Analysis of Upper Limb Contraction Pattern Using Electromyographic Signal during Activities of Daily Living: a Pilot Study

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***Abstract*— The upper limb is extremely important in the performance of Activities of Daily Living (ADLs), and its function is highly compromised when considering the sequelae of neuromotor diseases. It is essential to obtain more accurate information about the contraction patterns of the upper limb in healthy individuals, for a better understanding and assessment of the movements performed during ADLs in pathological situations, since conventional assessment methods do not provide objective data on the patient's performance. The integration of technological devices in the assessment of the contraction pattern will be an asset in obtaining more accurate information to expand our ability to know, predict and diagnose health conditions. A pilot study was conducted to characterize upper limb neuromotor biosignals during five ADLs in 18 healthy individuals. The BiosignalsPlux device was used to monitor the contraction pattern of the shoulder muscles by means of electromyography (EMG). Thus, the main objective of this article is to describe the results of the application of an experimental protocol to analyze the contraction pattern of six shoulder muscles during ADLs, through the electromyographic signal. Through this study, differences were verified in the patterns of muscle activation amplitude between ADLs directed to the midline, between ADLs directed to the contralateral side, as well as between these two groups of activities.**

Keywords- upper limb; electromyography; technology, activities of daily living, biomechanics.

I. INTRODUCTION

The performance and participation in Activities of Daily Living (ADLs) are strongly affected by the limitation of functional movements of the upper limb [1]. Functional use of the upper limb is highly compromised when considering stroke sequelae [2]. It is estimated that this affects about 80% of acute patients and 40% of chronic patients after stroke [3].

Upper limb paresis after stroke is characterized by decreased muscle strength [4] and loss of autonomy in ADLs [5]. About 37%-55% of subjects with stroke have deficits in the performance of these activities [6]. These deficits in the performance are related to the omission of small actions, changes in the sequence and in the quality of their performance, as demonstrated in studies related to the preparation of meals [7] and hygiene [8].

Impairment and disability in clinical settings are generally assessed by ordinal scales that are not very sensitive to the smallest and most specific changes [9]. More objective assessment methods are needed to evaluate and describe the upper limb function in detail [10].

An important factor for a better understanding and assessment of movements performed during ADLs, in pathological situations, is to understand the characteristics of the contraction patterns of the upper limb in healthy individuals in these same activities. The integration of technological devices that make it possible to obtain more accurate data about the contraction patterns in healthy subjects is extremely important here, since the expansion of knowledge about the contraction pattern in ADLs is only achieved through this type of information, so that later, in pathological conditions, we can predict and diagnose the changes more objectively.

A. Data analysis of upper limb movement in ADLs

Several studies have been performed using technology to study upper limb performance during functional tasks related to ADLs [10]-[16]. Although these studies are directed to the analysis of upper limb functionality, most of them focus on the study of kinetic and kinematic parameters and not on biosignals. Mainly using only technological tools such as optoelectronic motion analysis systems and inertial measurement sensors (3D accelerometer, 3D magnetometer and 3D gyroscope) [10]-[12][14][15]. However, they focus

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their analysis only on the performance of the activity, drinking from a glass [10]-[13][15] and only two of them analyzed the pattern of contraction of the muscles of the upper limb in ADLs [13][16], using surface electromyography (EMG).

Although kinematic analysis and kinetic analysis provide us with very relevant information in movement analysis, only through EMG can we know the amplitude of muscle activation of a group of muscles involved in ADLs.

EMG is the measurement of the electrical signal associated with muscle activity. Muscle excitation is then analyzed through the amplitude of the EMG signals, which means that the more motor units are recruited and the higher the firing rates, the greater the contraction by the muscle [17]. Through the EMG signal, muscle contraction and relaxation data are obtained, indicating whether the muscle is actively participating in the execution of the movement.

B. Analysis of the muscle activation amplitude of the upper limb in ADLs

According to one of the studies found [13], the sequence of muscle activation amplitude in the activity of drinking water from a glass, differs between subjects with and without stroke, regarding shoulder and arm muscles. In shoulder muscles, Superior Trapezius is activated throughout the activity, contrary to healthy subjects, who only activate in the phases of taking the glass to the mouth and returning to the table. The deltoids (anterior, middle, and posterior) in individuals with stroke are activated in the phases of "initial position to reach", "reach for the cup", "carry to mouth", while the control group only activates the anterior deltoid in the two first phases, the middle deltoid in the third phase and the posterior deltoid in the "return to pick up point" and "return hand to initial position".

