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Robot-assisted upper limb rehabilitation in chronic stroke patients

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Abstract**—The goal of this study is to evaluate the effects of upper limb robot-assisted treatment in chronic post-stroke patients using clinical outcome measures and kinematic parameters.**

Thirty-two chronic stroke patients participated in the study. Fugl-Meyer (FM) Assessment scale and Motricity Index (MI) were used for clinical assessment, and a set of kinematic parameters was computed.

A significant decrease in motor impairment after the robot-assisted treatment (FM p<0.001 and MI p<0.001) was found. Movement mean velocity (p<0.001) and accuracy (p<0.05) increased.

Robotic treatment is effective to reduce motor impairment in chronic stroke patients. The exclusive use of clinical scales do not provide an exhaustive evaluation of effectiveness of treatment and our study suggests that kinematic parameters should be computed as well.

I. Introduction

Recent systematic reviews showed that upper limb robot-assisted rehabilitation treatments in stroke subjects improve short- and long-term motor control, even if no consistent influence on functional abilities [1], [2] and participation, based on the International Classification of Functioning framework, was found. Evidence of better results providing intensive treatments, both robotic and conventional rehabilitative techniques, was recently reported [3].

Several studies on robot-assisted rehabilitation treatment in chronic stroke patients have shown a reduction of the upper limb impairment, but till now evidence on the advantage of using robotic therapy compared to other types of intervention (i.e., electrical stimulation) is still lacking [4], even if robotic therapy can provide safe and intensive training able to improve upper limb coordination and function [5].

Till now only few studies have investigated the effects of robotic therapy on subacute patients [6]-[10] and a comparison between subacute and chronic stroke patients is still to be further investigated [11].

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A large study on chronic stroke patients, involving 127 patients, did not found any difference between the group treated by robotic device and the group treated by intensive usual care, supposing that the key point for a better outcome could be intensity and not linked to specific features of treatment provided by robotic devices, such as repeatability [3].

In most studies only standard clinical instruments (e.g., Fugl-Meyer Assessment Scale, Ashworth Scale) were used as outcome measures and only few studies have analyzed the effects of robotic treatments using kinematic parameters [12], [13]. Indeed , improvement in functional performance after stroke can also result from compensatory adaptations, which often occur adopting abnormal patterns of movement [14] in order to accomplish a specific task, together with recovery of inter-joint coordination and muscle synergies. These compensatory adaptation mechanisms are measured as improvement by a rather exclusive use of clinical scales, which are not able to capture changes in the quality of motion.

The goal of rehabilitation is to stimulate and facilitate both compensation and recovery processes in order to maximize the patient's functional outcome [15]: a set of kinematic parameters may contribute to discriminate between compensation and true recovery.

Robotic systems can provide measurements related to changes of impairment on the treated limb segment through recording of physical variables, such as position, velocity and interaction forces which give useful information able to quantify the qualitative changes of motion, and not only the total amount of movement.

The main goal of this study is to evaluate the effects of robot-assisted therapy on the outcome of proximal regions using as outcome measure both standardized clinical evaluation scales and a set of kinematic parameters based on the measurements recorded at the robot's end-effector.

II. Methods

A. Subjects

Thirty-two chronic stroke patients (age range 29-86, mean age 59.58 ± 14.63 years, nineteen men and thirteen women), who experienced the acute event at least one year prior to the study, were recruited for this study and assigned to robotic treatment for training shoulder/elbow joints.

Fifteen had a history of right hemiparesis, and seventeen had incurred in left hemiparesis. All subjects were right-handed.

The experimental protocol was approved by the local ethics committee and each subject signed a consent form.

B. Equipment

The InMotion 2 shoulder/elbow (Figure 1) (Interactive Motion Technologies, Inc., Watertown, MA, USA), designed for clinical and neurological applications [16], [17] was used for this study. The robotic systems allow subjects to execute reaching movements through an "assist as needed" control strategy.

