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ACUTE NEUROMUSCULAR RESPONSES TO A RESISTANCE EXERCISE SESSION PERFORMED USING THE DELORME AND OXFORD TECHNIQUES

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ABSTRACT
Purpose. The purpose of this study was to examine and compare acute neuromuscular behavior during a resistance exercise session (RES) conducted with the DeLorme and Oxford techniques. **Methods.** Seven healthy and trained participants volunteered to carry out two RES, one week apart, of unilateral elbow flexion. Each session was conducted with the DeLorme or Oxford techniques in a counterbalanced order. Electromyographic (EMG) data were recorded from the biceps brachii (BB) and triceps brachii (TRIC) during a maximal isometric voluntary contraction. Normalized EMG amplitude from BB and TRIC and the co-contraction ratio (CCR) during the concentric and eccentric phases were calculated. **Results.** The EMG amplitude from BB and TRIC as well as the CCR of both the concentric and eccentric phases were similar in both techniques. Additionally, normalized EMG amplitude from BB was higher during the concentric phase when compared with the eccentric phase for both techniques, supporting the hypotheses of distinct neural control for concentric and eccentric phases of movement. The DeLorme and Oxford techniques induced similar acute neuromuscular responses during the RES. **Conclusions.** Our results may support previous findings on similar strength gains after resistance training performed with both analyzed techniques.

Key words: strength training, electromyography, co-contraction

Introduction

The use of resistance training (RT) has grown in popularity over the past two decades, particularly due to its beneficial role in improving health, the skeletal muscle rehabilitation process, and athletic performance by promoting muscle hypertrophy and strength gains [1–3]. The design of an effective RT program is a complex synergism of processes, requiring the inclusion of progressive scientific principles based on research findings, veteran and modern practices, and professional knowledge accommodating individual situations, needs, and goals [4, 5].

Resistance training methods have been applied in many rehabilitation settings, with two of the more widespread methods being the DeLorme and Oxford techniques. The DeLorme technique was proposed by Thomas DeLorme and involves a progressive resistance exercise (PRE) program based on 10 maximum repetitions (10RM), where subjects perform the first set of 10 repetitions at 50% 10RM, the second at 75% 10RM, and the third (final) set at the 10RM [2, 6]. The Oxford technique is different in that the full 10RM is performed as the first set and the subsequent two sets are reduced to 75% and to 50% of 10RM. Interestingly, only few studies have been conducted to compare the DeLorme and Oxford techniques [2, 6]. Fish et al. [6] and Silva et al. [7] examined the effectiveness of the DeLorme versus Oxford method of RT training on strength performance, but knowledge relative to acute neuromuscular responses during a resistance exercise session conducted with the DeLorme and Oxford techniques is limited.

The increased ability of skeletal muscle to generate force following resistance training results from two important changes: the adaptation of the muscle fiber and the extent to which the motor neurons can activate the muscle fibers (neural adaptation) [1]. The increase in muscle strength during the early period of a resistance training program comes from a neural training mechanism involving improved motor unit recruitment ability, firing rate of motor units, and synchronization of motor units and a reduction in the coactivation of antagonist muscles, all of which can be evaluated through electromyographic (EMG) activity [1, 8–11]. Surface EMG has been widely used to evaluate muscle activity and neuromuscular behavior due to its noninvasive nature [12, 13], allowing for the straightforward identification of changes in activation patterns and sarcolemma properties [12].

The synchronization of motor units that occurs during resistance exercise bouts may act as a training stimulus where repetition produces a training response [14].

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In addition, when submitted to resistance exercise bouts, the nervous system learns to minimize antagonist co-activation, allowing strength gains through optimal agonist muscle contractions with low antagonist co-contractions [15]. It is important to note that training adaptations are a consequence of the applied stimulus which, whose optimization depends on various training features such as rest interval length, load, volume completed, and the method in which the load is applied [3].

