Effects of robot-assisted wrist therapy in chronic stroke patients: a kinematic approach

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Abstract—The main goal of this study is to present preliminary results on wrist robot-aided rehabilitation in chronic post-stroke patients, assessed by using clinical scales and kinematic parameters.

Eleven chronic stroke patients participated in the study. The InMotion 3 robotic system for the wrist rehabilitation was used. Clinical scales were used for assessment. Kinematic parameters were measured at the robot’s end-effector.

Outcome clinical measures show a decrease in motor impairment after the treatment. The kinematic data show an improvement between admission and discharge.

Our results show that the robot-assisted wrist training can contribute to reduce the motor impairment; clinical outcome measures and kinematic parameters demonstrate this improvement. The analysis of kinematic data associated to a quantitative motor assessment provided by clinical evaluation scales is able to quantify the rate of improvement in the quality of motion obtained after robot-assisted wrist therapy in stroke patients.

I. INTRODUCTION

The use of robotic systems in upper limb motor rehabilitation programs has been already demonstrated to provide safe and intensive treatment to subjects with motor impairments due to a neurological injury: several studies showed the advantages of robotic therapy [1]-[5] on chronic post-stroke patients, even if no consistent influence on functional abilities was found [6], [7] and evidence of better results providing intensive treatments, both robotic and conventional rehabilitative techniques, was found [8].

Till now only few studies analyzed the effects of robot-assisted therapy on the wrist joint of stroke patients [9]-[12].

The analysis of mechanisms of recovery in stroke patients, which is now based on the use of clinical scales only, assumes great importance in the rehabilitation domain, as it can support the clinical decision process, although differences about mechanisms underlying motor recovery in chronic and subacute stroke patients can be hypothesized, but are still to be demonstrated.

With regard to this, the use of robotic systems, which allows recording and monitoring of several biomechanical data (speed, forces, etc.), can be addressed to differentiate motor recovery mechanisms in stroke patients at different stages of rehabilitation and evaluate the effects of treatments.

Clinical assessment scales represent the most common outcome measures in rehabilitation so far [13]; they provide merely quantitative information on the patient’s motor performance but are unable to provide qualitative information, which could be useful to differentiate the mechanisms underlying motor recovery.

Some robotic systems are capable of controlling and quantifying the intensity of practice and objectively measuring changes in terms of biomechanical parameters representing kinematical variables and forces, which can be used as quantitative and repetitive assessment of the effects of rehabilitation treatment, allowing the use of robotic devices not only in terms of delivery of motor rehabilitation treatment, but also as evaluation tools [14].

Previous studies proposed different kinematic and kinetic measures for assessing the motor performances of post-stroke subjects during robot-aided rehabilitation treatment [15]-[18]. Our previous study on 25 chronic stroke patients treated using robotic device for shoulder/elbow rehabilitation (InMotion 2, Interactive Motion Technologies, Watertown, MA, USA) showed that Fugl-Meyer (FM) scores changes significantly, but kinematic parameters (i.e., position and velocity) did not change after treatment [19].

The aim of this study is to present preliminary results on wrist robot-aided rehabilitation in chronic post-stroke patients, assessed by using clinical scales and kinematic parameters.

II. METHODS

A. Subjects

Eleven chronic stroke subjects, age range 38-72 (mean age 61.6±17.7) years, seven men and four women, were recruited for the study. Four were resulted in right hemiparesis, and seven in left hemiparesis. They had experienced the acute event at least one year prior to the study (mean time from onset of neurological damage 24 months).

The level of the upper limb impairment for each stroke patient at admission was assessed using the “Stage of Arm” section of the Chedoke-McMaster (CM) Stroke Assessment Scale [20]. One chronic stroke subject had a CM score of 2, seven a CM score of 4, and three a CM score of 5.
Inclusion criteria for both patients’ groups were: (i) unilateral paresis as result of first stroke, (ii) ability to understand and follow simple instructions, (iii) ability to remain in a sitting posture, even through seat belts for trunk fixation. Exclusion criteria were: (i) bilateral impairment, (ii) severe sensory deficits in the paretic upper limb, (iii) cognitive impairment or behavioural dysfunction that would influence the ability to comprehend or perform the experiment, (iv) inability to provide informed consent and (v) other current severe medical problems. All subjects were right-handed.

