Electromyographic assessment of the shoulder girdle and arm muscles during exercises with axial and rotational loads*

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ABSTRACT

The knowledge of the electromyographic activity produced during shoulder exercises can help in determining its clinical applicability. The purpose of this study was to assess the influence of the load direction and the extremity condition on the electrical activity of the shoulder girdle and upper limb muscles during exercises with fixed distal extremity and external axial load (FEAL) and mobile extremity with rotational external load (MERL). Twenty 23.2 ± 0.9 years old female sedentary volunteers were selected. The triceps brachii, biceps brachii, major pectoral, trapezium and deltoid muscles were assessed. The surface electromyography was recorded during two FEAL and two MERL exercises using 100% of the previously established maximal resistance. The RMS values normalized by the maximal voluntary contraction were compared by a mixed effect model with 5% significance level. In these experimental conditions, the results found in the present study have shown that similar exercises classified by extremity condition and load direction applied on the upper limbs promote similar levels of the electromyographic activity only in part of the assessed muscles. These findings discuss the ability of the classification system used in this study to predict the type of the muscular response expected during different tasks with the same classification.

Keywords: Electromyography. Upper limbs. Shoulder. Exercises.

INTRODUCTION

The articular region of the shoulder and the shoulder girdle is constantly involved in injuries as consequence of the sports practices that involve the technical usage of the upper limbs.

More recent studies on the rehabilitation of the pathologies of the upper limbs, especially those related to the articular complex of the shoulder have been searching for the description of the most frequently used exercises according to the level of the electrical activation of the involved musculature[1-5]. The use of the surface electromyography as the methodology to study the shoulder exercises is justified by the need to know the muscular activity, once for that articular complex, the musculature actuates in a decisive manner to the articular stability, and therefore, to the biomechanics of that region.

The use of exercises classified as closed kinetic chain (CKC) has been grown in the last few years, since it is believed that these types of exercise simulates the biomechanical situations that are considered functional and promoting the proprioceptive stimuli[6,7]. The use of the CKC exercises to the lower limbs is strongly established in the literature, and, for instance, it is recommended as integral part for the rehabilitation in patients submitted to the ligamentous reconstruction surgery[8]. Although the scientific and clinic reasoning towards the application of the CKC exercises in the lower extremity seems to be obvious, the use of CKC exercises in the upper limbs seems to be less clear[8], although they are used in the rehabilitation and training of the upper limbs as well[7].

The kinetic chain concept was originally derived from the mechanical engineering[9]. In 1955, Steindler[10] made an adaptation of that concept to the human body proposing that each limb could act as a portion of a rigid chain within a whole system connected by joints, and that system would be considered closed when the distal extremity is fixed to a steady support in which the movement of a joint would produce a movement into the others. Still, that author considered the system open when the distal portion has no movement restriction. Thus, it is generally accepted that the existing differences between the open kinetic chain (OKC) and the CKC are determined by the movement or absence of movement in the distal extremity of the limb related to its most proximal portion.

Nevertheless, Dillman *et al.*[11] proposed a classification system to the exercises performed in the upper extremity based on the extremity conditions, that means, whether it is fixed or free to perform movements, and in the presence or absence of a load. Upon the utilization of such classification, the authors tried to encompass activities that did not fit in the definition proposed by Steindler[10]. Thus, the exercises could be performed: 1) having the extremity mobile and with load, representing the end of the closed kinetic chain; 2) exercises with mobile extremity and no load, as being the end of the open kinetic chain, and 3) exercises with the extremity mobile and a load representing the intermediary area between the open and closed kinetic chain. Despite only one volunteer had been assessed by those mentioned authors, they reached to a hypothesis that biomechanical similar exercises would have comparable electromyographic activities in the primary muscular groups, and the quantity of the load in the extremity would be a more relevant fact to that similarity than the portion to be fixed or moving while performing the exercises.

Assessing the classification proposed by Dillman *et al.*[11], Lephart and Henry[12] proposed a Functional Classification System where the direction of the load was also included in the classification of the exercises of the upper limbs, and whenever it would be present, this may be a rotational or axial load.

The Functional Classification system also involves the load magnitude (high velocity-low resistance, or low velocity-high resistance), the muscular action (co-contraction, acceleration, and deceleration) and presence or absence of articular movement.

