ORIGINAL RESEARCH ARTICLE

Upper Limb Robot-Assisted Therapy in Chronic and Subacute Stroke Patients

A Kinematic Analysis

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ABSTRACT

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Objective: The aim of this study was to compare motor recovery in subacute and chronic stroke patients through clinical assessment scales and a set of kinematic parameters recorded using a robotic system.

Design: Fifty post-stroke patients, 25 subacute and 25 chronic, and 20 healthy subjects participated in this study. The InMotion 2.0 robotic system for shoulder/elbow rehabilitation was used. Clinical outcome measures were used for assessment. Kinematic parameters related to the speed measured at the robot's end effector and to the movement's smoothness were computed.

Results: The results of this study show that the robot-assisted training can contribute to reduce motor impairment in both subacute and chronic stroke patients. The evaluation of the kinematic parameters and their correlation with the clinical scales highlight some differences in mechanisms of recovery in subacute and chronic stroke patients.

Conclusions: The proposed set of kinematic parameters and the analysis of the reaching movements' onset time, associated with a quantitative evaluation of motor improvement provided by the clinical outcome measures, are also able to quantify the changes in the quality of motion obtained after robot-assisted therapy in stroke patients. The higher gain in the subacute stroke patients suggests that the rehabilitative treatment provided at an earlier stage is able to avoid the development of pathologic patterns, resulting in a better quality of motion.

Key Words: Rehabilitation, Robotics, Stroke, Upper Limb, Assessment

The use of robotic systems in upper limb motor rehabilitation programs has already been demonstrated to provide safe and intensive treatment to subjects with motor impairments caused by a neurologic injury. Currently, several studies have already shown 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 treatment intensity as a factor promoting better results was found, delivered by either robotic devices or conventional rehabilitation.[8]

Until now, only a few studies have been carried out on subacute stroke patients,[9–13] and few provide data from subacute and chronic stroke patients[14,15]; therefore, the comparison between subacute and chronic stroke patients is still to be further investigated. Improvement in functional performance after stroke can result from compensatory adaptations, which can occur by using abnormal patterns of movement to accomplish a particular task (e.g., to help stabilize an object with the paretic arm), as well as from recovery of movement and normal muscle activation synergies.

The goal of rehabilitation is to maximize the patient's functional outcome, through both compensation and true recovery processes.[5,16]

The relationship between motor recovery and motor learning has received little attention, but it seems to be most relevant in neurorehabilitation because motor recovery shares different mechanisms with motor learning and could explain phenomena such as true recovery *vs.* compensation.

Motor learning is likely mediated by different modifications in function (synaptic strength) and structure of neural circuits in different brain regions, and motor recovery is based on neural circuits not affected by injury, which learn to compensate for lost cells and connections, thereby re-enabling effective movements (i.e., neuroplasticity).[17–20]

The analysis of mechanisms of recovery in subacute and chronic stroke patients, which is now based on the use of clinical scales only, assumes great importance in the rehabilitation domain because it can support the clinical decision process, although differences in 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 the motor recovery mechanisms in subacute and chronic stroke patients and evaluate the effects of early and late treatment supporting the hypothesis of a wider neuroplasticity in early stages after the acute event.

The most common clinical assessment scales used as outcome measures in rehabilitation[21] are able to provide merely quantitative information on the patient's motor performance and 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. These devices can be used not only for delivering motor rehabilitation treatment but also for evaluation purposes,[22] as already proposed in previous studies in which different kinematic and kinetic measures for assessing motor performances of post-stroke subjects during robot-aided rehabilitation treatment were computed.[23–26]

The aim of this work was to evaluate the difference of motor recovery between subacute and chronic post-stroke patients through clinical assessment scales and kinematic parameters, computed starting from physical variables recorded by the robotic device.

METHODS

Subjects

Two groups of stroke patients and one group of healthy subjects (sex and age paired) were enrolled for this study. A group of 25 subacute stroke subjects, aged 44–82 yrs (mean ± SD age, 70.2 ± 9.4 yrs), 16 men and 9 women, was recruited for this study. Ten resulted in right hemiparesis; and 15, in left hemiparesis. They had experienced the acute event 25 ± 7 days before the study. 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.[27] One subacute stroke subject had a CM score of 1; thirteen, a CM score of 2 or 3; and eleven, a CM score of 4 or 5.