Interestingly, neuromuscular behavior is transient in nature and has been shown to be significantly affected by its contractile history through a phenomenon of acute neuromuscular enhancement called postactivation potentiation [16]. It is plausible to think that during a resistance exercise session (RES) with multiple sets, the load of the previous set could influence the following sets. Despite this, to the authors' knowledge, no previous studies were conducted comparing the influence of a RES using progressive or regressive load on neuromuscular behavior.

Due to the limited amount of data available in this area, this aim of this study was to examine and compare acute neuromuscular behavior during a RES performed with the DeLorme and Oxford techniques. Based on the mechanism of postactivation potentiation, we hypothesized that neuromuscular behavior should differ between a RES carried out with the DeLorme and Oxford techniques, with greater EMG activity present in resistance exercise sets based on the Oxford technique due to the high load applied in the first set. For this purpose, EMG data as well as the co-contraction ratios were recorded and studied during a single elbow flexion exercise using both techniques on the biceps brachii and triceps brachii (long head) muscles.

Material and methods

Seven right-handed college-aged males volunteered to participate in this study (age 22 ± 1 years; height 175 ± 4 cm, body mass 80 ± 5 kg). All subjects were classified as experienced recreational lifters, having consistently performed a minimum of three strength workouts per week for the previous 3 years, and who trained with a constant load for all sets (i.e., 8–10 repetitions in 3–4 sets at 75–85% of 1RM with a 1–2 min rest between sets for the majority of the muscle groups, including elbow flexors). The purpose and procedures were explained to the participants and informed consent was obtained according to the Declaration of Helsinki following approval from the local Ethics Committee.

Data collection occurred over a period of four weeks with one test session held each week. At the first two test sessions, 10RM was determined (test and re-test) for each subject using standardized procedures adopted in submaximal strength testing [17]. For the next two test sessions, 3 sets of single elbow flexion exercise were performed with progressive load (Delorme technique: 50%, 75%, and 100% of 10RM) and regressive load (Oxford technique: 100%, 75%, and 50% of 10RM). A rest interval of 3 min was adopted between sets for both techniques. A counterbalanced design was used to determine the order of exercise technique for each testing session to control for order effects. Participants were allowed to continue with their normal workouts throughout the duration of the study with the following exceptions: they were instructed not to perform elbow flexions in their personal workouts nor work out on the day of their scheduled test session.

Participants performed two warm-up sets before testing: the first warm-up set was performed at 50% of 10RM for 10 repetitions, while the second warm-up set was performed at 75% of 10RM for 5 repetitions according to Willardson and Burkett [18]. After the warm-up, the resistance was modified in accordance to the exercise technique (progressive or regressive loads as explained previously) and each subject completed 10 repetitions in each set.

To ensure that all subjects were completing each repetition at approximately the same velocity, each set was timed using a metronome that determined a cadence for the eccentric and concentric phases of each repetition. The repetition cadence consisted of a 2-s eccentric phase followed by a 2-s concentric phase. The subjects performed the unilateral elbow flexion exercise seated with their right upper limb on a custom-made preacher curl bench (Fig. 1). During the concentric and eccentric components of the exercise, the participant sat at the preacher curl bench with his shoulder joint angle at 45° flexion with 0° abduction. The elbows of both arms were placed on the angled pad so that the posterior upper arms rested flat against the pad. The back was held in an upright position while the feet remained flat and stable. The axillary region was not permitted to rest over the edge of the bench. The inactive arm hung freely over the front of the bench with

