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Peak of neuromuscular activation and angle where it occurs during bench press exercise performed with different repetition number and duration in resistance trained individuals

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ABSTRACT

The present study compared neuromuscular activation, measured by surface electromyography (EMG) amplitude [measure by EMG peak (EMG_{PEAK})] and range of motion (ROM) where EMG_{PEAK} occurred between two training protocols, matched by time under tension, but with a different number and duration of repetitions. Sixteen recreationally trained males performed 2 training protocols with 3 sets, 180 s of rest with 60% of one-repetition maximum(1RM) on the bench press performed in a Smith machine. Protocol A consisted of 6 repetitions with a repetition duration of 6 s and protocol B consisted of 12 repetitions with a repetition duration of 3 s. EMG activity of anterior deltoid, pectoralis major and triceps brachii muscles were recorded. The results showed a general higher EMG amplitude (regardless of the muscle) in protocol B ($p = 0.010$), and pectoral and triceps brachii consistently presented higher neuromuscular activation than anterior deltoid at both protocols ($p = 0.007$). Additionally, the ROM where EMG_{PEAK} occurred in triceps brachii was in the middle of the concentric action (~50% of ROM), this occurred in the first half of the same action (~24% of ROM) in the other muscles. In conclusion, protocol B demonstrated an increased EMG amplitude over protocol A, although both protocols responded similarly by achieving the highest EMG amplitude at same ROM among the muscles analysed.

1. Introduction

Surface electromyography (EMG) has often been used to measure muscle activation (i.e. EMG amplitude) during resistance training (RT) protocols in resistance trained individuals (Burd et al., 2012; Fahs et al., 2015; Schoenfeld et al., 2014). Duration of the repetition (DR) and number of repetitions (NR) are some of the variables of RT (Kraemer and Ratamess, 2004) and attention has been given in order to understand their influence on EMG amplitude (Burd et al., 2012; Lacerda et al., 2016; Looney et al., 2016; Nóbrega et al., 2018). For instance, Burd et al. (2012) demonstrated a higher EMG amplitude when longer DR (12 s) was used compared to shorter DR (2 s) with the same NR. Contradictorily, Sakamoto and Sinclair (2012) compared three different DR (1.9 s vs. 2.8 s vs. 5.6 s) and intensities (40–80% of 1RM) until muscle failure and found greater EMG amplitude during concentric actions when shorter durations and greater NR were performed. However, the protocols being performed until failure may have presented different time under tension (TUT), which is a well-known factor that interferes with neuromuscular responses (Lacerda et al., 2016; Tran and Docherty, 2006). Tran and Docherty (2006) showed that training protocols with different TUT (60 s vs. 150 s) resulted in no differences in EMG amplitude, albeit a lower force generating capability during maximal voluntary contraction for longer than shorter durations was found, reinforcing the importance of TUT in a RT program. Thus, investigating how EMG amplitude varies during a resistance training protocol and where it occurs (specific joint angle) would provide valuable information regarding muscle activity among different resistance training protocols.

The measure of muscle activation is often given by the EMG amplitude and during bench press exercise it has been calculated by the root mean square (RMS) (Clark et al., 2011; Sakamoto and Sinclair, 2012; Snyder and Fry, 2012), integral (area under the curve) (Keogh et al., 1999; Ojasto and Hakkinen, 2009) and/or by peak amplitude (Calatayud et al., 2016, 2015; Keogh et al., 1999; Schoenfeld et al., 2016). However, although different methods have been applied to calculate EMG amplitude, some type of assessments may require a specific calculation. For instance, in order to identify a specific joint angle during a dynamic contraction and

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match this point with EMG amplitude, the use of EMG peak (EMG_{PEAK}) may be more appropriate. This assumption might be justified because EMG amplitude changes with different joint angles (Lanza et al., 2017). Thus, even a small-time window of RMS rather than EMG_{PEAK}, would not be from a specific angle (e.g. 65°) but from a range of angles (e.g. 61–68°), not allowing a precise measure of joint position. Therefore, the use of peak amplitude may allow a more rigorous biomechanics approach given it will provide a precise measure of EMG amplitude at a specific joint angle. Moreover, it is unknown if neuromuscular activation of the muscles required to perform a bench press occur at the same joint angles and if this varies with DR and NR.