In the study that our team developed previously [16] but in only one healthy individual, the results are indicative of differences in the pattern of activation amplitude between ADLs directed to the midline (drinking from a cup, eating soup and brushing teeth), between ADLs directed to the contralateral side (brushing the hair on the contralateral side of the head and washing the contralateral upper limb), as well as between these two groups of activities. In this study, two parameters were used to characterize the pattern of muscle contraction, the maximum peak of contraction amplitude (mV), that is, the maximum contraction amplitude verified in each of the muscles, as well as the time (s) in which these same maximums occur during the ADLs performance, which makes it possible to perceive the sequence of maximum amplitude of contraction activation of each muscle during the activity.

To better understand and evaluate the compensatory motor strategies developed by patients with neuromotor disorders, such as stroke, and to verify an inadequate pattern of muscle activation during ADLs, it is necessary to know the normal pattern of muscle activation in these activities, in healthy individuals. These compensatory motor strategies are very common in stroke patients and can cause severe musculoskeletal disorders, worsening the functional status of patients [18]. Therefore, it is essential that these compensatory patterns are detected early, thus preventing the installation of other types of dysfunctions resulting from stroke.

Biosignals give thus valuable information that provides a better perception of the patient's clinical status, constituting an important tool for clinical decision-making and measurement of the evolution resulting from clinical intervention [19].

The issue of this investigation focuses on exploring the applicability of the protocol [16] and characterizing the muscle activation pattern in healthy individuals in ADLs. This study aims to analyze and explore the characteristics (amplitude and sequence of muscle activation peaks) of the activation pattern of the electromyographic activity of the shoulder main muscles [20] during ADLs (eating, drinking, dressing and personal care) [21] in healthy individuals.

This article describes in Section 2, the materials, and methods (participants, equipment, and the experimental procedure of the investigation), in Section 3 the results, in Section 5, the discussion of them from a critical perspective and in Section 6 the main conclusions and perspectives.

II. MATERIALS AND METHODS

This study was previously approved by the Ethics Committee and the Board of Directors of NOVA School of Science and Technology at NOVA University of Lisbon, and data collection was carried out at the same university.

A. Characterization of the Sample

This protocol was applied to 24 healthy adult subjects, selected for convenience. Of these individuals, 6 were excluded due to failure to capture the EMG signal during activities, leaving the sample with n=18 individuals. As exclusion criteria, diagnosis of neuromotor, cognitive or language deficits and changes in visual acuity not compensated by glasses or contact lenses were defined. The volunteer joined the study after reading and signing the informed consent.

The 18 participants who make up the sample of this study present the following characteristics: mean age of 29.1 years ± 3.2 in a range 19-62 years, in which 6 men and 12 women, 17 were dominant right-handers.

B. Instruments

To collect the EMG signals, the Biosignalsplux device was used, wirelessly connected to the OpenSignals (r)evolution software, for data acquisition, visualization, and processing, being a specific software for PLUX biosignal hardware platforms [22]. 6 channels were used to record bipolar EMG related to 6 different muscles and the signal was collected at a sample frequency of 1000Hz. [13].

The electrodes were placed 2 cm apart [23], according to the agonist muscles of the main shoulder movements namely the Pectoralis Major (PM), Anterior Deltoid (AD), Middle Deltoid (MD), Posterior Deltoid (PD), Upper Trapezius (UT) and Lower Trapezius (LT), responsible for flexion (F), extension (E), abduction (ABD), adduction (AD), scapular elevation (SE), and scapular depression (SD) [19].

C. Experimetal Procedure

The procedures for carrying out this study consisted of:

