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RELATIONSHIP BETWEEN WORKLOAD AND NEUROMUSCULAR ACTIVITY IN THE BENCH PRESS EXERCISE

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Abstract

Objective: To investigate the relationship between strength and electromyographic (EMG) signal in different intensities in the bench press exercise.

Methods: Eleven healthy resistance trained men (22.8 ± 3.5) participated into the present study. Maximal isometric strength was determined in the bench press exercise using a load cell. Muscle activation was assessed using surface electromyography (EMG) signals from the muscles pectoralis major, anterior deltoid and posterior deltoid at intensities ranging to 60-90% of maximal voluntary contraction (MVC), in the bench press exercise. This procedure allowed the analysis of the strength/EMG relationship.

Results: In all muscles assessed, there were significant differences in the normalized muscle activation between the intensities of 60 and 70% of the MVC, as well as between 70 and 80% ($P<0.05$), while there were no differences between 80 and 90% of MVC. In addition, there were significant correlations between strength and EMG signals for the muscles pectoralis major ($r=0.43$, $P=0.04$), anterior deltoid ($r=0.52$, $P=0.01$), and posterior deltoid ($r=0.32$, $P=0.046$).

Conclusions: These results suggest that levels of muscle activation near to maximal are obtained at the intensity of 80 of MVC and no additional motor unit recruitment are achieved at 90% of MVC.

Key words: *electromyography, strength training, muscle activation, bench press*

Introduction

The most relevant acute variable for strength training is the intensity, in other words, the training workload [1-3]. The intensity determines the level of muscle activation, in which the greatest is the workload, the greater will be the activation level of the agonists muscles involved in action [1,4-6]. Considering the activation pattern of the antagonist muscle at different training intensities, it has been observed increases as well as decreases in the antagonist coactivation at greater training intensities [7]. The decrease in the antagonist coactivation seems to be associated to the increase of strength development of the agonist muscle [7,8]. On the other hand, the increase in the antagonist coactivation gives the joint a greater stability and integrity [7].

The muscle activation level during resistance exercises has been assessed through surface electromyography (EMG) [1,2,9-14]. The EMG shows graphically the action potential generated in the recruited motor units of the muscle investigated. As the overload imposed to certain action increases, there is an increment in the amplitude of the electromyographic signal [13-17]. Thus, it seems that there is a strong relationship between the force development and the EMG signal (strength/EMG relationship) during specific muscle actions. However, the most of the studies that investigated the association between muscle strength and EMG signal, showed this association during exercises for the lower limbs. Few studies, therefore, have investigated this relationship during exercises for upper limbs, such as the bench press exercise.

The strength training intensity is often determined using the workloads relative to the maximal load (values for 1 maximal repetition - 1RM). With regards to the maximal strength training, it is widely suggested that greater increases in this capacity occur at intensities ranging from 85-100% [3,18], since the recruitment of the greater number of motor units would be possible at these intensities. However, it was not determined by the literature whether an increase in the workload over 60% of maximal strength enhances the EMG signal in upper-body exercises. The investigation of the strength/EMG relationship in upper-body exercise could give insights about whether perform greater workloads is necessary to optimize the neuromuscular activity in the muscles involved.

Given the scarce data regarding the relationship between strength and EMG signal in the bench press exercise, as well as the importance of investigating the pattern of motor units recruitment at different intensities, the purpose of the present study was investigate the association between strength and EMG signal at different intensities in the bench press exercise. Our hypothesis is that there is an association between strength and EMG signal, and as the workloads increases, the greater will be the amplitude of the EMG signals of the muscles investigated.

Methods

Participants

Eleven healthy young men (22.8 ± 3.5 years-old) recreationally trained in resistance training, for at least one year, participated of the present study. Calculation of the sample "n" was carried out using the PEPI program (version 4.0) with a statistical power of 90%. Each subject was informed about the methodological procedures of the present study through the reading of a free informed consent. This study was approved by the University Institutional Review Board, and is in accordance with Helsinki Declaration. Sampling characteristics are described on Table 1.