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According to that classification, there are four types of activity: a) fixed extremity-axial load, b) mobile extremity-axial load, c) mobile extremity-rotational load, and d) mobile extremity and no load. Nevertheless, the features of the electromyographic activations related to the proposed classification system were not previously compared.

Thus, the purpose of this research was to assess the electromyographic activity in exercises on the upper limbs, classified according to the extremity condition and the load direction. The hypothesis assessed was that exercises with the same classification would have similar electrical activity indexes, and therefore, they would be equally applicable in the different phases of the rehabilitation of the upper limbs, in order to obtain the muscular co-activation (fixed extremity-axial load) or higher activation of the primary motors (mobile extremity-rotational load).

METHOD

Volunteers: Twenty right handed sedentary volunteers with mean 23 years old (± 0.9 years) were selected, and they did not present any limitation in the range of motions in the upper limbs joints, osteomyoarticular disorders or history of trauma in the shoulder region, and they signed a formal consent to participate, according to the CNS 196/96 rules.

Assessed tasks: The isometric tasks with fixed extremity-axial load (FEAL) performed the wall-press with a 90º of arm elevation on the scapular plane (figure 1A), and the bench-press with a 90º of arm anterior flexion (figure 1B). The isometric tasks with free extremity rotational load (MERL) were the 90º of arm elevation on the scapular plane (figure 1C), and the horizontal extension (figure 1D).

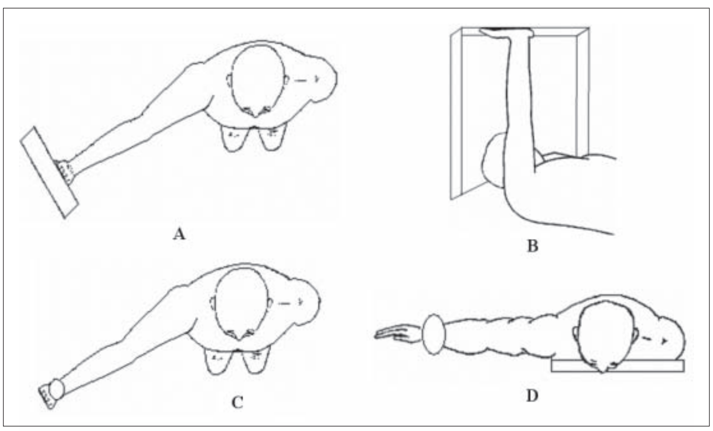

***Fig. 1** – Assessed tasks to the upper limb with fixed distal extremity and external axial load. **A)** Wall-press (FEAL-I), **B)** Bench-press (FEAL-II), **C)** Elevation of the arm on the scapular plane (MERL-I), and **D)** Horizontal extension (MERL-II).*

Instruments: The myoelectrical signals were collected using differential active surface electrodes (Lynx Electronics Ltda.). To the electromyographic recording, the following devices were used: 1) Acquisition System of Signals – Signal Conditioner Device (Lynx Electronics Ltda.) with 16 channels; 2) Lynx Electronics Ltda. A/D converter board, CAD 12/32 model adjusted for 1 KHz sampling frequency, 12 bites of dynamic band resolution; Butterworth 509 Hz low-pass filter and 10.6 Hz high-pass filter and 50 times gain (Lynx Electronics Ltda.), and 3) Aqdados Software, version 4.18 (Lynx Electronics Ltda.) to the simultaneous presentation of signals from different channels, and to attain the amount of the electromyographic signal amplitude.

Experimental procedure: The establishment of the maximal resistance of the tasks performed having mobile extremity and axial load was performed using two repetition tests both of the abduction on the scapula plane and the horizontal extension in a randomized sequence. The test initiated with a minimum 1 kg weight, and the volunteer was asked to perform two repetitions of each movement having the fixed load on the wrist of his dominant upper limb (right). In the event the movement would be performed with no difficulty, the load was increased in 0.5 kg, and the volunteer was asked to perform another two repetitions with a two minutes interval between each series successively, up to it was observed any stability loss of the contraction, of the accessory movement or inability to elevate the load. The amount of the load before noticing the inability to adequately perform the movement was set as the maximal resistance load. The loads were increased an average of four times, and the maximal resistances were 2.9 and 3.1 kg to the abduction and the horizontal extension. In order to minimize the effects of the fatigue, the test was repeated after 24 hours, following the same conduct used in the first day of the trial, but the test was initiated with the maximal load considered in the previous day.