- Participants first performed activities directed to the midline (drinking from a cup, having soup, brushing teeth) and then to the contralateral side (brushing hair and washing the contralateral side), with the dominant limb [16].
- During the tests of activities directed to the midline, the subjects will be seated in a chair without an armrest (40 cm high) with the dorso-lumbar region of the spine supported on the back of the chair, next to a table (75 cm height), with the feet well supported on the floor, knees and hips flexed at 90º. The upper limbs are placed on the table, assuming as the initial position the shoulder in neutral position, elbow flexed at 90º, forearm in pronation, wrist in neutral position and two in extension.
- In activities directed to the contralateral side, participants are seated in a chair, in the same position as in the previous activities, but away from the table. The upper limbs are supported on the thighs, shoulders in a neutral position, elbows flexed at 45º, forearms and wrists in a neutral position and fingers semi-flexed. In these activities, only an object (hairbrush) is used, which is in the subject's hand in the initial position. To carry out these activities, a glass cup, a metal spoon, a soup bowl, a toothbrush, a toothpaste, and a hairbrush were selected as materials (Table I).
- The materials will be placed before the start of the rehearsal of each of the respective activities, in the respective marks on the table towards the midline of the subjects' body: the cup at the 8x8cm mark 30 cm from the edge of the table, the soup bowl at the 14x14 cm mark at 3 cm from the edge of the table and the toothbrush and toothpaste in the same mark.
- Before data collection, each activity is explained and given the opportunity to perform the movement so that subjects feel comfortable with the execution of it [10].
- Participants will be instructed to perform 5 trials in each of the 5 activities, making a total of 20 trials.
- Once the subjects are ready, the command "you can start now" is given and the subject will perform the activity at a speed comfortable for him/herself and five trials are collected.
- Between each trial, subjects will have a 2-minute rest period and a further rest period (5 minutes) between the set of activities aimed at the midline and activities aimed at the contralateral side to minimize muscle fatigue.

D. Activities performed

The activities performed by the participants consist of complex movements of the joints of the upper limbs. Considering their complexity, it is important to distinguish their phases [11][24] (Table I), as well as the respective movements performed by the shoulder [20] (Table II).

TABLE I. ACTIVITY PHASES IN ADLS

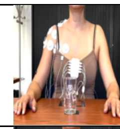
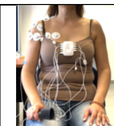
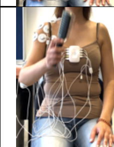
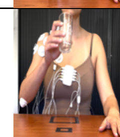
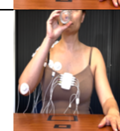
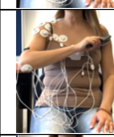
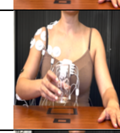
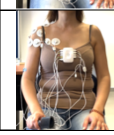
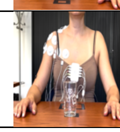
Activities Phases			
Activities to the midline		***Activities to the contralateral side***	
1.Starting position to reaching		1.Grasping	
2.Grasping		2.Transporting to the contralateral side	
3.Transporting to the mouth		3.Reaching the contralateral side	
4.Introduced in the mouth		4.Return to the thigh	
5.Return to the pick point		5.Return to initial position	
6.Return to initial position			

TABLE II. EXPECTED MOVEMENTS BY PHASE.

Activity phases	**Activities to the midline**		
	Drinking	***Eating soup***	***Brushing teeth***
1.Starting position to reaching	AD, F	AD, F, SE	AD, F, SE
2. Grasping	AD, F, SE	AD, F, SE	AD, SE, F
2. Introduced to the mouth	F, ABD, SE	F, ABD SE	F, ABD, SE
4.Transporting to the mouth	F, ABD, SE	F, ABD SE	F, ABD, SE
5. Return to the pick point	AD, E, SE	AD, E, SE	AD, E, SE
6. Return to the initial position	E, SE, ABD	E, SE, ABD	E, SE, ABD
Activity phases	**Activities to the contralateral side**		
	Drinking	***Eating soup***	***Brushing teeth***
1.Grasping	AD	AD	AD
2. Transporting to the contralateral side	F, AD, SE	F, AD, SE	F, AD, SE
3.Reaching the contralateral side	F, AD, SE	F, AD, SE	F, AD, SE
4.Return to the thigh	E,ABD, SD	E, ABD, SD	E, ABD, SD
5.Return to initial position	E,ABD, SD	E, ABD, SD	E, ABD, SD

TABLE III. MEANS OF THE AMPLITUDE AND TIME OF PEAKS OF MAXIMUM AMPLITUDE.

