©Journal of Sports Science and Medicine (2016) **15,** 111-117
http://www.jssm.org

Research article

Comparison between Pre-Exhaustion and Traditional Exercise Order on Muscle Activation and Performance in Trained Men

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Abstract

The purpose of this study was to measure the acute effects of pre-exhaustion vs. traditional exercise order on neuromuscular performance and sEMG in trained men. Fourteen young, healthy, resistance trained men (age: 25.5 ± 4.0 years, height: 174.9 ± 4.1 cm, and total body mass: 80.0 ± 11.1 kg) took part of this study. All tests were randomized and counterbalanced for all subjects and experimental conditions. Volunteers attended one session in the laboratory. First, they performed ten repetition maximum (10RM) tests for each exercise (bench press and triceps pushdown) separately. Secondly, they performed all three conditions at 10RM: pre-test (bench press and triceps pushdown, separately), pre-exhaustion (triceps pushdown+bench press, PE) and traditional (bench press+triceps pushdown, TR), and rested 30 minutes between conditions. Results showed that pre-test was significantly greater than PE ($p = 0.031$) but not different than TR, for total volume load lifted. There was a significant difference between the pre-test and the time-course of lactate measures ($p = 0.07$). For bench press muscle activity of the pectoralis major, the last repetition was significantly greater than the first repetition (pre-test: $p = 0.006$, PE: $p = 0.016$, and TR: $p = 0.005$). Also, for muscle activity of the triceps brachii, the last repetition was significantly greater than the first repetition (pre-test: $p = 0.001$, PE: $p = 0.005$, and TR: $p = 0.006$). For triceps pushdown, muscle activity of the triceps brachii, the last repetition was significantly greater than the first repetition (pre-test: $p = 0.006$, PE: $p = 0.016$, and TR: $p = 0.005$). For RPE, there were no significant differences between PE and TR ($p = 0.15$). Our results suggest that exercise order decreases repetitions performed, however, neuromuscular fatigue, lactate, and RPE are not impacted. The lack of difference in total volume load lifted between PE and TR might explain, at least in part, the similar metabolic and perceptual responses.

Key words: Exercise performance, resistance training, biomechanics.

Introduction

Optimal prescription of resistance training programs relies on proper organization of training variables, such as frequency, intensity, volume, rest intervals, velocity, choice and order of exercise, and periodization (Baker et al., 2010; Foster et al., 2001). Previous research has demonstrated the importance of varying exercises and volume load (repetitions x intensity) during a resistance training program designed to increase muscle cross-sectional area and maximum strength (Fonseca et al., 2014).

The exercise (multi-joint vs single-joint exercises) significantly affects several acute training responses, such as maximal number of repetitions, neuromuscular activity (sEMG), neuromuscular fatigue, oxygen consumption, and rating of perceived exertion (RPE) (Simao et al., 2012). Multiple-joint exercises, such as bench press and back squat, require more complex neural responses, considering the high number of active muscles. In contrast, single-joint exercises, such as triceps pushdowns, have been used by those with low technical skills to target specific muscle groups (Ratamess et al., 2009). Although, there are several different ways to organize the exercise order in a resistance training program, many of them are related to sequencing of single- and multiple-joint exercises (Ratamess et al., 2009). The scientific literature has focused on primarily two different exercise order sequences, which may be classified as either whole-body or specific muscle (Simao et al., 2012; Soares and Marchetti, 2013). A whole-body exercise order is comprised of several multi- and single-joint exercises sequentially (Belleza et al., 2009; Chaves et al., 2013; Monteiro et al., 2005; Romano et al., 2013; Silva et al., 2009; Simao et al., 2007; Spreuwenberg et al., 2006), while a specific exercise order involves performing one exercise after another for the same mucle group, such as a traditional sequence (TR) (Ratamess et al., 2009) or pre-exhaustion (PE) sequence (Augustsson et al., 2003; Brennecke et al., 2009; Gentil et al., 2007). The PE sequence involves working the same muscle or muscle group to the point of neuromuscular failure using a single-joint exercise immediately followed by a related multi-joint exercise while the TR sequence uses the reverse order (multi-joint prior to single-joint) (Augustsson et al., 2003; Brennecke et al., 2009; Gentil et al., 2007). The rationale for a PE sequence lies in increased motor unit recruitment during neuromuscular fatigue, resulting in greater muscle activation for subsequent multi-joint exercises. However, Gentil et al. (2007) investigated the effects of a PE sequence on upper-body muscle activation during bench press exercise and reported that performing a pec deck exercise immediately