Only two volunteers had a 0.5 kg increase in their maximal resistance loads while performing the second test. The electromyographic signals of the triceps and biceps brachii, the clavicular portion of the major pectoral, the upper fibers of the trapezium, and the anterior portion of the deltoid of the dominant limb were recorded during three maximal voluntary isometric contractions (MVIC) positioned for the muscular function prove[13], in order to attain the reference values to the normalized root mean square (RMS) of the assessed tasks. The MVC recording lasted four seconds each, with 2 minute intervals between repetitions. The placement of the electrodes was guided by the location of the motor point using an electrical stimulator. Once the motor point was marked, the electrode was put between the innervation zone and the tendinous insertion, and it was kept between the medium line of the belly and the side edge of the muscle, according to suggestions made by the European Recommendations for Surface Electromyography of the SENIAM project[14]. The assessed tasks had a three times repetition, and each of them with four minutes minimum endurance in order to record the electromyographic signal and with a two minute interval between repetitions, and the sequence was randomly determined. The assessed tasks were performed 24 hours after recording the MVIC. The researcher was vigilant in order to avoid that the volunteers would perform any compensatory movement.

Data analysis: The amounts of the amplitude of the electromyographic activation attained during the four seconds recording of each assessed task are presented by the result of the RMS calculation suggested among the possible presentation forms of that variable by the standardization rules for the electromyographic studies of the surface[14]. The mean RMS value for each assessed muscle was normalized through the mean RMS value of the three records of the myoelectrical activity attained in the MVIC for the same muscle, which means, by the ratio of the mean amount attained in the assessed tasks and the mean value of the MVIC recordings.

With the purpose to assess the influence of the load direction and the extremity condition [type of the exercise proposed] in the mean RMS normalized values [amplitude of the electrical activation], it was used a linear model of mixed effects[15]. This type of data analysis is proposed whenever the responses from a same individual is collected and the supposition of independence between the observations of the same group is not adequate[16]. In this event, the responses (normalized RMS values) can be considered as individually collected, and the information of each volunteer submitted to each of the assessed exercises is used in the model as randomized effects. After constructing the model, a residue analysis was performed, and the logarithmic transformation was adequate to attend some of the suppositions associated to the proposed model. The adjustment model was performed through the PROC MIXED procedure of the SAS software, version 8[17]. It was set a 5% ($p < 0.05$) level, in order to define the statistical significance between the compared values.

RESULTS

The mean normalized RMS values corresponding to the assessed tasks with fixed extremity-axial load and mobile extremity-rotational load are presented on table 1. The mixed effects model showed significant differences between the activation amplitudes of the assessed muscles in all the assessed tasks ($p < 0.05$) which are detailed next.

TABLE 1
Mean values and standard deviations of the normalized RMS recorded while performing the assessed tasks in the upper limb with fixed distal extremity and external axial load (*wall-press* – FEAL-I and *bench-press* – FEAL-II), and free extremity and rotational load (elevation on the scapular plane – MERL-I and horizontal extension – MERL-II). Values in arbitrary units (a.u.). n = 10

Exercise	Biceps	Triceps	Deltoid	Trapezium	Pectoral
FEAL-I	0.25 ± 0.17*	0.37 ± 0.20Œ	0.53 ± 0.27*	1.08 ± 0.48	0.48 ± 0.50
FEAL-II	0.19 ± 0.21*	0.77 ± 0.48	0.46 ± 0.30*	0.22 ± 0.13*#£	0.27 ± 0.18
MERL-I	0.48 ± 0.27	0.23 ± 0.16Œ#	0.98 ± 0.58	1.44 ± 0.60	0.32 ± 0.19
MERL-II	0.13 ± 0.11*#	0.18 ± 0.06Œ#	0.16 ± 0.18Œ*•	0.86 ± 0.69*	0.15 ± 0.06*#

Significant values of $p < 0.05$ to the comparison of the electromyographic amplitude values "*" related to the MERL-I task, "#" related to the FEAL-I task, "Œ" related to the FEAL-II task, and "£" related to the MERL-II task.