The InMotion 2 robotic system has two translational degrees of freedom (DoFs) and it consists of a direct-drive five-bar-linkage SCARA (Selective Compliance Assembly Robot Arm) mechanism driven by two brushless motors rated to 7.86 Nm of continuous stall torque (considerably higher torques can be produced, but only for limited periods of time) with 16-bit resolvers for position and velocity measurements.. The workstation for shoulder/elbow is mounted on a custom-made adjustable chair, which allows the chair to be rotated 360° and translated 0.5 m toward a table-top, specially designed to facilitate transfer of wheelchair-disabled patients. The robot can guide the movement of the upper limb of the subjects and record end-effector physical quantities, such as position, velocity, and applied forces.

Figure 1. Stroke patient during robot-assisted shoulder/elbow rehabilitation

C. Robot-assisted therapy

Patients were asked to perform 20 sessions of goal-directed reaching tasks moving from the centre target to each of 8 peripheral targets (Figure 2a), which emphasized shoulder and elbow movements, by using the InMotion 2 system; Each subject performed 5 robot-assisted sessions per week for 4 weeks. Each session was formed by (i) a series of 16 assisted clockwise repetitions to each robot target (training test); (ii) a series of 16 unassisted clockwise repetitions to each robot target (Record); (iii) 3 series of 320 assisted clockwise repetitions (Adaptive). At the end of each Adaptive series, the patient was asked to perform a further series of 16 unassisted clockwise movements (Record). Kinematic data were recorded from the robotic systems before and after the therapy, during the Record series of exercises. Upon demonstration of competency and understanding by the patient, minimal feedback was provided and verbal encouragement and environmental distraction was kept to a minimum.

C. Clinical outcome measures

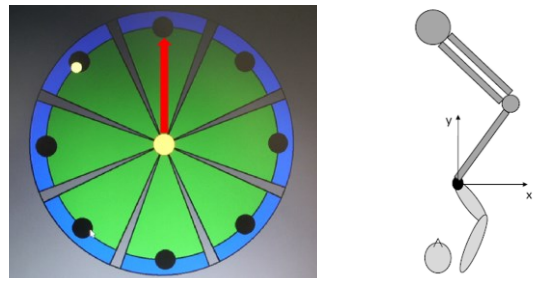
Each subject underwent an upper limb evaluation using the (i) shoulder/elbow subsection of Fugl-Meyer (FM) Assessment Scale [18] and (ii) Motricity Index (MI) [19].

TABLE I
PRE- AND POST- TREATMENT VALUES OF OUTCOME MEASURES

	PRE (mean±sd)	POST (mean±sd)	Change (mean±sd)	p
FM/se	17.38±11.81	23.22±11.67	5.84±4.93	< .001
MI	34.59±19.73	45.06±22.68	10.47±7.70	< .001

Legend: PRE, pre-treatment; POST, post-treatment; FM/se, Fugl-Meyer shoulder/elbow subsection

Evaluation tools were used for each subject before (Pre-treatment), after (Post-treatment) the delivery of the robotic therapy.



(a) (b)

Figure 2. a) "Clock-like" robot-assisted therapy scenario; b) reference coordinate system

D. Kinematic parameters measuring movement dynamics

All the gathered recordings represent a large amount of raw biomechanical data that should be processed in order to capture relevant characteristic features with respect to stroke patient recovery. The analysis was carried out considering only the direction from the center to the north target (red arrow in Figure 2a), which represents the movement performed against pathological pattern, as it requires shoulder flexion and elbow extension. For such reason, the x- and y-component of position and y-component of velocity (Figure 2b) were extracted and used for computation of parameters. The mean distance between the ideal and actual path was computed, as well. Recorded data were digitally low-pass filtered forward and backward in time at 5 Hz with a 10th-order Butterworth filter. The velocity is defined as the discrete-time velocity signals along the axes y. The velocities of movements performed by each subject along y axis ($v_y[k]$) were computed during Record series. The mean speed vector is defined as follows:

$$\overline{v_y} = \frac{1}{N}\sum_{k=1}^{N} v_y[k] \quad (1)$$

where N represents the number of samples for each recording.