	Activities to the midline					
	Drinking		***Eating soup***		***Brushing teeth***	
	Amplitude contraction peak (mV)	Time amplitude peak (s)	Amplitude contraction peak (mV)	Time amplitude peak (s)	Amplitude contraction peak (mV)	Time amplitude peak (s)
Pectoral Major	367 ±37	2.83 ±0,25	639 ±408	3.08 ±0,30	448 ±90	3.57 ±0,20
Anterior Deltoid	1970 ±218	2.42 ± 0,08	1665 ±239	2.73 ±0,23	1355 ±138	4.13 ±0,33
Middle Deltoid	1203, ±134	2.96 ±0,26	1144 ±132	2.30 ±0,26	757 ±63	5.05 ±0,46
Posterior Deltoid	413 ±39	3.43 ±0,28	402 ±42	2.24 ±0,22	341 ±34	4.01 ±0,55
Upper Trapezius	1893 ±265	2.56 ±0,24	2244 ±337	2.53 ±0,17	1976 ±238	4.42 ±0,41
Lower Trapezius	532 ±83	2.71 ±0,29	375 ±56	2.88 ±0,37	1445 ±1005	3.55 ±0,50

TABLE IV. MEANS OF THE AMPLITUDE AND TIME OF PEAKS OF MAXIMUM AMPLITUDE.

	Activities to the contralateral side			
	Arm washing		***Brushing the hair***	
	Amplitude contraction peak (mV)	Time amplitude peak (s)	Amplitude contraction peak (mV)	Time amplitude peak (s)
Pectoral Major	1190 ±181	1.72 ±0.10	855 ±135	1.71 ±0.10
Anterior Deltoid	2171 ±23	1.46 ±0.71	3134 ±360	1.52 ±0.80
Middle Deltoid	1112±117	2.20 ±2.67	1891 ±220	1.67 ±0.10
Posterior Deltoid	538 ±80	2.15 ±0.27	550 ±44	1.92 ±0.25
Upper Trapezius	1216 ±145	1.88 ±0.28	1952 ±269	1.57 ±0.16
Lower Trapezius	382 ±40	1.73 ±0.16	413 ±46	1.59 ±0.10

E. Signal Analysis

MATLAB software, version R2022a, was used to process the EMG signals. The files were imported into this software, and channels related to the EM activity were selected for each of the activity.

After selecting the epoch of 7000 points corresponding to the activity (part of the signal to be analyzed), the sample points were transformed into units of time (s), the mean of the signal was subtracted, the signal was placed in absolute values, and a moving mean was applied at the same.

Although most studies opt for a normalization of the contraction amplitude, we chose to obtain the values of the maximum peak amplitude (mV) of activation of each of the analyzed muscles and the time (s) in which they were in the activity, considering it as an advantage to be able to compare our results with the results of the previous study [16].

For the descriptive statistical treatment of data (mean and standard deviation) the Statistical Package for the Social Sciences (SPSS) software, version 28, was used.

III. RESULTS

The information on the maximum amplitude peaks (mV) of each muscle and the time (s) at which they occur during the performance of activities are presented in Table III (ADLs for the midline) and in Table IV (ADLs for the side contralateral). Graphs are also presented that exemplify, in a subject, the signal obtained in each of the ADLs performed, Figures 1, 2 and 3 (ADLs directed to the midline) and Figures 5 and 6 (ADLs directed to the contralateral side). It is verified in Table III that the ADLs directed to the midline (drinking from a glass, eating soup and brushing teeth) present a sequence of the average of the peaks of maximum amplitude of muscle activation that are different from each other, as well as the temporal sequence in which they occur also differs between them.

The only similarity verified is related to the muscles that present greater amplitude peaks, that is, the AD, UT, and MD (drinking from a glass and eating soup are common). The activity of brushing the teeth has in common with the two previous activities the UT and the AD (Table III).

Like with the previous activities, in Table IV, it is verified that ADLs directed to the contralateral side (washing the arm and brushing the hair) present a sequence of the average of the peaks of maximum amplitude of muscle activation that are also different from each other, as well as the temporal sequence in which they occur. The only similarity is the fact that the AD and UT are among the muscles that reach the highest amplitude peaks during the activity, as well as the PD and the LT among those that reach the lowest amplitude (Table IV).