Different DR and NR may have an impact on EMG amplitude. Lacerda et al. (2016) showed that protocols matched by TUT (but different DR and NR) have greater EMG amplitude with shorter DR compared to longer DR. They suggested that faster movements may have an impact in EMG amplitude due to a greater need to accelerate and decelerate the equipment than slower movements. Moreover, the impact on EMG amplitude could increase when a higher NR are required. In addition, if the peak force corresponds to the EMG_{PEAK} with shorter DR, the peak may occur at angles closer to the beginning of the concentric muscle actions (Sakamoto and Sinclair, 2012; Sampson et al., 2014). Understanding which joint angle EMG_{PEAK} occurs may inform the impact of different protocols on EMG amplitude and how this differs between the muscles required at the same task (i.e. bench press). Moreover, it would provide further information about the performance needs according to the strength and velocity demands during the task.

Thus, the aim of the present study was to compare EMG_{PEAK} and the range of motion (ROM) where EMG_{PEAK} occurred, between two training protocols matched by TUT but with different DR and NR. The first hypothesis is that the protocol with higher velocity (shorter DR) would result in an overall greater EMG_{PEAK} than protocol with lower velocity (longer DR). The second hypothesis is that the protocol with higher velocity would present higher EMG_{PEAK} at the beginning of the ROM given the necessity to produce greater force output and accelerate the bar.

2. Material and methods

2.1. Participants

Sixteen recreationally trained males (age = 22.73 ± 3.19 years; height = 1.77 ± 0.08 m; body mass = 76.63 ± 9.7 kg; 1 repetition maximum [1RM] = 88.11 ± 14.54 kg; data presented as mean ± standard deviation [SD]) engaged in resistance training for at least 6 months completed this study. The inclusion criteria were: (1) practicing resistance training continuously, and performing bench press exercise, for at least 6 months before the start of the study; (2) no functional limitations regarding performing the 1RM test or the training protocols; and (3) the ability to lift a weight corresponding to their own body mass on the 1RM Smith machine bench press. Ethical approval was granted by the local ethics committee and participants provided written informed consent prior to their participation according to the principles of The Declaration of Helsinki.

2.2. Experimental procedures

Each participant attended the laboratory at a consistent time of the day, on 4 different sessions separated by a minimum of 48 h and maximum of 72 h. Participants were instructed to avoid any exercise in the 24 h before each session and they were familiarized with the experimental procedures. The bar ROM, the hand position on the bar, the body position on the bench and the bench position relative to the fixed structure of the smith machine were controlled to ensure individual standardization and the same position was used throughout the study (Lacerda et al., 2016). ROM was determined by trajectory from the upper limit bar to the lower limit (Fig. 1). The position of the hands (grip) on the bar and the body of the volunteer on the bench was marked with tape on the device itself (Lacerda et al., 2016).

Session 1 was used to familiarize the participants with the bench press 1RM test performed on a Smith machine followed by a familiarization with the use of the metronome (60 or 120b. min^{-1}) and visual feedback. A standard warm-up of 10 repetitions with the weight of the bar (~23 kg) was performed on each session before the test begin. On session 1, hand and head position were standardized, as well as the range of motion and used throughout the other sessions. Session 2 consisted of the 1RM test followed by another familiarization with duration of the repetition. The 1RM test began with an eccentric action (ECC) lowering the bar to the sternum, followed by a concentric action (CON) by extending the elbows. The test was determined within a maximum of 6 attempts, with 5 min rest periods between each attempt (Lacerda et al., 2016). The 1RM from the second session was used as the reference for the testing protocols.