A group of 25 chronic stroke patients, aged 31–86 yrs (mean ± SD age, 58.8 ± 13.1 yrs), 17 men and 8 women, was recruited for this study. Twelve resulted in right hemiparesis; and 13, in left hemiparesis. The chronic stroke patients had experienced the acute event at least 1 yr before the study (mean time from onset of neurologic damage, 24 mos).

TABLE 1 Demographic and clinical variables of the patients at admission

Variables	*n*	%	Mean	SD	Percentiles		
					25th	50th Median	75th
Chronic group	25						
Age			58.8	13.1	51.5	63.0	67.0
Sex							
Female	8	32.0					
Male	17	68.0					
CM			3.3	0.9	3.0	3.0	4.0
FM			20.9	11.5	12.5	17.0	32.0
MI			36.5	22.8	18.0	29.0	54.0
Subacute group	25						
Age			70.2	9.4	68.7	72.0	75.5
Sex							
Female		9	36.0				
Male		16	64.0				
CM			3.1	1.2	2.0	3.0	4.0
FM			26.3	12.1	18.5	27.0	37.0
MI			40.4	26.3	19.5	48.0	64.0

Sixteen chronic stroke subjects had a CM score of 2 or 3; and nine, a CM score of 4 or 5.

Table 1 shows the demographic and clinical characteristics of the patients. Intergroup comparison on age revealed statistically significant differences using the D'Agostino-Pearson omnibus test.

A group of 20 healthy subjects, aged 27–60 yrs (mean ± SD age, 38.0 ± 9.8), 9 men and 11 women, was recruited for comparison purposes.

The inclusion criteria for both patient groups were (1) unilateral paresis as result of first stroke; (2) ability to understand and follow simple instructions; and (3) ability to remain in a sitting posture, even supported by seat belts for trunk fixation. The exclusion criteria were (1) bilateral impairment, (2) severe sensory deficits in the paretic upper limb, (3) cognitive impairment or behavioral dysfunction that would influence the ability to comprehend or perform the experiment, (4) inability to provide informed consent, and (5) other current severe medical problems. All subjects were right handed. The local ethics committee approved the experimental protocol, and each subject signed a consent form.

Experimental Setup

The InMotion 2.0 robotic system (Interactive Motion Technologies, Inc, Watertown, MA), a robot designed for clinical and neurologic applications,[28] was used for this study. The robotic system (Fig. 1) supports the execution of reaching movements in the horizontal plane through an "assist-as-needed"

FIGURE 1 *A stroke patient during upper limb therapy using the InMotion 2.0 shoulder/elbow robotic system.*

control strategy. The robot can guide the movement of the upper limb of the patients and record end-effector physical quantities such as the position, the velocity, and the applied forces.

Intervention

Each subject was asked to perform five sessions per week (6 wks for the subacute stroke patients and 4 wks for the chronic stroke patients because hospitalization time for the latter usually cannot exceed 4 wks) of goal-directed, planar reaching tasks, which emphasize shoulder and elbow movements, moving from the center target to each of eight peripheral targets equally spaced on a 0.14-m–radius circumference around the center target (Fig. 2). In each group, robotic therapy was the only rehabilitation treatment provided on the shoulder and elbow joints.

Although the two groups received different treatment durations, the analysis of biomechanical parameters after the treatment in both groups was performed on data recorded at the 20th session to compare the two groups after the same number of sessions. In addition, values of the kinematic parameters were also computed on data recorded at the 30th session in the subacute group. As for clinical outcome measures, the effectiveness of treatment was evaluated after 20 sessions in the chronic stroke patients and after 30 sessions in the subacute group.

Each session is formed by (1) a series of 16 assisted clockwise repetitions to each robot target (training test), (2) a series of 16 unassisted clockwise repetitions to each robot target (record), and (3) three 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).

