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Quantitative assessment of the EMG patterns of upper limb muscles during robotic rehabilitation

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***Abstract* – Human upper limb is involved in many daily human activities. The muscle activities during basic and daily upper-limb motions are an important area of research in rehabilitation field in order to evaluate the recovery of patients affected by congenital or acquired brain injury. Much better results in sensorimotor and cognitive processes are promised by the emerging robot-mediated therapy. Although the shoulder is the most complex joint in the body, both as to freedom range and for the muscular-tendon structure, not so many research devices have been proposed to study its movements and no study has proposed standardized electromyographic assessment during robot-assisted reaching movements of the upper arm. This study aimed to develop a quantitative assessment of the electromyographic pattern of the arm's muscles involved in reaching movements robot-assisted by means of indices used to describe effectively the main features of the pattern in five normal subjects to implement rehabilitation strategies patients oriented.**

I. INTRODUCTION

Human upper limb consists of several degrees of freedom (DOF); basically 3DOF in the shoulder joint, 2DOF in the elbow joint and 2DOF in the wrist joint. The basic motions of upper-limb can be categorized into eight individual motions and is activated by many kinds of muscles. Some of them are bi-articular muscles and the others are uni-articular [1]. The upper-limb motions are very important for the human daily activities, such as eating, drinking, brushing teeth, combing hair and washing face. It is sometimes difficult for physically weak elderly, disabled, and injured individuals to perform daily upper-limb activities. However, it is important that physically weak individuals are able to take care of themselves in the present society in which the number of physically weak population is increasing and the number of young population is decreasing. Recently, many power-assist robotic systems have been developed to assist daily life motions and/or rehabilitation of physically weak persons [2-6]. Particularly, among those currently available, we can mention 1) the mirror image motion enabler (MIME) robots [7], developed for unrestricted unilateral or bilateral 2D shoulder and elbow movement; 2) the Bi-Manu-Track [8], enabling the bilateral passive and active practice of forearm and wrist movement; and 3) the Gentle/s system [9], which can provide robot mediated motor tasks in a three dimensional space. Robotic devices are capable of guiding or perturbing movements of a patient's upper limb and can record motions and mechanical quantities such as position, velocity and forces applied. RMT can play a role particularly relevant in the rehabilitation of the upper limb by means of specific exercises [10;11] allowing quantitative kinematic evaluations to estimate the patient's progress, while traditional clinical scales permit only qualitative and potentially disagreeing evaluations[12]. Many robotic systems have been used to promote motor recovery and quantify treatment efficacy in patients affected by congenital or acquired brain injury, such as stroke [13-14]. Although all these systems showed that stroke involves abnormal and stereotypical upper limb movement patterns that impact the performance of activities of daily living, at the best of our knowledge, no studies proposed a standardized quantitative electromyographic evaluation during robot assisted upper arm reaching movements.

This study aimed to develop a quantitative assessment of the electromyographic pattern of upper limb muscles involved in robot assisted reaching movements by means of indexes useful to evaluate changes in muscle activation, underlying improvements in muscle strength and function, and to implement targeted patients oriented rehabilitative approaches.

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II. MATHERIALS AND METHODS

A. Shoulder Rehabilitation Device

The shoulder rehabilitation device used for this study was the Multi-Joint-System (MJS) of the Tecnobody (Fig.1). Its mechanical arm is provided with four freedom ranges, giving the patient freedom of joint movement in the three fundamental axes of movement (Anterior-Posterior, Adduction-Abduction, Internal rotation-External rotation).

Figure 1. subject under test sit at the Tecnobody MJS robot with applied telemetric EMG electrodes on the studied muscles.

B. Motor Tasks and Training Protocol

We studied five healthy subjects (3 males and 1 female). Each subject underwent to 2 sessions, with at least intervals of 15‘ of resting time between them. Each session was composed by 4 reaching tasks (2 horizontal and 2 vertical). During the exercise, subjects were asked to seat on the ergonomic robot chair with the trunk erected, neck straight fixing the central green starting point on the front monitor. The arm under test holding the robot grip by the hand in a position parallel to the floor at 90° with the trunk, the arm not under test on side handle close to the seat. Kinematic task consists on a visually-guided planar reaching task. Four targets were equally spaced of 30° from a center target and visual feedback of both target and robot handle location were provided on a computer screen in front of the robot. The task required each subject to move his arm from the center position to the target and then return to the center with an 8 movements sequence (Table I) exploring horizontal flex-extension and vertical adduction-abduction movements of the shoulder joint. We assumed the handle position right on the target if within 1 cm radius from the target circle for more than 100 ms, as indicated by an audiovisual biofeedback.