The experimental sessions 3 and 4, participants randomly performed (flipping a coin) protocol A or B which consisted of 3 sets at 60% of 1RM and 3-min rest between sets. Protocol A was performed with 6 repetitions and 6 s DR (3 s CON, 3 s ECC) and protocol B with 12 repetitions and 3 s DR (1.5 s CON, 1.5 s ECC). The metronome (and visual feedback) was used to control the duration

Fig. 1. Photos of beginning (0 position; B) and end (100 position; A) of the range of motion during the bench press exercise used in the experiment. Electrogoniometer positioned on the right elbow of one participant (C).

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of the repetitions during the protocols and if the participant failed to keep the intended duration an alert was provided.

2.3. Instrumentation

The EMG procedure (Biovision, Wehrheim, Germany) followed SENIAM guidelines (Hermens et al., 2000). Bipolar surface electrodes (Ag/AgCl) were placed parallel to the muscle fibers on the participants right anterior deltoid (AD), pectoralis major (PM; sternal portion), and triceps brachii (TB; long head portion) muscles. The skin area was shaved and cleaned with alcohol and a cotton pad before placing the electrodes. The electrodes were placed in pairs, 2 cm apart from their centers at the point of the greatest muscle area. The ground electrode was fixed at the olecranon. The electromyographic data acquisition was amplified 500 times and stored, data was filtered (second-order Butterworth band-pass filter of 20–500 Hz) and rectified (full-wave) and smoothed with a low pass filter with a time constant of 50 ms to calculate the signal amplitude through the root mean square electromyography and EMG_{PEAK} was extracted (Hibbs et al., 2011). Before initiating each experimental session, participants were asked to perform 2 repetitions at 60% 1RM, using a repetition duration of 2 s CON and 2 s ECC and the EMG_{PEAK} from this test was used as a reference for normalization (normalization test) as previously used (Lacerda et al., 2016; Sakamoto and Sinclair, 2012) and recommended (Allison et al., 1993). Finally, the mean protocol peak EMG_{RMS} of CON obtained during protocols A and B were calculated, and the value was divided by the reference value previously described, generating a normalized EMG_{PEAK} per protocol.

A calibrated electrogoniometer (Noraxon, Scottsdale, AZ, USA), which was synchronized with EMG, was fixed on the right elbow of participants using double-sided adhesive tape and elastic bands. Once stored, the electrogoniometer raw data was converted into angular displacement (to determine elbow ROM) data and filtered through a fourth order Butterworth low-pass filter with a cutoff frequency of 10 Hz (Lacerda et al., 2016). The duration of each muscle action was comprised of the time spent between the maximum (elbow flexion) and minimum (elbow extension) angular positions and the elbows flexion angles were recorded (Fig.1). The electromyographic and electrogoniometer signals were synchronized and converted using an A/D board (Biovision) and sampled at a frequency of 1,000 Hz. Appropriate software (DasyLab 11.0; Measurement Computing Corporation, Norton, MA, USA) was used to record and treat the data. Due to the anthropometric characteristics and the individual positioning on the Smith machine equipment, each volunteer performed the training protocols with different ROM and bar displacement. Thus, in order to compare ROM between participants, the maximal CON ROM [difference between maximum (elbow flexion) and minimum (elbow extension) angular positions] performed during the normalization test (see above) was used as reference value. Additionally, the beginning and end of the CON was considered as a percentage (0 and 100% of ROM, respectively; Fig.1). The percentage of ROM where EMG_{PEAK} occurred (normalized ROM_{PEAK}) during the CON was identified and the mean value of each protocol was calculated.