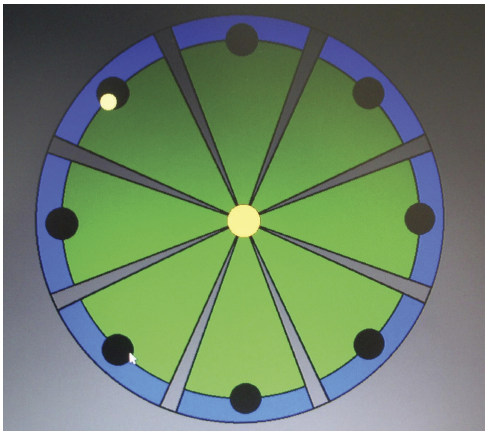

FIGURE 2 *The clock-like robot-aided therapy scenario.*

Biomechanical data were recorded from the robotic system during the Record series of the first and the last session, at a self-paced velocity. The low impendence of the system facilitates the residual movement of patients with more severe impairment: if the patient is not able to reach the target, after an adjustable time threshold, here set at $t = 5$ secs, the blinking cursor to be reached automatically moves from one target to another. Kinematics parameters are recorded even if the patient performs the movement partially without reaching the target.

Upon demonstration of competency and understanding by the patient, minimal feedback was provided. Verbal encouragement and environmental distraction were kept to a minimum.

Clinical Outcome Measures

Each subject underwent an upper limb evaluation by an experienced blinded physical therapist not involved in the rehabilitation treatment team, using the upper extremity subsection of the Fugl-Meyer (FM-UE) Assessment Scale[29] (maximum score, 66) and the upper limb component of the Motricity Index (MI) for motor impairment after stroke.[30]

The same evaluation tools were used for each subject immediately before the first session (pretreatment) and after the last session (posttreatment) of robotic therapy. Data of the CM Stroke Assessment Scale, for classifying the patients according to different degrees of severity in upper limb impairment, were compiled only before the treatment.

Kinematic Parameters

Speed

All the gathered recordings represent a large amount of raw biomechanical data that should be processed to capture relevant characteristic features with respect to stroke patient recovery. Every recording contains discrete-time trajectories of speed with respect to two perpendicular directions in the horizontal plane.

These data were then digitally low-pass filtered forward and backward in time at a 5-Hz cutoff frequency with a tenth-order Butterworth filter. The velocities $v_x\ [k]$ and $v_y\ [k]$ are defined as the discrete-time velocity signals along the x and y axes, respectively. The velocity reference coordinate system is shown in Figure 3.

The velocities of movements performed by each subject along the x and y axes ($v_x\ [k]$, $v_y\ [k]$) were computed for the Record series.

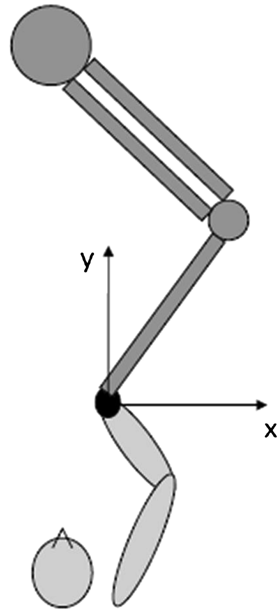

FIGURE 3 *The robot's reference coordinate system.*

In this study, only the resultant velocity in the xy plane is considered; 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 is defined as follows:

$$v_{xy} = \frac{1}{N} \sum_{k=1}^{N} \; v_{xy}[k]$$

where N represents the number of samples for each recording.

For each patient, the mean velocity value was computed on each direction. Then, an average of the values of the mean velocity among the 16 directions was computed on the different groups.

Movement Smoothness

The movement trajectories of the healthy subjects are smooth, characterized, in theory, by single-peaked and bell-shaped velocity profiles. In contrast, impaired voluntary movements of the paretic arm in post-stroke patients are characterized by the loss of smoothness in the movement trajectory.[31]

In addition to the mean velocity, three measures of smoothness were computed starting from the kinematic data acquired during reaching movements. These parameters were analyzed to evaluate and quantify the smoothness of movements: number of speed peaks, speed metric, and acceleration metric.

(1) Number of speed peaks (NSP)

NSP in the xy plane velocity profile is a metric used to quantify the smoothness of movement in stroke patients.[32,33] Low values of NSP indicate few periods of acceleration and deceleration, resulting in a smooth movement.