Table 1. *Physical Characteristics (n= 11)*

Characteristics	Mean ± SD
Age (years)	22.8 ± 3.5
Height (cm)	177.2 ± 7.8
Body Mass (kg)	76.7 ± 8.7
% Fat mass	8.7 ± 1.8
Maximal Voluntary Contraction (N)	1173 ± 284

Force and Electromyographic Acquisition and Analysis

Before start the experimental protocol, subjects were familiarized performing specific muscle contractions at submaximal effort using very light loads. In order to obtain the maximal isometric strength, the subjects warmed up for 5 minutes on a cycle ergometer and were, then, horizontally positioned in the bench of the Smith machine (Sculptor, Porto Alegre, Brazil). The bar was fitted with a load cell with 200 kg of capacity, connected to an A/D converter (Miotec, Porto Alegre, Brazil), which made it possible to quantify the traction exerted when each subject executed the exercise at a determined angle. The subjects were positioned lying in the bench with the shoulder and the elbow at a 90° angle, strapped to the bench at the waist height. The load cell was positioned perpendicular to the bar and the humerus and parallel to the forearm. Subjects were instructed to exert the maximum strength as possible when trying to extent both elbows. Subjects had three attempts to obtain their MVC, each lasting 5 seconds, with a 3-minute rest between each attempt. During this test, verbal encouragement was provided so that the subjects would feel motivated to develop their maximal strength. The force-time curve was obtained using Miograph software (Miotec), with an acquisition rate of 2000 Hz and later analyzed using SAD32 software. Signal processing included filtering with a Butterworth low-pass filter at a cut-off frequency of 9 Hz. Later, in order to determine the highest MVC, a 1-second slice was made in the plateau of force, between the 2^{nd} and 4^{th} second of the force-time curve. The test-retest reliability coefficient (ICC) was 0.94 to MVC.

During the isometric strength test, the maximal muscular agonist activation was evaluated using surface electromyography in the pectoralis major and anterior deltoid, and the antagonist coactivation was determined in the posterior deltoid. Electrodes were positioned on the muscular belly in a bipolar configuration (20mm inter-electrodes distance) in parallel with the orientation of the muscle fibers, according to Leis & Trapani [19]. Shaving and abrasion with alcohol were carried out in the muscular belly, as previously described elsewhere, in order to maintain the inter-electrodes resistance above 2000 Ω [14]. Reference electrode was fixed on the clavicle. The raw EMG signal was acquired simultaneously to MVC using a 4-channel electromyography (Miotool, Porto Alegre, Brazil), with a sampling frequency of 2000 Hz per channel, connected to a personal computer (Dell Vostro 1000, São Paulo, Brazil). Following signal acquisition, the data were exported to the SAD32 software, in which they were filtered using the Butterworth band-pass filter, with a cut-off frequency ranging between 20 and 500 Hz. After that, the EMG records were sliced exactly in the 1 second when the MVC was determined in the force-time curve and the root mean square (RMS) values were calculated. The RMS values of posterior deltoid were normalized by the maximum RMS values of this muscle, obtained during the MVC of horizontal extension at 90° (Figure 1).

After determination of maximal muscular activation, submaximal muscular activation (relative to maximal) was randomly evaluated at different intensities of MVC (60, 70, 80 and 90%). In this protocol, subjects were oriented to maintain a specific force value for three seconds, receiving a visual feedback in the computer that showed, in real-time, the strength values. One trial was performed for each intensity, and the resting time between trials was of 5 minutes. The apparatus and the collection and analysis procedures were the same used to determine the maximal EMG signal. The submaximal RMS values were normalized by the maximum RMS values obtained during the MVC for each muscle. The test-retest reliability coefficients (ICC values) of the EMG measurements were over 0.85.