2.4. Statistical analysis

Statistical analysis was performed with the software IBM SPSS Statistics for Windows version 20.0 (SPSS, Inc., Chicago, IL, USA). Paired-sample t-tests were used to compare repetition durations, TUT (CON and ECC), and ROM. Probability was set at $p \leq 0.05$ for statistical significance for all tests. The normalized values of ROM_{PEAK} and EMG_{PEAK} of all muscles were used for statistical analysis. Normality and homogeneity of variances were verified using Shapiro-Wilks and Mauchly's tests, respectively. The normalized peak EMG_{RMS} and peak ROM_{PEAK} showed significant deviations from normality; therefore, the median was used as an indicator of central tendency and the quartile indicated the dispersion of the variables analyzed across experimental sessions. A nonparametric procedure [analysis of variance (ANOVA)-type statistics] as previously suggested (Brunner et al., 2002) was used to check the response of the normalized peak EMG_{PEAK} and peak ROM_{PEAK} during the training protocols for the main effects of protocol and muscle, as well as the interactions between these factors. The intraclass correlation coefficient ($ICC_{[3,1]}$) of EMG_{PEAK} and ROM_{PEAK} found in the normalization test of experimental sessions 3 and 4 was calculated. These intersession values were 0.96 for AD, 0.89 for PM, and 0.95 for TB to EMG_{PEAK} and 0.88 for AD, 0.92 for PM, and 0.77 for TB to ROM_{PEAK}. In addition, eta squared (η^2) values are reported to reflect the magnitude of the differences in each treatment (small = 0.01, medium = 0.06, and large = 0.14) (Cohen, 1988).

3. Results

Protocol B showed shorter mean DR than protocol A (3.01 ± 0.05 s vs. 5.92 ± 0.06 s, respectively; $t_{(15)} = 221.12$, $p < 0.010$) while no differences were found on the average CON TUT between both protocols (17.39 ± 0.45 s vs. 17.59 ± 0.44 s, respectively; $t_{(15)} = 2.34$, $p = 0.140$). Additionally, differences were found on the average ECC TUT (18.11 ± 0.09 s vs. 18.43 ± 0.14 s, respectively; $t_{(15)} = 5.33$, $p = 0.030$), but the magnitude of the difference was less than 2.0%. No differences were found on the average ROM (75.10 ± 3.29° vs. 75.00 ± 3.12°, protocol A and B respectively; $t_{(15)} > 0.001$, $p = 0.930$).

Although no interaction was found (protocol × muscle; $H_2 = 1.10$, $p = 0.570$, power = 0.07, $\eta^2 = 0.001$), a main effect of protocol was identified for normalized EMG_{PEAK}, where protocol B was higher than protocol A ($H_1 = 5.74$, $p = 0.010$, power = 0.95, $\eta^2 = 0.04$; Fig. 2). In addition, a main effect of muscle also was found with higher normalized EMG_{PEAK} for PM and the TB compared to AD (H2 = 9.92, p = 0.007, power = 0.34, η2 = 0.59).

Normalized ROM_{PEAK} presented a main effect of muscle and EMG_{PEAK} of TB at a larger ROM (49.4 ± 19.7% and 51.4 ± 17%, protocol A and B respectively) than PM (21.1 ± 22.2% and 27.4 ± 20.9%, protocol A and B respectively) and AD (25.6 ± 20.6% and 28.2 ± 18.1%, protocol A and B respectively) that occur at the beginning of the CON with similar values between both protocols