(2) Speed metric (SM)

SM represents the normalized mean speed and is computed as the mean speed divided by the peak speed.[33] Post-stroke patients typically present movements appearing as composed of a series of short and rapid submovements, and the resulting speed profile has a series of peaks with deep valley in between. The value of mean speed for such a movement is rather lower than that of the peak speed, resulting in a relatively low value of SM.

(3) Acceleration metric (AM)

AM is defined as the ratio between the mean acceleration and the peak acceleration. The acceleration data were calculated by the first derivative of speed data recorded during each Record series. The acceleration in the xy plane was considered. Like the SM parameter, AM value should be lower at the admission and higher at the end of robot-aided treatment because of the increase in the movement smoothness.

Data were processed using custom routines developed under Matlab environment (Mathworks Inc, Natick, MA).

Movement Onset Time

Movement onset time is defined as the instance when the subject starts the motion of the robot end effector, toward the target, without indecision. The movement onset time was calculated by selecting the time when the movement speed was greater than 10% of the peak speed.[34]

Statistical Analysis

To evaluate statistical significance of the difference before and after the treatment on the clinical outcome measures (i.e., FM-UE and MI) between the chronic and subacute stroke patients, a two-way analysis of variance was computed on scores recorded before and after the treatment.

A two-way analysis of variance was also used for the statistical analysis of differences of the kinematic parameters before and after the treatment in the two groups of patients and for comparison of the groups.

TABLE 2 Pretreatment and posttreatment values of the FM clinical scale

	Pretreatment	Posttreatment	Change	*P*
Chronic	20.92 ± 11.55	28.12 ± 13.11	7.20 ± 5.60	<0.05
Subacute	26.28 ± 12.10	35.66 ± 12.34	9.50 ± 7.83	<0.05

Values are expressed as mean ± standard deviation.
Intergroup comparison: $P < 0.05$.

Multiple comparison procedures using the Holm-Sidak method (overall significance level, 0.05) were carried out as well.

To evaluate the correlation between the biomechanical parameters and scores of the clinical scales, statistical correlations were computed between changes in each metric and changes in the clinical outcome measures (FM-UE and MI). The Pearson product moment correlation coefficient was used as a parametric method; the Spearman rank correlation coefficient was used as a nonparametric method. For this correlation, the kinematic parameters at the sixth week of treatment of the subacute stroke patients were computed and compared with the changes in the clinical assessment scales at the same time.

RESULTS

Clinical Outcome Measures

The robot-assisted therapy was well accepted and tolerated by all patients, and no patients dropped out. The results from the clinical outcome measures showed a significant decrease in motor impairment in the paretic upper limb after the robot-aided treatment both in the chronic and subacute stroke patients.

Statistically significant improvements were found on the FM-UE in both groups, the chronic and subacute stroke patients ($P < 0.05$), between pretreatment and posttreatment. Table 2 summarizes the results obtained using the FM-UE clinical scale, before and after the robotic treatment.

No statistical significance on the FM-UE scores at pretreatment between the chronic and subacute stroke patients was found, showing that before treatment, the two groups were homogeneous. A statistically significant difference was found in the value change from admission to discharge between the two groups, showing a higher improvement in the subacute stroke patients ($P < 0.05$). A limitation associated with the previous statement relies on the different duration of treatment, although the perception of a larger window for the subacute stroke patients is confirmed by kinematic data analyzed at the 20th session both in the chronic and subacute group.

No statistical significance on the MI scores both at pretreatment and posttreatment between the chronic and subacute stroke patients was found. Statistically significant improvements were found on the MI scores in the subacute group between pretreatment and posttreatment ($P < 0.05$), whereas in the chronic stroke patients, no statistically significant difference was found between pretreatment and posttreatment. A statistically significant difference was found in the value change from admission to discharge between the two groups ($P < 0.05$). This result confirms the higher improvement of the subacute stroke patients compared with the chronic stroke patients. Table 3 summarizes the results obtained using MI, before and after the robotic treatment.

Kinematic Data

No statistical significance on each kinematic measure at pretreatment in the chronic and subacute stroke patients was found, showing that before the treatment, the two groups were homogeneous.