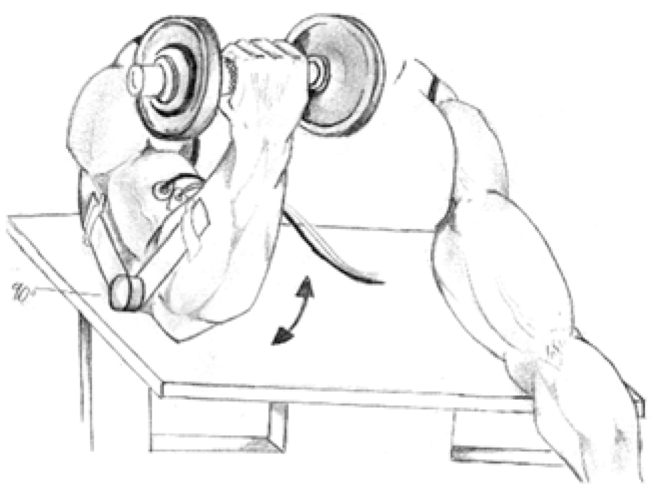


Figure 1. Diagram of the unilateral elbow flexion exercise on the preacher curl bench showing the design for EMG/range of motion data collection

the palm in a supinated position to not allow for gripping. This seated position minimized trunk rotation and maximized the contribution of the biceps brachii in the effort. The elbow range of motion during the exercise was 0° denoting full extension to ~150° of flexion.

Surface EMG signals were obtained continuously throughout the task using an eight channel module (model EMG800C, EMG System, Brazil) with a total amplifier gain of 2000x, a common mode rejection ratio of 120 dB, sampled at 2000 Hz, and band-pass filtered at 20–500 Hz. A 12-bit converter with an anti-aliasing filter digitalized the analog signals at a sampling frequency of 2000 kHz for each channel. Pre-amplified Ag/AgCl bipolar superficial electrodes (model Kendall Meditrace 100, Tyco, Canada) were used with an inter-electrode (center-to-center) distance of 20 mm. After shaving and cleaning the skin with alcohol, the muscle and anatomical landmarks were determined by palpation and the electrodes were placed over the biceps brachii and long head of triceps brachii muscle according to SENIAM (surface EMG for a non-invasive assessment of muscles) procedures [19] and guided by bone prominences and the direction of the muscle fibers. The range of motion of the elbow joint was recorded simultaneously with the EMG signal by an electrogoniometer connected to the same eight channel module (EMG800C) used to obtain EMG data. Range of motion recordings were sampled at 2000 Hz and synchronized to the EMG recordings. Identification of the phases of movement (concentric and eccentric phases) was done visually, where the elbow range of motion ranged from 0° (full extension) to ~150° of flexion.

Prior to the warm-up and exercise protocol, EMG signal data was recorded while participants performed maximal isometric voluntary contractions (MIVC) of the right elbow during a 90° flexion and extension. The position of the body was the same as that assumed during the dynamic elbow flexion task. Participants were directed to contract as fast and as forcefully as possible and hold all contractions for 2–3 s. The mean amplitude from the EMG signal obtained from biceps brachii and triceps brachii (long head) during the MIVC was used to normalize the EMG data acquired during the dynamic task as proposed by Soderberg and Knutson [20].

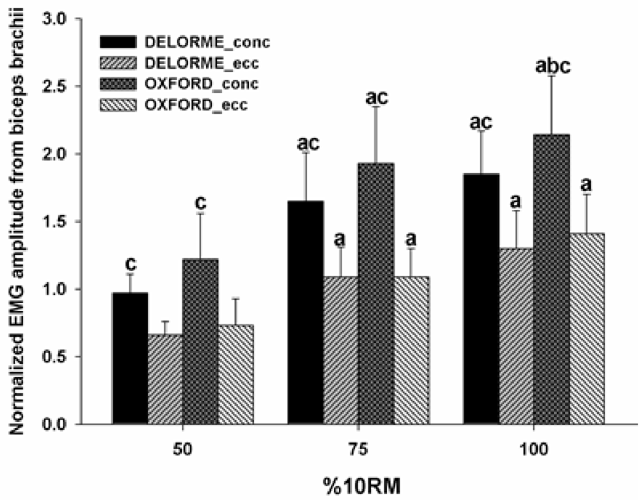
EMG data from the concentric and eccentric phases of the tasks were studied in the time domain (EMG amplitude). A specific program was developed in Matlab ver. 7.0.1 software (MathWorks, USA). For the time domain analysis, we calculated the amplitude of EMG signals during each concentric and eccentric phase using the root mean square (RMS). To reduce the variability of the obtained signal, the normalized EMG amplitudes (RMS) from the biceps brachii and triceps brachii were averaged over the 10 repetitions for each load (50%, 75%, and 100% of 10RM) for the concentric and eccentric phases. The normalized EMG amplitude of the triceps brachii was divided by the normalized EMG amplitude of the biceps brachii to calculate the co-contraction ratios (CCR) as proposed by Russell et al. [21].