Table I. Description of the eight movements sequence.

Task	Description
RH1	Horizontal abduction of the right (left) shoulder from the middle position to the outer right (left)
LH1	Horizontal adduction of the right (left) shoulder from the right external position (left) to the center
UV1	Elevation of the shoulder from the middle position to the top
DV1	Lower down of the shoulder towards the middle position
LH2	Horizontal abduction of the right (left) shoulder from the middle position to left (right) external one
RH2	Horizontal adduction of the right (left) shoulder from the outer left (right) position to the middle one
DV2	Lower down of the shoulder from the middle position to the bottom
UV2	Elevation of the shoulder from the bottom towards the middle position

Experimental setting consisted in simultaneously triggered recordings of both kinematics and electromyographic signals during the above described motor tasks. Kinematic information was derived by MJS with two signals corresponding to the vertical anterior-posterior and horizontal adduction-abduction handgrip position, with a 1/10° degree resolution and a sampling rate of 20 Hz. Eight EMG channels were acquired by a wireless BTS Freemg 300 system with variable geometry mounting clip surfaces electrode, 16-bit resolution, 1 kHz sampling rate, in the 10-400 Hz frequency band, over the main muscles involved in the above described motor task and exactly: sternal and clavicular major pectoralis (SP and CP), medial and descending trapezius (MT and DT), brachial triceps (BT), brachial biceps (BB), anterior and medial deltoid (AD and MD). All surface EMG recordings have been performed according to SENIAM recommendation [15].

The onset and end times of movements of the kinematic phases were automatically detected and classified by means of an algorithm based on the bell-shaped velocity profile, as previously elsewhere described [16-21]. Differently from commonly used methods [20], the acquired EMG signals has been filtered by a high pass forth order Butterworth 10 Hz cutoff filtering, removing motions artefacts. The linear envelope (LE) has been computed by rectifying the signal with a digital rectifier (absolute value) and filtering via a low-pass filter with 8 Hz cutoff. Algorithms usually proposed [22] consider a muscle activation in case of an EMG amplitude higher than basal activity plus 3 times its standard deviation for about 30 ms.

However, this solution does not fit the muscular effort required to initially hold the arm in the exercise starting position, leading to a confounding identification of activation/deactivation muscle's patterns. To overcome the above problem, concerning the baseline activity epoch selection, two different thresholds have been used so defined:

1. **activity threshold** = mean (EMG) + std (EMG)/2
2. **resting threshold** = mean (EMG) - std (EMG)/2

These thresholds distinguish the EMG signals into three different areas representing different muscle activation levels: 1) a *basal area*, with the muscle activity inside the two thresholds, representing the basal activity necessary to maintain the initial central position of the robotic arm; 2) an *active area*, with the muscle activity above the activity threshold, corresponding to the muscular effort required for reaching movements; 3) a *resting area*, with the muscle activity below the resting threshold, corresponding to a muscle relaxation. We identified EMG activation/deactivation in case of thresholds exceeding longer than 200 ms. The quantitative analysis of the muscle patterns have been described by means of the following three indices:

- **EMG-active time (EAT)**: duration of the muscle activations of each particular reaching movement, ranging between [0-1] where 0 value is relative to the start position and 1 value is relative to the end of the reaching movement.

- **EMG-area(EA)**: areas of the muscle activations related to the particular reaching movement ranging between [0-1] where 0 value is relative to "lack of activation" and 1 value indicates the activation of the muscle for the entire duration of the movement

- **EMG-max index (EM)**: position of the maximum muscle activation in each movement.

III. RESULTS AND DISCUSSIONS

The system has been tested on 5 healthy subjects. Each subject underwent the above described motor task and EMG recording for an total of 80 reaching movements. The following results are referred only to the activations phases. In Table II are reported the indices computed on EMG signals.

RH1: to make a movement so complex capable of bringing the arm out of body axis, it is needed the joint work of all muscles analyzed except sternal and clavicular major pectoralis. The muscles mainly involved are the anterior and medial deltoid, involving more than half the length of the movement (Fig.2).