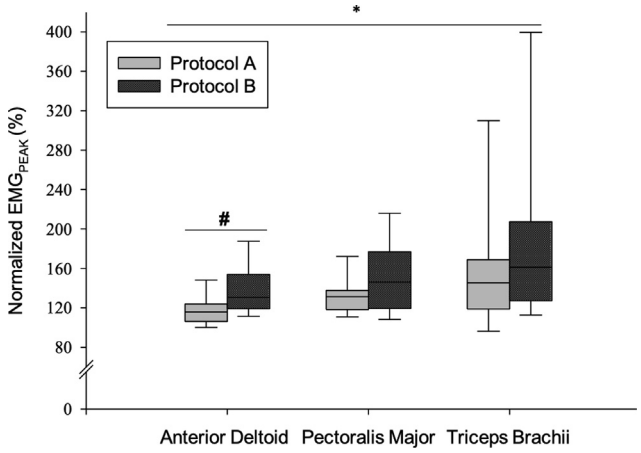

Fig. 2. Median (horizontal line within the box); first and third quartiles (lower and upper box limits); minimum and maximum (whiskers) concentric normalized EMG_{PEAK} of the Anterior Deltoid, Pectoralis Major, and Triceps Brachii muscles for each training protocol. * Protocol B different from Protocol A; #lower than the others.

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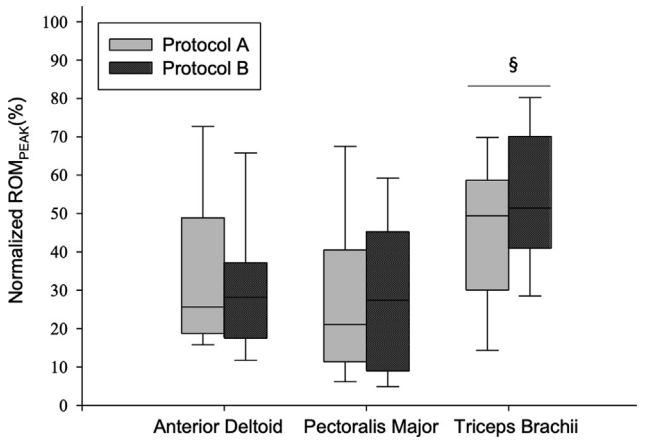

Fig. 3. Median (horizontal line within the box); first and third quartiles (lower and upper box limits); minimum and maximum (whiskers) concentric normalized ROM_{PEAK}, of the Anterior Deltoid, Pectoralis Major, and Triceps Brachii muscles for each training protocol. § Higher than the others.

($H2 = 17.98$, $p < 0.001$, power = 0.88, $\eta 2 = 0.23$; Fig. 3). Moreover, no main effect of protocol ($H1 = 0.14$, $p = 0.700$, power = 0.23, $\eta 2 = 0.002$) or interaction ($H2 = 1.19$, $p = 0.550$, power = 0.27, $\eta 2 = 0.01$) were found in both protocols.

4. Discussion

The present study compared the EMG_{PEAK}, and the ROM where EMG_{PEAK} occurred, between two training protocols matched by TUT but with different NR and DR during the bench press exercise. The main findings of the present study were: (1) EMG_{PEAK} was higher with shorter DR (protocol B) compared to longer DR (protocol A), confirming our first hypothesis; (2) EMG_{PEAK} was higher for PM and TB muscles compared to AD, independently of protocol; (3) the ROM where EMG_{PEAK} occurred in TB was in the middle of CON while the other muscles was at the first half of CON, which was the same for both protocols, refuting our second hypothesis. Taken together, the present findings highlight that a protocol with shorter DR but higher NRs presented increased neuromuscular activation than a protocol with longer DR but lower NR. However, both protocols responded similarly by achieving the highest neuromuscular activation at same ROM among the muscles analysed.

Previous studies have analyzed neuromuscular activation while performing resistance training protocols by using different NR and DR. Similar to the present study, Lacerda et al. (2016) showed higher neuromuscular activation in protocols with shorter DR, higher NR and same TUT. Additionally, other studies that investigated neuromuscular activation also showed similar results to the present study even without matching TUT between protocols (Looney et al., 2016; Hatzel, 2012). Thus, DR and NR appear to be important factors that influence neuromuscular activation during dynamic contractions. Augmented neuromuscular activation has been associated with increased motor units recruitment, modulation of discharge frequency and synchronization of motor units or by a combination of these factors (Enoka, 1988; Gabriel et al., 2006).