Statistical analyses included calculating means and standard deviations for all collected data. A mixed-design three-way analysis of variance (2 techniques × 2 phases × 3 loads) with repeated measures on all factors was used to compare the EMG amplitude of the biceps brachii, triceps brachii, and co-contraction ratios. ANOVA results were followed by suitable post-hoc tests with Bonferroni corrections. A significance level of $p < 0.05$ was adopted as the level of statistical significance.

Results

All participants were able to complete each set of the exercises. Figures 2 and 3 present the normalized EMG data from the biceps and triceps brachii during the concentric and eccentric phases of the elbow flexion exercise using the DeLorme and Oxford techniques. No significant difference were evident between the techniques, $F(1, 6) = 0.225$, $p > 0.05$, $\eta^2 = 0.036$, observed power = 0.069. The DeLorme and Oxford techniques showed similar neuromuscular behavior during the concentric and eccentric phases at all studied loads. A significant main effect was found for phase, $F(1, 6) = 18.14$ $p = 0.005$, $\eta^2 = 0.751$, observed power = 0.951, and for load, $F(2, 12) = 16.26$, $p < 0.0001$, $\eta^2 = 0.731$, observed power = 0.996. Post hoc analysis demonstrated significant differences between phase and among load only for the biceps brachii muscle ($p < 0.05$).

For the biceps brachii, both techniques had higher ($p < 0.001$) normalized EMG amplitude during the concentric phase than the eccentric phase at 50% (Delorme $p < 0.01$, Oxford $p < 0.01$), 75% (Delorme $p < 0.01$, Oxford $p < 0.01$) and 100% of 10RM (Delorme $p < 0.04$,



(a) Difference from 50% 10RM, (b) difference from 75% 10RM,
(c) difference from eccentric phase

Figure 2. Concentric (conc) and eccentric (ecc) phases of normalized EMG from biceps brachii ($\bar{x} \pm SD$) during the elbow flexion exercise with the DeLorme and Oxford techniques at 50%, 75%, and 100% of 10RM

Oxford $p < 0.04$). Comparison of normalized EMG amplitude from biceps brachii during the concentric phase demonstrated higher values at 100% of 10RM when compared to 50% of 10RM for both techniques (Delorme $p < 0.03$, Oxford $p < 0.01$). During the concentric phase, differences were observed between 75% and 100% of 10RM only when the RES was carried out with the Oxford technique ($p < 0.03$). The normalized EMG amplitude from the biceps brachii during the eccentric phase was higher ($p < 0.05$) at 75% and 100% of 10RM when compared to 50% for both techniques.

Analysis of normalized EMG amplitude from the triceps brachii demonstrated a main effect for load, $F(2, 12) = 4.48$, $p = 0.035$, $\eta^2 = 0.427$, observed power = 0.651, with smaller values at 50% of 10RM when compared with the other loads (75% and 100% of 10RM). No significant main effect was found for technique, $F(1, 6) = 0.006$ $p = 0.939$, $\eta^2 = 0.011$, observed power = 0.051, or phase, $F(1, 6) = 0.067$ $p = 0.804$, $\eta^2 = 0.001$, observed power = 0.056, as shown in Figure 3.