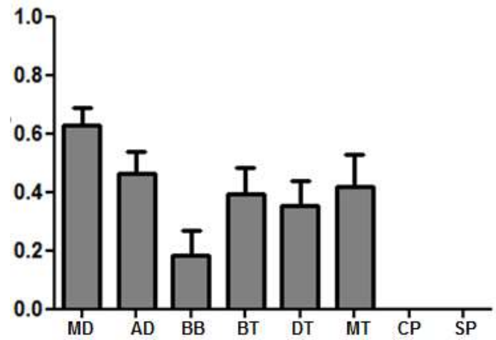

Fig.2 EMG-active time in RH1.

LH1: to move the arm in resting position all the muscles retain almost the basal activity except that the brachial bicep active for about half of the phase kinematic (Fig.3). Sternal and clavicular major pectoralis and medial trapezius resulted relaxed.

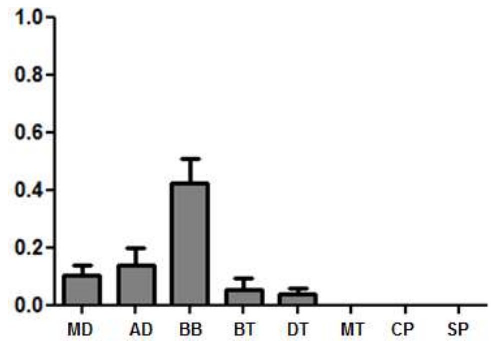

Fig.3 EMG-active time in LH1.

LH2: anterior and medial deltoid, biceps, triceps sternal and clavicular pectoralis are active while the medial and descending trapezius (both active in RH1) resulted relaxed. The muscle mainly involved are sternal and clavicular major pectoralis which are both inactive in RH1.

RH2: the return to the resting position involves a reduction of muscle activity of all muscles while descending trapezius results inactive.

UV1: in this movement all muscles are active except the pectolaris. Each muscle is activated for almost the entire kinematic phase, particularly the deltoid and descending trapezius, and this is probably due to the presence of gravity that hinders movement (see also Fig.4).

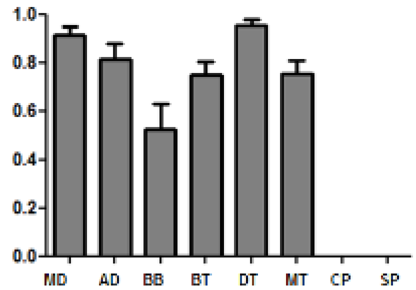

Fig.4 EMG-active time in UV1

DV1: the biceps is the only muscle contributing to this movement, while everyone else are relaxed. This behavior is due to the simple reason that the arm movement is facilitated by the presence of the gravitational force that acts in the same direction of motion.

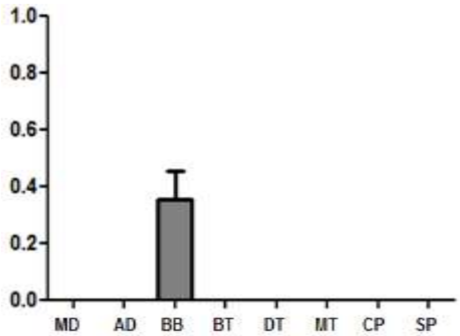

Fig.5 EMG-active time in DV1

DV2: the gravitational force facilitates the movement (Fig.5). The results is that only the biceps, although minimally, is active while the other muscles retain the basal activity.

UV2: all muscles are active except the pectoralis maintaining their basal activity and The muscle mainly involved are medial and descending trapezius.

This study has allowed us to highlight which are the muscles that are mainly involved in the point-to-point reaching movements. The results shown such as to make RH1and LH1 it is needed the joint work of all analyzed muscles. Very interesting is the behavior of the pectoralis that are not very active during the horizontal movements and are non-active during gravitary/anti-gravitary movements. Moreover, the gravitational force facilitates the anti-gravitary movements, so during this movement the only muscular group that appears to be active is the brachial bicep, while the other muscles maintain the basal activity. These results could lead to minimize the number of muscles to be analyzed thus simplifying the experimental setup (number surfaces electrode for EMG), speeding the clinical evaluation in healthy and pathological subjects and to help to better plan the robot aided rehabilitation exercises. The recording of EMG pattern, additionally to usually evaluated kinematics indexes, may provide very useful information in upper arm rehabilitation protocols. The proposed method showed to effectively describe the main pattern's features in normal subjects.