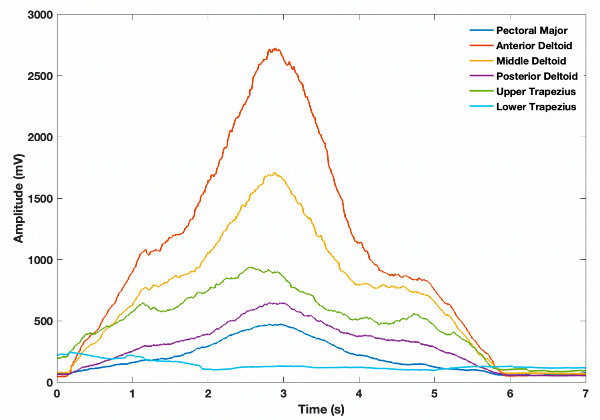


Figure 1. Amplitude pattern of muscle activation over time of drinking from a cup activity

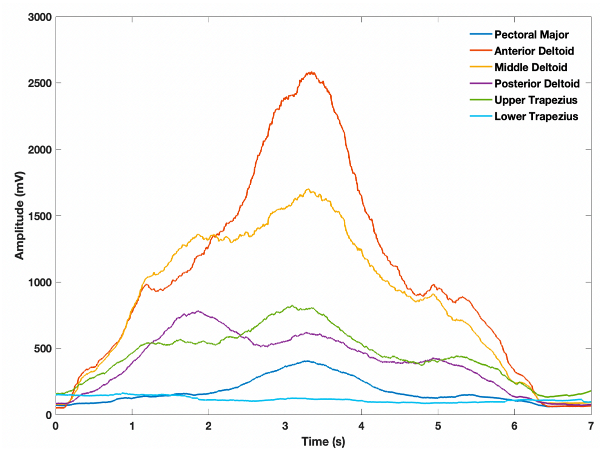


Figure 2. Amplitude pattern of muscle activation over time of eating soup activity.

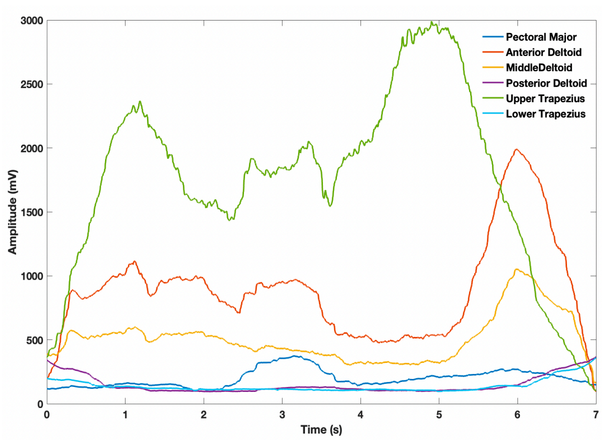


Figure 3. Amplitude pattern of muscle activation over time of brushing teeth activity.

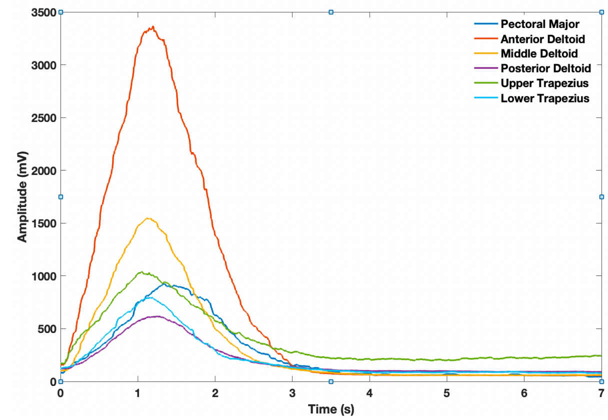


Figure 4. Amplitude pattern of muscle activation over time of washing the upper limb activity

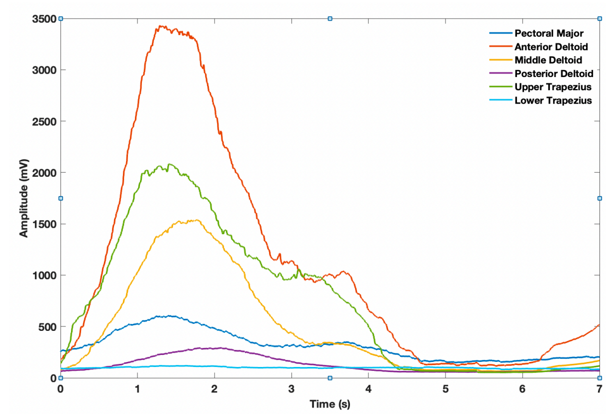


Figure 5. Amplitude pattern of muscle activation over time of brushing hair activity.

Regarding the period in which the average peaks of maximum muscle activation amplitude are found during the activity, we can see in Table III that the ADLs directed to the midline occur between 2.24s and 5.05s. In the activity of drinking from a glass, they occur in the interval of 1.01s (2.42s ± 0.08s and 3.43s ±0.28s), in eating the soup between 0.84s (2.24s ±0.22s and 3.08s ±0.30s) and brushing the teeth. between 1.5s (3.55s ±0.50s and 5.05s ±0.46s).