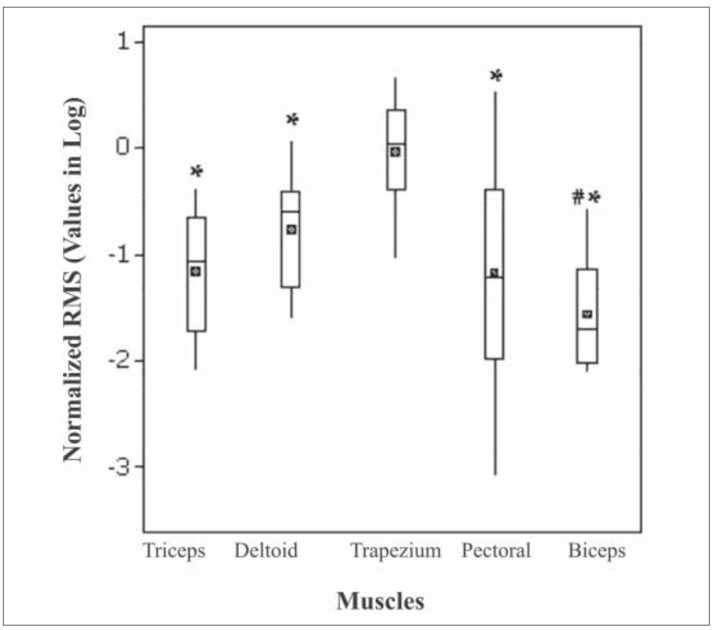

***Fig. 2** – Mean values and standard deviations of the normalized RMS recorded while performing the assessed tasks to the upper limb with fixed distal extremity and external axial load, the* wall-press *(FEAL-I). Values in logarithm scale. n = 10.*

Significant values of $p < 0.05$ to the comparisons of the electromyographic amplitude values "*" related to the upper portion of the trapezium muscle, and "#" related to the anterior portion of the deltoid muscle.

Whenever the normalized activation amplitude values were compared in order to evidence any difference between the proposed tasks, it was found no statistically significant differences ($p > 0.05$) between the activation amplitude of the deltoid and pectoral muscles compared to the wall-press (FEAL-I) and bench-press (FEAL-II) tasks, and among the activation amplitudes of the triceps muscle compared to the elevation tasks on the scapular plane (MERL-I) and the horizontal extension of the arm (MERL-II).

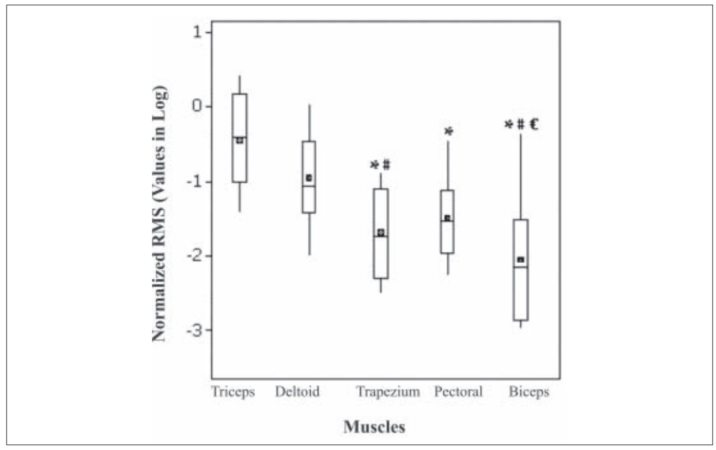

***Fig. 3** – Mean values and standard deviations of the normalized RMS recorded while performing the assessed tasks of the upper limb with fixed distal extremity, and external axial load, the bench-press (FEAL-II). Values in logarithmic scale. n = 10.*

Significant values of $p < 0.05$ to the comparisons of the electromyographic amplitude values "*" related to the upper portion of the triceps muscle, "#" related to the anterior portion of the deltoid muscle, and "€" related to the clavicular portion of the pectoral muscle.