The experimental clinical trial was performed at the Neurological and Traumatic Brain Injury Unit, “Auxilium Vitae” Rehabilitation Centre, Volterra, Italy. The local ethics committee approved the experimental protocol and each subject signed a consent form.

B. Equipment

The InMotion 3 robotic system (Interactive Motion Technologies, Inc., Watertown, MA, USA), a robot designed for clinical and neurological applications [21], was used for this study. The wrist robot was designed with three active degrees of freedom (dof): abduction-adduction (ab-ad), flexion-extension (flex-ext), pronation-supination (pro-sup). This robot, shown in Figure 1, has ranges of motion of 60°/60° in flex-ext, 30°/45° in ab-ad, and 70°/70° in pro-sup.

The design of the system was aimed at delivering a predetermined range of forces, stiffness and impedance at the end-effector; the system is characterized by a low inertia, low friction, compliance and back-drivability. The device can record mechanical quantities such as the position, velocity, and forces applied. During therapy the patient is seated on a chair provided with seat belts limiting the trunk movements, in order to avoid torso compensations (Figure 1).

C. Intervention

Each subject performed five sessions per week for 4 weeks of goal-directed reaching tasks, which emphasized wrist movements, moving from the centre target to each of 8 peripheral targets equally spaced on a 0.14 m radius circumference around a centre target (Figure 2).

Each session is 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 is asked to perform a further series of 16 unassisted clockwise movements (Record).

Kinematic data were recorded from the robot’s end-effector before starting and at the end of the therapy, during the Record series of exercises.

The low impendence of the system facilitates the residual movement of more severely impaired patients: if the patient is not able to reach the target, after an adjustable time threshold, here set at $t = 5$ sec., the blinking cursor to be reached, automatically moves from one target to another. Kinematic data are recorded even if the patient performs partially the movement, without reaching the target.

D. Clinical outcomes

Each subject underwent an upper limb evaluation by an experienced physical therapist not involved in rehabilitation treatment team using the upper extremity (maximum score = 66) and wrist (maximum score = 10) subsections of the Fugl-Meyer (FM) Assessment Scale [22], and the Modified Ashworth Scale (MAS) on the wrist [23].

The same evaluation tools were used for each subject before (Pre-treatment) and after (Post-treatment) the robotic therapy. Chedoke Stroke Assessment scale was compiled only before the treatment for classifying the patients according to different degrees of severity in the upper limb impairment.

E. Kinematic data analysis

Gathered recordings represent a large amount of raw data that should be processed in order to capture relevant characteristic features with respect to stroke patient recovery. Every recording contains discrete-time trajectories of end-effector’s position and speed with respect to two perpendicular directions in the horizontal plane.
These data were then digitally low-pass filtered using a 10th-order Butterworth filter. The velocities $v_x[k]$ and $v_y[k]$ are defined as the discrete-time velocity signals along the axes $x$ and $y$, respectively. The velocities of movements performed by each subject along $x$ and $y$ axes ($v_x[k]$, $v_y[k]$) were computed for Record series. The mean speed vectors $v_x$ and $v_y$ are defined as follows:

$$v_x = \frac{1}{N} \sum_{k=1}^{N} v_x[k]$$

$$v_y = \frac{1}{N} \sum_{k=1}^{N} v_y[k]$$

where $N$ represents the number of samples for each recording. In this study the resultant velocity in the $xy$-plane is considered only; this variable is defined by its components $v_x[k]$ and orthogonal $v_y[k]$, as follows:

$$v_{xy}[k] = \sqrt{(v_x[k])^2 + (v_y[k])^2}$$

The mean velocity vector is defined as follows:

$$\overline{v}_{xy} = \frac{1}{N} \sum_{k=1}^{N} v_{xy}[k]$$

For each patient the mean velocity value was computed. Then, an average of the values of the mean velocity among the 16 directions was computed on different groups. As velocity measures are equally ranged, a Student’s t-test was used for the statistical analysis of differences before and after the treatment in the group of patients.

Kinematic parameters were analyzed using custom software routines developed under Matlab environment (Mathworks Inc., Natick, MA, USA). On the wrist joint, kinematic parameters were computed on single directions able to stimulate specific motor patterns: North toward-Abduction; South toward-Adduction; East toward-Extension; West toward-Flexion (red arrows in Figure 2).