TABLE 3 Pretreatment and posttreatment values of the MI clinical scale

	Pretreatment	Posttreatment	Change	*P*
Chronic	36.52 ± 22.83	44.20 ± 22.44	7.68 ± 6.23	NS
Subacute	40.42 ± 26.35	56.37 ± 26.25	15.95 ± 12.49	<0.05

Values are expressed as mean ± standard deviation.
Intergroup comparison: $P < 0.05$.
NS indicates not significant.

TABLE 4 Kinematic parameters at posttreatment in the subacute stroke patients on the fourth week (20 sessions) and the sixth week (30 sessions)

	20 Sessions	30 Sessions	*P*
v_{xy}, m/sec	0.10 ± 0.03	0.09 ± 0.03	NS
NSP	4.81 ± 4.10	4.52 ± 2.82	NS
SM	0.49 ± 0.07	0.50 ± 0.07	NS
AM	0.43 ± 0.06	0.45 ± 0.09	NS

Values are expressed as mean ± standard deviation.
NS indicates not significant.

Statistically significant improvements were found on each kinematic measure, through values measured at the beginning and the end of the robotic treatment, in the subacute stroke patients, whereas in the chronic stroke patients, only mean speed and NSP significantly improved. Values of the kinematic parameters at the sixth week in the subacute stroke patients did not differ from those recorded at the fourth week (Table 4).

Speed

Mean velocity in the xy plane significantly changed at the end of the treatment in both groups ($P < 0.05$). At the end of treatment, the patients executed movements at higher speed than at the beginning (Fig. 4). A statistically significant difference was found in the value change from admission and discharge both in the subacute and chronic stroke patients ($P < 0.05$), although no statistically significant difference was found between the groups.

Movement Smoothness

NSP significantly decreased at the end of the robot-aided treatment in both groups ($P < 0.05$). At the end of the treatment in both groups, movements were smoother than at the beginning of treatment because the reduction of NSP corresponds to a more regular velocity profile (Fig. 5).

No statistically significant difference was found in the value change from admission and discharge between the subacute and chronic stroke patients.

SM (Fig. 6) and AM (Fig. 7) significantly increased at the end of the robotic therapy in the subacute group ($P < 0.05$), but no statistically significant difference was observed in the chronic group at the end of the treatment.

These improvements in the subacute stroke patients can be linked to an increase in upper limb movement smoothness after the training. In detail, after the robot-assisted therapy, the speed profile becomes smoother, with shallower valleys between peaks in the subacute stroke patients, as shown by higher SM values. In the chronic stroke patients, the SM value did not increase.

No statistically significant differences were found in the value change between the start of treatment and the 20th session on both SM and AM discharge between the subacute and chronic stroke patients.

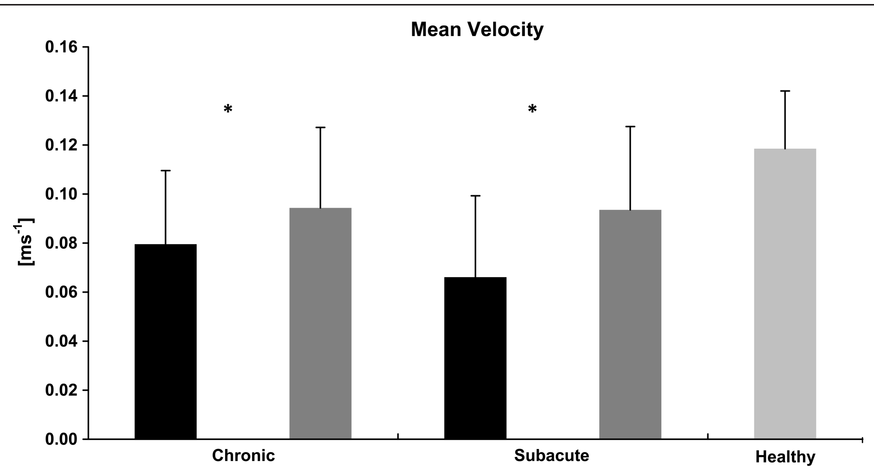

FIGURE 4 *Mean velocity and standard deviation of the chronic and subacute stroke patients at pretreatment (black) and posttreatment (dark gray) and of the healthy subjects (light gray); *P < 0.05.*