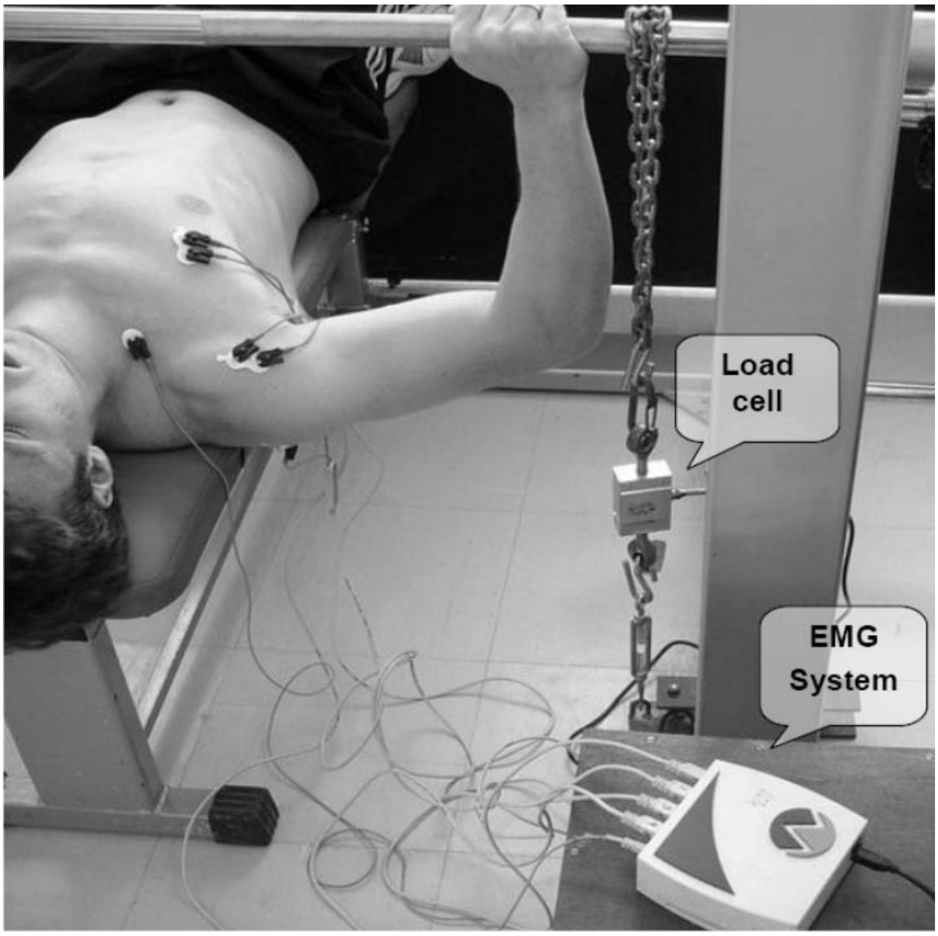

Fig. 1. *Apparatus used for EMG record*

Statistical Analysis

In order to analyze the collected data, descriptive statistics were used, with the data presented as Means ± standard deviation (SD). The Shapiro-Wilk's test was used to verify the normal distribution of data. Pearson product-moment linear correlation was used for test the relationship between strength and EMG signals for monitored muscles. ANOVA for repeated measures was used to compare relative values of force and EMG signal between different MVC intensities. When applicable, LSD post-hoc was used. Significance was accepted when $p < 0.05$ and the statistical power was 90%.

Results

There were significant differences between all percentages of strength assessed. The values of strength (N) corresponded to the pattern expected: 100% (1173 ± 284 N) > 90% (1030 ± 265 N) > 80% (927 ± 242 N) > 70% (814 ± 271 N) > 60% (703 ± 279 N) of MVC ($P<0.001$). The values of the normalized EMG signals are shown on Table 2. The pattern of activation from the muscles pectoralis major, anterior deltoid and posterior deltoid at the intensities assessed has shown to be similar (Figure 2). The normalized EMG signal from the muscles pectoralis major, anterior deltoid and posterior deltoid did not present significant differences between the intensities of 80 and 90% of MVC, however, both intensities were significantly greater ($P<0.01$) than those corresponding to 60 and 70% of MVC, which presented significant differences between them ($p=0.04$). There were observed significant correlations between strength values and EMG signal from the muscles pectoralis major ($r=0.43$; $P=0.04$), anterior deltoid ($r=0.52$; $P=0.01$), and posterior deltoid ($r=0.32$; $P=0.046$).