Future developments must be addressed to study the deactivation patterns and to focus to novel indexes in deeper clinical evaluation of patients during fine movements assessment.

		MD	AD	BB
RH1	**EAT**	0.63±0.2	0.46±0.24	0.18±0.27
	EA	0.69±0.18	0.55±0.27	0.21±0.2
	EM	0.60±0.16	0.62±0.26	0.40±0.3
LH1	**EAT**	0.10±0.12	0.14±0.20	0.42±0.26
	EA	0.12±0.14	0.2±0.15	0.49±0.25
	EM	0.10±0.13	0.11±0.17	0.30±0.30
RH2	**EAT**	0.10±0.10	0.10±0.10	0.2±0.20
	EA	0.10±0.10	0.10±0.10	0.21±0.31
	EM	0.11±0.23	0.14±0.30	0.40±0.40
LH2	**EAT**	0.11±0.18	0.64±0.19	0.33±0.30
	EA	0.13±0.21	0.72±0.19	0.35±0.30
	EM	0.27±0.44	0.64±0.11	0.30±0.37
UV1	**EAT**	0.91±0.11	0.81±0.21	0.52±0.33
	EA	0.93±0.10	0.85±0.18	0.55±0.33
	EM	0.53±0.21	0.54±0.25	0.36±0.29
UV2	**EAT**	0.17±0.25	0.22±0.33	0.26±0.40
	EA	0.20±0.29	0.24±0.35	0.27±0.40
	EM	0.17±0.23	0.11±0.18	0.15±0.23
DV1	**EAT**	0	0	0.32±0.31
	EA	0	0	0.30±0.30
	EM	0	0	0.40±0.40
DV2	**EAT**	0	0	0.20±0.30
	EA	0	0	0.20±0.30
	EM	0	0	0.10±0.10

		BT	DT	MT
RH1	**EAT**	0.39±0.29	0.35±0.28	0.42±0.35
	EA	0.45±0.31	0.40±0.30	0.44±0.35
	EM	0.56±0.30	0.53±0.30	0.44±0.28
LH1	**EAT**	0.10±0.10	0.10±0.10	0
	EA	0.10±0.10	0.10±0.10	0
	EM	0.10±0.10	0.12±0.31	0
RH2	**EAT**	0.24±0.24	0	0.27±0.27
	EA	0.27±0.26	0	0.31±0.29
	EM	0.26±0.31	0	0.44±0.31
LH2	**EAT**	0.10±0.10	0	0
	EA	0.13±0.18	0	0
	EM	0.31±0.40	0	0
UV1	**EAT**	0.75±0.17	0.95±0.10	0.76±0.16
	EA	0.80±0.15	0.97±0.10	0.80±0.14
	EM	0.60±0.18	0.49±0.18	0.50±0.25
UV2	**EAT**	0.3±0.30	0.70±0.13	0.81±0.16
	EA	0.32±0.34	0.77±0.11	0.85±0.13
	EM	0.36±0.31	0.35±0.20	0.28±0.25
DV1	**EAT**	0	0	0
	EA	0	0	0
	EM	0	0	0
DV2	**EAT**	0	0	0
	EA	0	0	0
	EM	0	0	0

		CP	SP
RH1	**EAT**	0	0
	EA	0	0
	EM	0	0
LH1	**EAT**	0	0
	EA	0	0
	EM	0	0
RH2	**EAT**	0.10±0.10	0.10±0.10
	EA	0.13±0.27	0.13±0.22
	EM	0.10±0.10	0.10±0.10
LH2	**EAT**	0.85±0.15	0.84±0.13
	EA	0.9±0.10	0.9±0.10
	EM	0.66±0.10	0.68±0.12
UV1	**EAT**	0	0
	EA	0	0
	EM	0	0
UV2	**EAT**	0	0
	EA	0	0
	EM	0	0
DV1	**EAT**	0	0
	EA	0	0
	EM	0	0
DV2	**EAT**	0	0
	EA	0	0
	EM	0	0

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