In the ADLs directed to the contralateral side, it is verified in Table IV, that the averages of the maximum amplitude peaks of muscular activation occur between 1.46s and 2.25s. In the activity of arm washing, they occur in the interval of 0.79s (1.46s ±0.71s and 2.20s ±2.67s), in brushing the hair between 0.4s (1.52s ±0.80s and 1.92s ±0.25s).

Regarding the pattern of muscle amplitude activation, five graphs representing the muscle activation pattern of one of the subjects, for each of the five ADLs, are presented. In these graphs, in all activities, there is a phase corresponding to the increase in muscle activation amplitude, in which after

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each muscle reaches it maximum amplitude (Tables III and IV), there is a decrease in it. This can be seen in Figure 1 (drinking), Figure 2 (eating soup) and Figure 3 (brushing teeth), corresponding to ADLs directed to the midline. Figure 4 (washing the arm) and Figure 5 (brushing the hair) concern ADLs directed to the contralateral side.

IV. DISCUSSION AND CRITICAL PERSPECTIVE

Regarding the analysis of the average times in which the maximum amplitude peaks occur, it is verified that in the ADLs directed to the midline, such as drinking or eating soup, the muscles reach an average of their maximum activation peaks at around 2 to 3 seconds. This reinforces the results of previous studies [16]. However, the same is not verified for the activity of brushing teeth, in which the time interval corresponding to the average in which the peaks of maximum amplitude occur is around 3 to 5 seconds (Table III).

In ADLs directed to the contralateral side, the average time in which the peaks of amplitude occur are between 1 and 2 seconds, which corroborates previous studies [16]. The results referring to the period in which the peaks occur are indicative that there are two marked phases in all activities. These phases are also represented in the graphs that constitute examples of the signal collected in each of the activities.

The first phase, in which there is an increase in the amplitude of muscle activation, corresponds to an increase in contraction. A second phase follows, in which there is a decreased amplitude, that is, decreased muscle contraction.

From ADLs directed to the midline and considering Table II, and other studies that mention these same phases of activity [11][16][24], it can be inferred that the contraction phase corresponds to the first four phases of activity, and the decreased contraction to the remaining phases.

Regarding the ADLs directed to the contralateral side (Figures 4 and 5) and the phases of these same activities (Table II), it can be inferred that the contraction phase corresponds to the first three phases of the activity, and the decreased contraction to the remaining phases.

In ADLs directed to the midline, the sequence of muscle amplitude activation peaks is different between the three activities (drinking, eating soup and brushing teeth) (Table III).

This difference may be related to the different requirements of the activities themselves, in each of the phases. In each of the ADLs directed to the midline, there are different procedures, which leads us to infer that in the same phase, despite the same muscles being involved, the amount of muscle fibers that are recruited for the performance of that phase in each of the activities is different. The same happens with ADLs directed to the contralateral side, in which both activities are different in the sequence of mean values related to the maximum peaks. The sequence of the average of the peaks of activation of the maximum muscle amplitude is different between the two activities (washing the contralateral arm and brushing the hair), as shown in Table IV.

To better understand this fact, it would be necessary to analyze the average values representative of the entire muscle activation amplitude during the activity and not just the average of the maximum activation peaks, or the graphs of only one subject in the sample.

V. CONCLUSION

Although the shoulder muscle groups involved in ADLs are the same, the specifics of the activity point to the existence of different characteristics in the amplitude of muscle activation between the ADLs analyzed. Thus, the results are indicative of differences in the pattern of peak muscle activation amplitudes, as well as in the time sequence in which they occur, between ADLs directed to the midline, between ADLs directed to the contralateral side, as well as between these two groups of activities.

There is a need for future work to understand these indications in a larger sample, with an average age closer to the average age of subjects with stroke and with data analysis that includes the normalization of the amplitude of muscle activation throughout the activities, relating it to a with the different phases of the activities. Another suggestion is the use of EMG in conjunction with other technologies, such as accelerometry and optoelectronic motion capture systems.

This study thus contributed to establish a normative behavior of shoulder movements during ADLs in a healthy population, which, in the future, can be compared with the results using the same experimental protocol in patients with pathologies such as stroke.

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