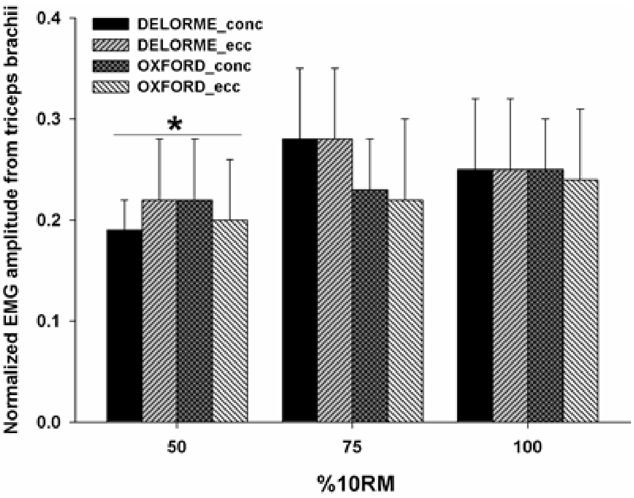
Analysis of the co-contraction ratios (CCR) demonstrated a significant main effect for load, $F(2, 12) = 37.22$, $p < 0.0001$, $\eta^2 = 0.861$, observed power = 1.000, with higher CCR at 50% of 10RM when compared with the other loads. A significant main effect was not demonstrated for technique $F(1, 6) = 0.001$ $p = 0.971$, $\eta^2 = 0.000$, observed power = 0.050, or phase, $F(1, 6) = 5.43$ $p = 0.059$, $\eta^2 = 0.475$, observed power = 0.498. The CCR values are shown in Figure 4.

Discussion

The aim of the study was to examine and compare acute neuromuscular behavior during a resistance exercise session (RES) conducted with the DeLorme and Oxford techniques. A seated unilateral elbow flexion exercise on a preacher curl bench was performed using both techniques and EMG data from the biceps brachii and triceps brachii as well as the co-contraction ratios were studied during the concentric and eccentric phases of the exercise. Our results demonstrated a significant difference between the concentric and eccentric phases and among the different loads used only for the biceps brachii in both techniques. There were no differences between techniques in all studied variables.

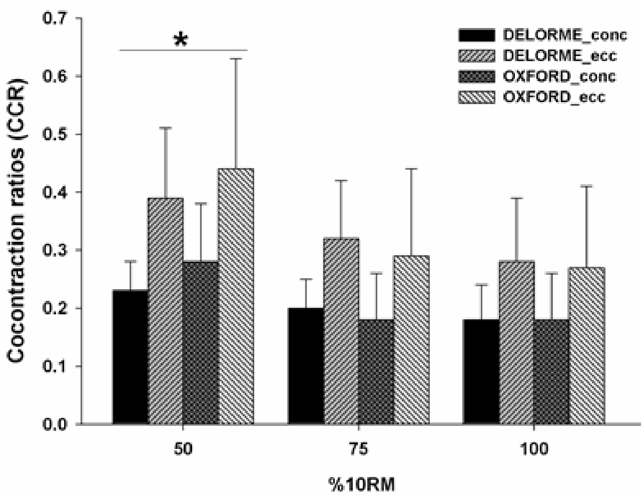
One of the main goals of resistance training is to improve strength although this depends on neural and mechanical factors. During a RES the applied load induces adaptations on muscular and neural levels. The muscular adaptations to resistance training involve hypertrophy, in which the trained muscle or muscle groups feature improvement in protein synthesis. Neural adaptations invoke an improvement in motor unit recruitment ability, the firing rate of motor units, and the synchronization of motor units and a reduction in the coactivation of antagonist muscles [1, 8–11].

Muscular coactivation, also called co-contraction, is operationally defined as the activation of both the agonist and antagonist muscle groups crossing the same joint [22]. Mechanically, increased activation levels of the antagonist muscle group results in greater joint stiffness, reduced agonist force output, and reduced net joint moment. During exercises that require maximum performance, the inhibition of antagonist muscles could be considered an efficient form of adaptation. If antagonist muscle forces increase, more work is required and this results in decreased efficiency for any given movement. In such a case, changes in muscular coactivation would be directly related to increased power output at a joint.