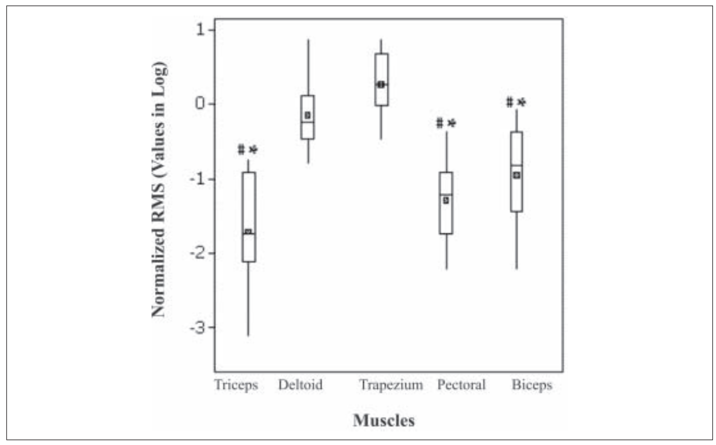

***Fig. 4** – Mean values and standard deviations of the normalized RMS recorded while performing the assessed tasks to the upper limb with free extremity, and rotational load, the elevation on the scapular plane (MERL-I). Values in logarithmic scale. n = 10.*

Significant values of $p < 0.05$ to the comparisons of the electromyographic amplitude values "*" related to the superior portion of the trapezium muscle, and "#" related to the anterior portion of the deltoid muscle.

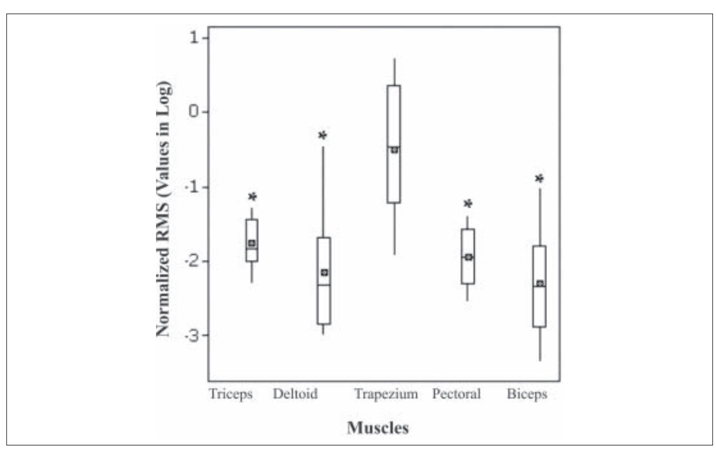

***Fig. 5** – Mean values and standard deviations of the normalized RMS recorded while performing the assessed tasks to the upper limb with free extremity, and rotational load, the horizontal extension (MERL-II). Values in logarithmic scale. n = 10.*

Significant values of $p < 0.05$ to the comparisons of the electromyographic amplitude values "*" related to the upper portion of the trapezium muscle.

The mean normalized RMS values are statistically greater ($p < 0.05$) in the bech-press task (FEAL-II) of triceps brachii, in the elevation of the scapular plane (MERL-I), of the deltoid, biceps and trapezium muscles, and in the wall-press task (FEAL-I) of the pectoral muscle.

Comparing the electromyographic amplitudes of the assessed muscles in each of the proposed tasks, the mean normalized RMS values of the trapezium muscle were higher than the biceps, triceps, pectoral and deltoid muscles ($p < 0.01$) in the wall-press (FEAL-I) task. In the bench-press (FEAL-II) task, the normalized electromyographic amplitude of the triceps muscle was significantly higher than the trapezium and the pectoral muscles ($p < 0.001$). Also, in the FEAL-II task, the amplitude of the normalized electromyographic of the deltoid muscle was significantly greater than the trapezium and the biceps muscles ($p < 0.05$), and the activity of the pectoral muscle was significantly greater than the biceps brachii ($p < 0.05$).

In the task of the arm elevation on the scapular plane (MERL-I), the mean normalized RMS values of the trapezium muscle were statistically greater than the biceps, triceps, and major pectoral muscles ($p < 0.001$), and the deltoid muscle attained greater normalized RMS values than the triceps, biceps, and major pectoral muscles ($p < 0.001$). The trapezium muscle presented a greater mean normalized RMS value compared to the deltoid, triceps, biceps, and pectoral muscles ($p < 0.001$) when performing the horizontal extension task of the arm (MERL-II).