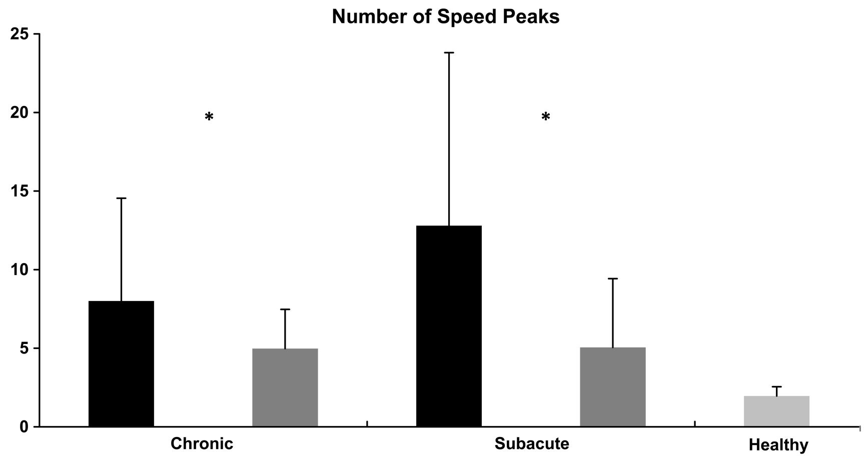

FIGURE 5 *NSP mean values and standard deviation of the chronic and subacute stroke patients at pretreatment (black) and posttreatment (dark gray) and of the healthy subjects (light gray); *P < 0.05.*

The abovementioned speed and smoothness parameters could be considered as qualitative indices of motor performances; after the treatment, their values move toward those recorded in the healthy subjects.

Movement Onset Time

The movement onset time decreases at the end of the robot-aided treatment (Fig. 8) in both groups ($P < 0.05$). This means that the patients reduced the latency period before starting the directed movement during the treatment. The movement onset time improved in both groups: the subacute stroke patients showed a significant ($P < 0.05$) mean decrease of approximately 1 sec, whereas the chronic stroke patients, starting with a lower mean value than that of the subacute stroke patients (approximately 1.5 secs) reached the same final value with a significant ($P < 0.05$) decrease. Because movement onset time could be considered as indirect evaluation of the anticipatory motor control level, such finding could be related to an improvement in movement planning capability.

Correlation Between Kinematic Parameters and Clinical Outcome Measures

Weak correlation values between changes in each metric and clinical scale (FM-UE and MI) were found. The Pearson product moment correlation coefficient ranges from −0.337 to 0.310; the Spearman rank correlation coefficient ranges from −0.208 to 0.043 (Table 5).

Obviously for this comparison, the kinematic parameters at the sixth week of treatment (30 sessions) for the subacute stroke patients were computed and compared with the changes in the clinical

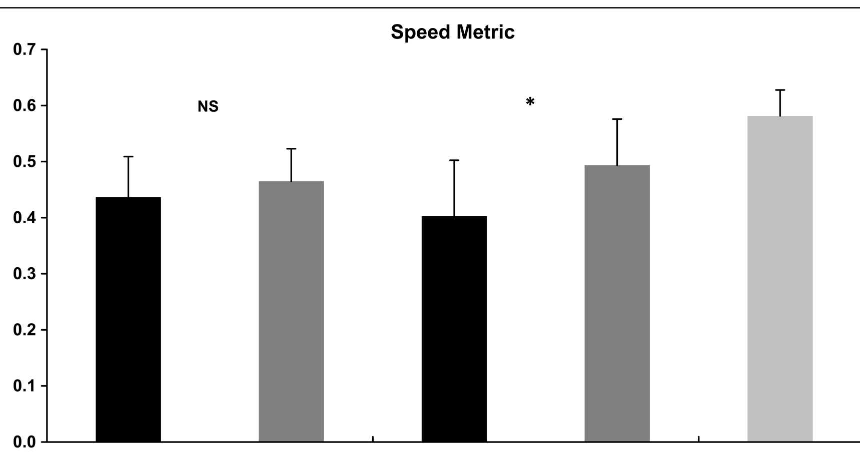

FIGURE 6 *SM mean values and standard deviation of the chronic and subacute stroke patients at pretreatment (black) and posttreatment (dark gray) and of the healthy subjects (light gray); *P < 0.05.*