Table 2. *Electromiography signal normalized by maximal voluntary contraction*

Muscle	60%	70%	80%	90%
Pectoralis major	68.5 ± 22.2[a]	79.9 ± 21.0[b]	92.7 ± 23.3[c]	97.9 ± 21.8[c]
Anterior deltoid	52.6 ± 16.9[a]	62.4 ± 18.3[b]	77.4 ± 21.8[c]	87.3 ± 21.4[c]
Posterior deltoid	3.8 ± 2.1[a]	5.0 ± 2.6[b]	5.6 ± 2.9[c]	7.1 ± 3.6[c]

%MVC: Percentage of maximal voluntary contraction. Values in mean ± SD. Different letters means significant differences, $p<0.001$ (pectoralis major and anterior deltoid) and $P=0,001$ (posterior deltoid).

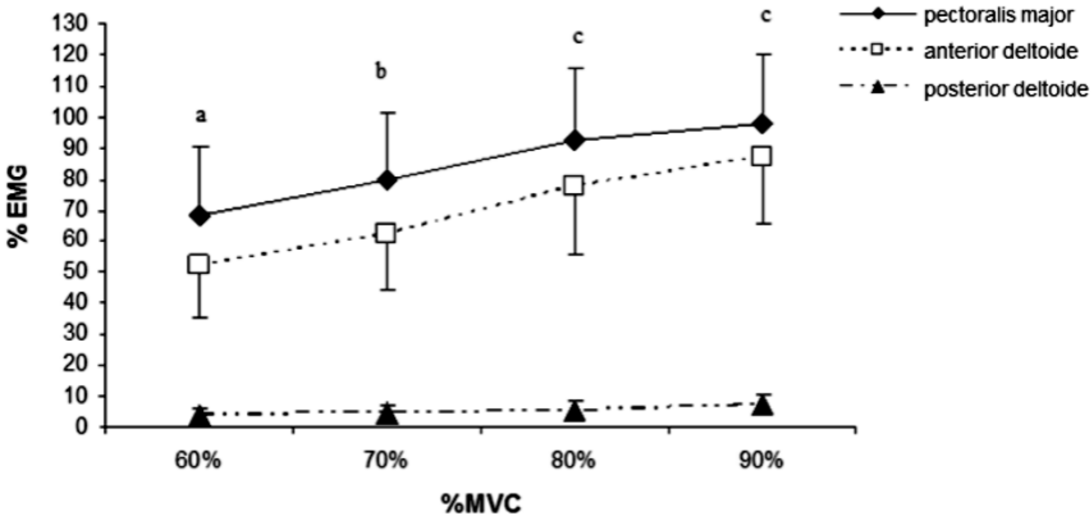

Fig. 2. *EMG signals normalized of pectoralis major, anterior deltoid and posterior deltoid with intensities expressed as percentages of maximal voluntary contraction (MVC). Different letters means significant differences between intensities analyzed (P<0.05).*

Discussion

The primary findings of the present study were the correlations observed between the isometric strength in the bench press and the EMG signal from the muscles pectoralis major, anterior deltoid and posterior deltoid. In addition, there were significant differences between the levels of muscle activation at 60, 70 and 80% of the MVC, with no difference observed between 80 and 90% of MVC.

Some studies which investigated the association between strength and EMG signal have shown the existence of a linear relationship between these parameters during isometric contractions [16,20]. However, the great majority these studies have investigated this associations in exercises for lower limbs, whereas few studies have investigated the relationship between strength and EMG signal in the upper limbs. In the present study, poor to moderate correlations were observed between strength and EMG signals of the muscles assessed. Regarding the agonist muscles (i.e. pectoralis major and anterior deltoid), the absence of a greater correlation index may be explained by the existence of other factors involved in strength production, such as the elastic components of skeletal muscles [17,21]. Another explanation to the results observed may be the exercise evaluated, since in the present study, a multi-joint exercise with broad muscle recruitment was performed. Besides the muscles monitored, the bench press involves the elbow joint, with a primary contribution of the triceps brachii muscle, which was not monitored in the present study. Furthermore, other muscles involved in the horizontal flexion of the shoulder and the abduction of the scapula, such as the coracobrachialis, the pectoralis minor, and the serratus anterior [5,22] were not monitored in the present study.