DISCUSSION

The results found in the present study have shown that exercises with the same classification (FEAL or MERL) promote similar levels in the electromyographic activity in some of the assessed muscles. This similarity in the electromyographic activity has occurred in three out of five assessed muscles compared to the tasks performed having fixed extremity-axial load and in only one muscle compared to the tasks performed having mobile extremity-rotational load. These results are in accordance to the ones found by Dillman *et al*.[11] in a study that even without considering the direction of the applied load to the classification of the exercises report that the exercises performed having mobile extremity-external load and fixed extremity-external load with similar biomechanics result in comparable muscular activity to part of the assessed muscles. Nevertheless, as that similarity does not occur in the majority of the studied muscles, it was not possible to establish a relationship between the classification used in the upper limb tasks and the level of the generated electromyographic activity.

This finding discusses the ability of the Functional Classification System[12] in predicting the type of the muscular response expected to perform different exercises with the same classification. According to the classification proposed by Lephart and Henry[12], the exercises performed with fixed extremity and axial load are characterized by promoting the co-activation resulting from the reflex afferences to the alpha motoneuron that promotes the extrafusal muscular activation[18]. Furthermore, the afferences are transmitted by mechanoreceptors which are present in the capsular and ligamentous structures, influencing the standard motor coordination, the reflex activity, and the articular stability in order to reduce the translations through the dynamic stabilization[18,19].

Nevertheless, the records attained in the present study on the wall-press and bench-press tasks, in which it was likely to find a similarity between the electromyographic activity of the assessed muscles caused by the coordination resulting from the axial load effect, has shown to have different activation levels between the assessed muscles.

The greater activation of the trapezium and deltoid muscles was attained in the maintenance of the abduction task on the scapular plane in the orthostatic position (FEAL-I). In this exercise, the contraction of the trapezium and the deltoid muscles was opposed to the arm aduction[20], suggesting that the rotational loads are capable to increase the electromyographic activity of the primary muscles related to their synergists more than producing a co-activation. The great values found in the myoelectrical amplitude of the trapezium and deltoid during that exercise can be explained by the need of a greater recruitment of the motor units demanded by the scapulohumeral rhythm in order to maintain the favorable force-length relationship of the scapulohumeral muscles in the elevation of the upper limbs movements[20]. However, it is also important to consider that while recording, the trapezium and deltoid muscles were in a shortened positioning, compared to the biceps and major pectoral muscles. When the muscle is in a shortened position, a greater number of motor units may be at that site of detection of the surface electrodes, and this may result in a greater electromyographic amplitude record[21].

Unlike the lower limbs where the most of the muscles are in the superficial layers, in the upper limbs, especially the scapular region, the activity of the deep muscles cannot be analyzed through the surface electromyography, as for instance in the electrical activity of the supraspinatus muscle.

Thus, for the exercise to attribute an important clinical value that causes a big electromyographic activity of the deltoid muscle, it should synergistically activate muscles, such as the infraspinatus and the teres minor muscles, in order to perform the appropriately control of the superior translation of the humeral head[20]. So, in order to allow a clinic interpretation of the applicability of the exercises assessed in this study regardless its relationship between the classifications proposed to the exercises for the upper limb and its electromyographic activation amplitudes, see references 1-6 and 22-23.

At last, the control of the produced muscular force must be considered in further studies focusing the assessment of the influence of the classification of the upper limb exercises used in this study. Also, the knowledge of the muscular activation of other superficial muscles related to the shoulder girdle and to the upper limbs must be investigated, in order to justify the rational clinical indication and the application in training protocols.

CONCLUSION

Under such experimental conditions, the results found in the present study have shown that similar exercises classified by the extremity condition and the load direction applied to the upper limbs promote similar levels on the electromyographic activity in part of the assessed muscles. These findings discuss the ability of the classification system in predicting the type of the muscular response expected while performing different tasks having the same classification. Thus, it seems to be more relevant the biomechanical analysis of the intended exercise aiming a rehabilitation protocol or training than its classification based on the extremity condition and the load direction applied, whenever it is intended to predict the ability of that exercise in clarifying some level of electromyographic activity. Future studies must consider the influence of the amount of force on the electrical activity related to the classification in upper limb exercises.

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