PM and TB presented higher EMG_{PEAK} values than AD independently of protocol in the present study. The review of Stastny et al. (2017), compiled fourteen studies that investigated the differences in muscle activation (PM vs. TB vs. AD) during the bench press exercise and concluded with similar results to the present study. Consistent with our results, higher neuromuscular activation of the PM and TB have been demonstrated when performing protocols with shorter DR and higher NR (Sakamoto and Sinclair, 2012). However, the authors did not find differences between protocols for AD when varying DR or NR. The lack of differences in AD neuromuscular activation between protocols may be explained as Sakamoto and Sinclair (2012) executed a single set, which may not have resulted in as high of a stimulus as the present study that used three sets. This would be justified by the fact that PM and TB muscles are considered dominant (i.e. higher neuromuscular activation) to AD during the bench press and possibly are more responsive to changes in movement velocity (Stastny et al., 2017).

No differences were observed between protocols regarding ROM where EMG_{PEAK} occurred. Thus, DR and NR appear to have no influence where EMG_{PEAK} occurs across the ROM during a bench press exercise. However, although TB ROM_{PEAK} occurred at the middle of the CON, PM and AD occurred at the first half of CON. To the best of the authors' knowledge, this is the first time it has been shown that the muscles involved in the bench press exercise presents EMG_{PEAK} in different points of the ROM. Thus, within the same exercise, muscles potentially present different patterns of neuromuscular activation. These differences in activation may be due to biomechanical characteristics (i.e. muscle architecture) of the analysed muscles and/or the positive correlation between torque and EMG (Ringelberg, 1985). Additionally, joint position (e.g. shoulder vs. elbow) also influences the ability of each muscle to produce torque (Bassett et al., 1990; Yu et al., 2011). For instance, PM and AD present a higher capacity to produce torque partially due to the greater moment arm during higher horizontal flexion angles (120°, where 0 is neutral position) which gradually reduces in extended positions (Yu et al., 2011). Conversely, TB has the capacity to keep a constant force production at a broad ROM given its larger physiological cross-sectional area and pennation angle (Murray et al., 2000). Putting this information together, maybe PM and AD would provide a higher force contribution to move the bar during the bench press at the beginning at the movement and overpower TB. However, towards the end of CON, PM and AD would decrease activation requiring TB to be more active to keeping moving the bar.

The present study has limitations and strengths that are worth highlighting. The equalization of the TUT between protocols provides further confidence that this variable does not influence the presents results. However, a limitation of the present study was the use of only two different velocities (DR). Although the present study found no differences in the angle where EMG_{PEAK} occurred between protocols, maybe faster and/or longer DR would have a different impact than demonstrated here. Future studies should focus on the use of different velocities (e.g. ballistic movements and/or slow contractions) which would provide further understanding about the changes in activation across different DR. Additionally, the use of images to measure muscle architecture (i.e. pennation angle) would allow insight on the influence of this variable on EMG amplitude with different velocities. The results of the present study maybe limited to the bench press performed in a Smith machine due to the free-weight bench press exercise the bar is free, and so more susceptible to movements which may influence EMG signal. Lastly, it is important to notice that given the muscle fibers movement below the electrode, the recording conditions may change across joint angles; hence, this might have an effect on the EMG recordings.

5. Conclusions

To conclude, the present study revealed that although a protocol with shorter DR and higher NR produce a higher EMG_{PEAK}, both protocols achieved EMG_{PEAK} at the same ROM. Additionally, PM and TB muscles presented higher neuromuscular activation than AD, regardless of protocol. Moreover, due to biomechanical joint characteristics, TB EMG_{PEAK} occurred in different ROM than the

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other muscles in both protocols. However, in order to further understand the mechanisms behind the changes in neuromuscular activation when protocols with different DR and NR (but equalized TUT) more research is required.

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Declaration of Competing Interest

All the authors declare no conflicts of interest exist.

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