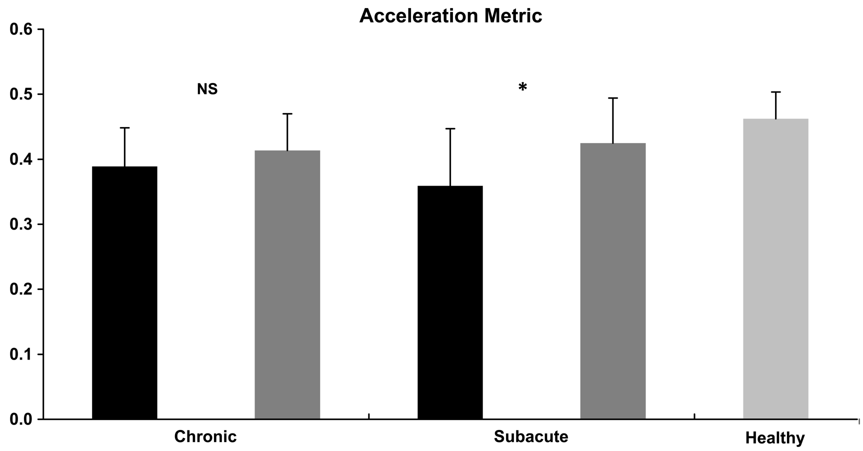

FIGURE 7 *AM mean values and standard deviation of the chronic and subacute stroke patients at pretreatment (black) and posttreatment (dark gray) and of the healthy subjects (light gray); *P < 0.05.*

outcome measures at the same time, whereas for the chronic stroke patients, the comparison between the clinical scales and the kinematic parameters was carried out at the fourth week (20 sessions).

DISCUSSION AND CONCLUSIONS

The results of this study show that both the subacute and chronic stroke patients significantly improved in the scores of the clinical scales and values of some kinematic parameters, which move toward the measure of the healthy population, as the treatment progressed.

The FM-UE scores significantly changed after the treatment in both groups, showing a reduction in the upper limb motor impairment. The FM-UE score in the subacute stroke patients significantly improved more than in the chronic stroke patients, as shown by two-way analysis of variance results. This finding can be as a result of the longer treatment provided to the former (6 wks) if compared with the latter (4 wks).

The MI scores did not change after the robot-assisted treatment in the chronic stroke patients, and no difference was found in the comparison between the subacute and chronic stroke patients: this finding may be explained by the lower sensitivity of MI to detect small changes.

The evaluation of the kinematic parameters performed after 20 sessions in both groups showed that all parameters significantly improved in the subacute group, between pretreatment and posttreatment, even if no statistically significant difference in the value change between the subacute and chronic stroke patients was found.

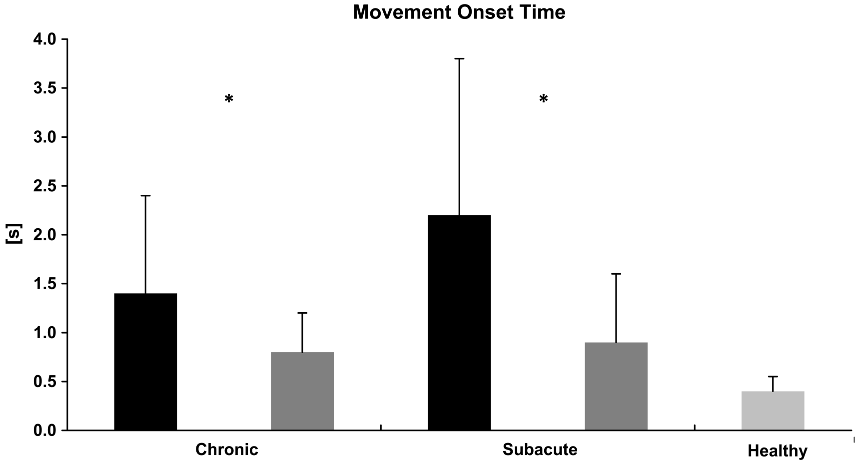

FIGURE 8 *Movement onset time mean values and standard deviation of the chronic and subacute stroke patients at pretreatment (black) and posttreatment (dark gray) and of the healthy subjects (light gray); *P < 0.05.*