* Significant difference from 75% and 100 % of 10 RM ($p < 0.05$)

Figure 3. Concentric (conc) and eccentric (ecc) phases of normalized EMG from triceps brachii ($\bar{x} \pm SD$) during the elbow flexion exercise with the DeLorme and Oxford techniques at 50%, 75%, and 100% of 10RM



* Significant difference from 75% and 100% of 10RM ($p < 0.005$)

Figure 4. Concentric (conc) and eccentric (ecc) phases of co-contraction ratios ($\bar{x} \pm SD$) of the elbow joint during the elbow flexion exercise with the DeLorme and Oxford techniques at 50%, 75%, and 100% of 10RM

Pereira et al. [23] demonstrated that muscular co-activation increases during exercise, especially when the task is performed until volitional failure. In the present study, the applied exercise protocol was designed to provide the same work volume (total work represented as the product of the total number of repetitions performed and the applied resistance) for both resistance training techniques and consequently, no high values of CCR were expected to be found. However, the aim of this study was to understand the influence of progressively increasing or decreasing load on successive sets during a RES on neuromuscular behavior. Our results demonstrate that neuromuscular behavior does not differ if the RES is conducted with progressive or regressive load for successive sets. Our results may support those of Fish et al. [6], who concluded that both the DeLorme and Oxford techniques improve strength with equivalent efficacy after nine weeks of training.

The study of neuromuscular behavior includes agonist and antagonist activation as well as the agonist/antagonist ratio (co-contraction ratio). The use of normalized EMG amplitude expressed as a percentage of maximal EMG amplitude provides an approximate estimate of exercise intensity and is often referred as "the level of neuromuscular activation" [24]. Increased normalized EMG amplitude from agonist muscles in response to training is commonly believed to reflect an increased recruitment and firing rate of motor units [25], which in turn increases the force output of the muscle. Antagonist EMG is typically normalized to reduce variability and/or to relate the signal contribution to the resultant joint moment. Our findings from the normalized EMG amplitude of the triceps brachii as well as the co-contraction ratio also indicate that both techniques impose similar stimuli to the neuromuscular system.

We hypothesized that neuromuscular behavior should be different when the RES is carried out with the DeLorme and Oxford techniques, with greater EMG activity exhibited during resistance exercise based on the Oxford technique owing to the high load applied in the first set. This, however, was not observed. Our results showed similar neuromuscular behavior for both techniques, allowing for the conclusion that there is no advantage between these two resistance training techniques.

Additionally, it is important to note that our data from the concentric and eccentric phases corroborate previous findings regarding neuromuscular control of movement phases. Enoka [26] and Duchateau and Enoka [27] proposed that the neuromuscular control of concentric and eccentric contractions is different, with smaller EMG amplitude during an eccentric contraction. The reduced EMG amplitude observed during a maximum eccentric contraction suggests an incomplete activation of the motoneurons that innervate the muscle and represents a physiological strategy to control the movement.

Conclusions

The results of this study show that acute neuromuscular behavior during a resistance exercise session based on the DeLorme and Oxford techniques are similar. Each technique demonstrated similar motor recruitment from agonist and antagonist muscles during both the concentric and eccentric phases and at 50%, 75%, and 100% of 10RM. In addition, it was demonstrated that different neural strategies are adopted for the concentric and eccentric phases of movement during a resistance exercise session, irrespective of technique. It is hoped that the findings of this study will pave the way for the clinical application of these resistance exercise techniques. Based on our results, physical therapists and physicians should feel free to select either of the studied techniques with their choice based more on professional experience or patient acceptance. However, additional research is necessary to assess the influence of delayed neuromuscular adaptation to the DeLorme and Oxford weight-training techniques.

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