful in managing this pathology.

It is possible that a different protocol would result in better functional recover. One possible reason is that robot-guided movements provided excessive guidance by continually discouraged deviations from the trajectory. Nevertheless, the ability to elicit previously unobserved muscle activity in targeted movements is promising for future interventions.

V. CONCLUSIONS

The Harmony exoskeleton was able to perform therapeutic exercises with a chronic stroke subject under varying movement guidance and subject effort. The robot's ability to support healthy shoulder motion during these different movements allows us to explore scapula-focused exercises and therapeutic motions over a large workspace. Active modulation of the desired SHR will be critical to future studies that explore how this motion should be controlled during rehabilitation.

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