We defined the following parameter:

$$MD = \frac{\sum_{k=1}^{N} |d_k|}{N} \quad (2)$$

where MD represents the mean absolute values of the distance (d_k) of each point of the path from the theoretic path (i.e., straight line from center to north target). When the value of this parameter approximates zero, movement accuracy is high. Data were processed using custom routines developed under Matlab environment (Mathworks Inc., Natick, MA, USA).

III. RESULTS

The robot-assisted therapy was well accepted and tolerated by all patients. The results from clinical outcome measures show a significant decrease in motor impairment of shoulder and elbow after the treatment with statistically significant changes on shoulder/elbow subsection of FM and the upper limb section of MI.

Values of mean velocity along y-axis computed on the direction from the center to north target significantly increased after the robot-assisted treatment ($p<0.001$) (Figure 3). MD significantly improved ($p<0.05$) (Figure 4).

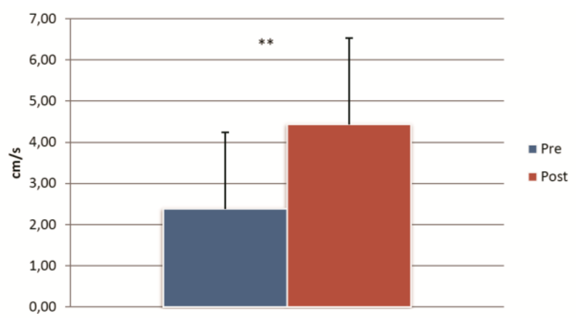


Figure 3. Mean velocity values, pre- (blue) and post- (red) robot-assisted training (** indicates $p<0.001$)

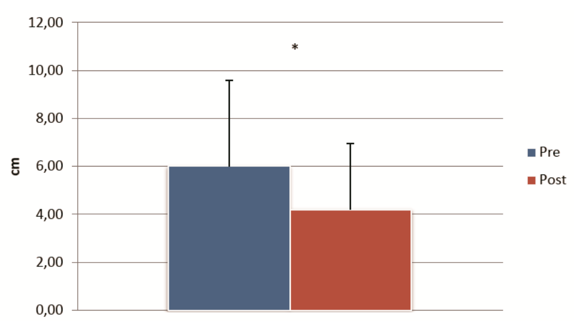


Figure 4. MD values, pre- (blue) and post- (red) robot-assisted training (* indicates $p<0.05$).

IV. DISCUSSION AND CONCLUSION

Our results confirm that the motor impairment in the upper limb of chronic stroke patients improve after the rehabilitation based on a robot-assisted treatment, as demonstrated by several previous studies [20]-[27].

Our results suggest that the robotic treatment is effective in reducing the upper limb motor impairment as shown by shoulder and elbow subsection of FM and MI score.

The analysis of kinematic parameters shows that also the mean velocity recorded at the robot's end-effector during shoulder and elbow treatment significantly improves after the robotic training (Figure 3), thus confirming that the intensive goal-directed treatment provided by a robotic device is effective in increasing the quality of motor performance. MD significantly changed suggesting an improvement of movement accuracy after the robot-assisted treatment.

In conclusion, clinical scales as FM and MI are able to detect the improvement between before and after robot-assisted treatments, whereas kinematic parameters seem to be able to capture an improvement of shoulder and elbow, quality of motion The exclusive use of clinical scales do not lead to an exhaustive evaluation of effectiveness of treatment as outlined by our study which suggests that kinematic parameters should be computed as well, and robotic systems used in the rehabilitation clinical practice should be designed in order to record physical variables during the overall treatment, using the same motor tasks for therapeutic and assessment purposes.

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