Regarding the posterior deltoid, the poor correlation observed indicates that, although there is a relationship between the force production in the bench press and the antagonist coactivation of the posterior deltoid, this association is not strong, at least when only one antagonist muscle is monitored. Another aspect that may have influenced the existent correlation between strength and the antagonist EMG signal is that the subjects who participated in the present study were strength-trained. Indeed, it has been demonstrated that systematic strength training reduces the antagonist coactivation [5,16,18,23]. Thus, a reduced pattern of antagonist coactivation may have influenced the poor association between force production and antagonist coactivation in the present study.

Our results were similar to those found in the study by Doheny et al. [18], in which was investigated the relationship between strength and EMG signal of agonists and antagonists muscles of the elbow flexion (biceps brachii, brachioradialis and triceps brachii). These authors observed coactivation values between 2 to 28% of the maximal activation (during a MVC) of the biceps brachii during elbow extension, between 20 to 38% of the maximal activation of brachioradialis and between 15 and 49% of the maximal activation of the triceps brachii during the elbow flexion. In the present study, the values of coactivation of the posterior deltoid remained within a range of 3.8 to 7.12% of MVC of this muscle.

In the present study, the comparison between the level of activation obtained in different intensities indicates that the difference in the amplitude of the EMG signal, which reflects the number of motor units recruited and the firing rate of these units, occurred between the intensities of 60, 70 and 80%. However, no difference occurred between 80 and 90%, which suggests an absence of increase on the neuromuscular activity of these muscles at the greater intensities. In another study, which the lower limbs were assessed, Suzuki et al. [24], analyzed the EMG signal of the knee extensor muscles at five different percentages of MVC (5, 10, 20, 30 and 50%) and they found two ranges of intensities which the neuromuscular activity were not significantly different, between 5 and 10% as well as between 20 and 30%. Hence, the results of the present study suggest that, to achieve a muscle activation close to maximal in the muscles evaluated during the bench press exercise, the intensity of 80% of MVC is a sufficient stimulus and no additional activation occurs at 90% of MVC. However, careful is necessary to extrapolating these results, since the muscle activation was assed isometrically in the present study. Thus, further studies investigating the muscle activation at percentages of the dynamic maximal strength are necessary to determine whether performing intensities over 80% of 1RM would increase the muscle activation of these muscles in the bench press exercise.

A possible limitation of the present study is the use of the surface electromyography to detect the muscle activity, since it have been extensively described that this technique has limitations, such as crosstalk from other muscles inquired, movement of muscle fibers, anisotropy and inhomogeneity of the muscle, fascia, fat and skin tissues, and the fact of the electrodes may not reflect the activity of all motor units activated, to cite some of them [1]. In addition, the surface EMG underestimates the activation signal sent from the spinal cord to muscle as a result of the cancellation of positive and negative phases of MU action potentials. Therefore, the results extracted from the sEMG amplitude about the motor unit recruitment of the MU may be underestimated since it is possible that there is an amplitude cancellation. Thus, the limitations of the technique may explain the weak associations between strength and muscle activity observed during the bench press exercise.

Conclusion

The present results, suggests that performing 80% of MVC is a sufficient stimulus to obtain a muscle activation close to maximal with no addition motor units recruitment at 90% of MVC. From a practical point of view, performing lower loads to achieve the same pattern of motor unit activation results in a less exigency of the joint structures (joint capsule, ligaments and tendons). It may also be suggested that approximately at 80% of MVC, the level of activation of the muscles pectoralis major and anterior deltoid is maximal, with a reduction in the joint overload and risk of injuries.

Declaration of interest

The authors report no conflicts of interest.

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