Mean position data at pre- and post-treatment, in flexion/extension, abduction/adduction and pronation/supination wrist movements in direction North toward, South toward, East toward, West toward are shown in Figure 3, Figure 4, Figure 5 and Figure 6, respectively. Mean velocity data at pre- and post-treatment, in flexion/extension, abduction/adduction and pronation/supination wrist movements in direction North toward, South toward, East toward, West toward are shown in Figure 7, Figure 8, Figure 9 and Figure 10, respectively.

III. RESULTS

A. Clinical outcomes

The robot-assisted therapy was well accepted and tolerated by all patients and no patients dropped out.

The results from clinical outcome measures showed a significant decrease in motor impairment in the paretic upper limb and wrist after the robot-aided treatment.

Table I summarizes the results obtained using the FM upper extremity (FM/ue) and wrist/hand (FM/w) subsections and MAS on the wrist (MAS/w), before and after the robotic treatment. Statistically significant improvements were found on the outcome measures in chronic patients recruited for this study, between pre- and post-treatment.

<table>
<thead>
<tr>
<th></th>
<th>PRE (mean ± sd)</th>
<th>POST (mean ± sd)</th>
<th>Change (mean ± sd)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM/ue</td>
<td>36.73 ± 10.17</td>
<td>44.73 ± 0.02</td>
<td>8.00 ± 4.71</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>FM/w</td>
<td>1.64 ± 1.28</td>
<td>3.00 ± 2.05</td>
<td>1.36 ± 1.12</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>MAS/w</td>
<td>1.00 ± 1.26</td>
<td>0.37 ± 0.67</td>
<td>-0.64 ± 0.81</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
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After robot-assisted wrist treatment, FM upper extremity scores (p<0.05), FM wrist component scores (p<0.05) and MAS wrist scores (p<0.05) show a significant reduction of motor impairment.

B. Kinematic data

Motor improvements were found on position and velocity data on the four selected directions, through values measured at beginning and end of the robotic treatment. All changes are not statistically significant (p>0.05).

Position (Figure 3) and velocity (Figure 7) data in direction North toward show an increase in abduction. An increase in extension is observed in position data as well, without significant changes in related velocity.

In direction South toward, position data (Figure 4) do not show a substantial change in adduction; an increase of velocity during the execution of this movement is observed (Figure 8). An increase in extension is observed in position data as well, without significant changes in related velocity.

Position (Figure 5) and velocity (Figure 9) data in direction East toward do not show changes in extension.

An increase in abduction is observed in position data as well, without significant changes in related velocity.
An increase in the velocity of flexion movement in direction West toward can be observed (Figure 10); position data (Figure 6) do not show remarkable changes. An increase in abduction is observed in position data as well, without significant changes in related velocity. Pronation/supination did not change in the selected four directions, as shown by position and velocity data.

IV. DISCUSSION AND CONCLUSIONS

Our study presents an improvement in wrist motor performances as showed by changes in FM scores in chronic post-stroke patients after the treatment based on robot-aided therapy training.

The analysis of kinematics parameters shows an increase in position after exercises in specific directions, but no statistically difference was found in velocity. It implies that a quantitative increase in range of motion, as showed by FM, can be observed after robot-assisted therapy, without changes in movement velocity.

In conclusion, robotic devices are able to provide important information about changes on movement’s quality during rehabilitation of stroke patients, adding further information about mechanisms underlying motor recovery. In fact, FM items, as most clinical evaluation scales, are scored without taking into account the timing of motor performance: changes in the quality of movement are rather difficult to be disclosed.
Only the simultaneous analysis of quality and quantity of motion can shed light on differences of motor recovery in stroke patients and can be used to tailor rehabilitation treatments in terms of intensity and duration.

Our study represents a novel contribution as focused on the effects of the robot-assisted therapy on the wrist joint of post-stroke patients.

The proposed approach based on the analysis of kinematic data associated to a quantitative motor assessment provided by clinical evaluation scales is able to quantify the rate of improvement in the quality of motion achieved after robot-assisted therapy on the wrist joint of stroke patients.

REFERENCES