TABLE 5 Correlation between changes in each metric and change in scale

	Chronic		Subacute	
	FM[a]	MI[a]	FM[a]	MI[b]
AM	0.117[c]	−0.236[c]	−0.217[c]	−0.208[c]
NSP	−0.016[c]	0.310[c]	0.028[c]	0.043[c]
SM	0.123[c]	−0.337[c]	−0.208[c]	−0.130[c]
v_{xy}, mean	0.069[c]	−0.159[c]	−0.040[c]	−0.078[c]

[a]Pearson correlation coefficient.
[b]Spearman rank correlation coefficient.
[c]$P > 0.05$.

In the group of the chronic stroke patients, only mean speed and NSP significantly changed, without any improvement in SM and AM, despite of a younger age.

The analysis of kinematic data performed after 30 sessions in the subacute stroke group did not show additional improvements compared with the values recorded after 20 sessions. This finding shows that a possible plateau could be reached after 4 wks of robot-assisted treatment in the subacute phase.

A possible explanation of this finding could be that a pathologic pattern already developed, which is responsible for generating higher speed peak, whereas the improvement in the quality of movements in the subacute group, whose motor performances approach more closely those of the healthy subjects compared with the chronic stroke patients, could be related to the lack of pathologic pattern, not yet developed.

The low correlation values found between the kinematic parameters and the clinical outcome measures used in this study can be explained on the basis of different observations' point of view. The former analyzes specific physical variables, which, quantifying qualitative movement features, are able to provide information concerning the use of compensation mechanisms; the latter are based on evaluations of movements, in which the contribution of distinct physical variables is not assessed, which can be performed without the identification of compensation mechanisms. Therefore, the changes in kinematic measures of movement do not represent the same changes in the subjects' performance.

In conclusion, the results of this study confirm the effectiveness of robotic therapy on the reduction of the upper limb motor impairment, both in the chronic and subacute stroke patients, providing an intensive and safe treatment.

Through the evaluation of the kinematic parameters, the subacute stroke patients showed an upper limb motor recovery characterized by values closer to those observed in the healthy subjects, thus reflecting a lower use of compensation mechanisms.

Therefore, an earlier start of rehabilitation treatments, besides avoiding the development of pathologic patterns, can also contribute to reach a better improvement in kinematic parameters, highlighting real motor recovery characterized by motor relearning and a reduced development of pathologic compensation mechanisms.

It is widely accepted that rehabilitation treatments have to be started as soon as possible after the acute event, but until now, no strong evidence for this assumption has been found. A wider range of neuroplasticity is supposed to be present at an early stage, and the lack of pathologic pattern development, characterized by spasticity; the change in the intrinsic characteristics of muscle fibers; and so on, could be responsible for a worst outcome of rehabilitative treatment if started in the chronic stage.

On the other hand, the rehabilitation intervention in later stages is now receiving increased attention because further reduction in the motor impairment seems to be possible after 1 yr or more, provided that an intensive treatment is delivered.

The measurement of outcome in neurorehabiliation is becoming a field of interest because different tools that are able to measure the changes at different levels are currently available.

Clinical assessment scales are commonly used, but special attention must be paid to the choice of the target level to be measured: body function and structure (e.g., FM Assessment Scale), ability (e.g., Barthel Index), or participation level (e.g., Quality of Life Questionnaires).

On the other hand, the evaluation of kinematic and kinetic parameters for the upper limb is not common as for the gait analysis, in which the kinematic parameters are recorded in a session separate from those used during the rehabilitation training, and the effectiveness of treatment on the upper extremity is quite often assessed using only clinical scales.

One possible explanation for the less attention reserved to the study of the upper limb motor performances can be attributed to the difficult implementation of tasks performed through closed kinematic chain for shoulder and elbow movements, which would result in movements unusually performed in activities of daily living.

Therefore, robotic systems for rehabilitation represent useful tools both for delivery of treatments and assessment of patients' motor performances based on the evaluation of changes in kinematic parameters.

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