Received: 01 May 2015 / Accepted: 12 January 2016 / Published (online): 01 March 2016

prior to a bench press led to similar sEMG amplitude of both the anterior deltoid and pectoralis major muscles. These results further demonstrated that the total number of repetitions were not significantly different between sequences; however, it was observed that there was an increase in triceps brachii activation and a performance decrement during the bench press exercise with a PE sequence. Despite this performance impairment, an increase in sEMG during the PE sequence may occur due to neuromuscular fatigue of some muscles which is compensated for by increased motor unit recruitment of other muscles in an attempt to maintain performance. Additionally, Brennecke et al. (2009) analysed the pectoralis major, triceps brachii and anterior deltoid activation in the bench press alone and in a PE sequence (pec deck fly and bench press) in trained men. The results reported by Brennecke et al. (2009) were similar to Gentil et al. (2007) in that the PE sequence did not increase muscle activation of either the pectoralis major or anterior deltoid muscles, but did increase sEMG in the triceps brachii.

Despite the existing literature that has examined volume load and sEMG characteristics of a PE exercise sequence, no previous research has compared these characteristics or others with a TR exercise sequence or muscle order. Therefore, the purpose of this study was to combine an analysis of load, maximal repetitions, metabolic characteristics, and sEMG in order to understand the varied aspects of exercise order. Therefore, the purpose of this study was to measure the acute effects of PE vs. TR exercise order on neuromuscular performance and sEMG in trained men.

Methods

Subjects

Based on a statistical power analysis derived from iEMG data from a pilot study, a sample size of ten subjects would be necessary to achieve an alpha level of 0.05 and a power (1-β) of 0.80 (Eng, 2003). Therefore, 14 young, healthy, resistance trained men (age: 25.5 ± 4.0 years, height: 1.75 ± 0.04 m, and total body mass: 80.0 ± 11.1 kg, biacromial width: 37.1 ± 2 cm; 10 RM bench press: 680.4 ± 170 N and 10RM triceps pushdown: 260.6 ± 80.1 N) were recruited to participate in the current study. The subjects had at least one year of experience with the bench press and triceps pushdown exercises with no previous surgery or history of injury with residual symptoms (pain) in the upper limbs within the last year. This study was approved by the University research ethics committee and all subjects read and signed an approved informed consent document.

Experimental procedures

All subjects were right-arm dominant based on their preferred arm to write. Subjects were instructed not to perform any resistance exercises for 48 hours before testing. All tests were randomized and counterbalanced for all subjects and experimental conditions. Volunteers attended one session in the laboratory which was separated into two parts. First, each subject was instructed in the proper technique and rate for each exercise as follows: (a) bench press – Subjects lay supine on a weight-lifting bench and grasped a barbell with the elbows fully extended, then the barbell was lowered vertically (eccentric phase) to touch the chest then returned to a fully extended elbow position (concentric phase) at the start position; and (b) triceps pushdown - push down with the hands by extending the elbows until they were fully extended (concentric phase) then returned to the start position (eccentric phase). All subjects performed ten repetition maximum (10RM) tests for each exercise (bench press and triceps pushdown) to determine the maximum weight that could be lifted for 10 consecutive repetitions at a constant rate of four seconds per repetition (two seconds concentric and two seconds eccentric). If they did not accomplish 10RM in the first attempt, the weight was adjusted by 4–10 kg and a minimum five minute rest was given before the next attempt. Only three trials were allowed per testing session in order to avoid neuromuscular fatigue. Subjects received standard instructions regarding technique, and exercise execution was monitored and corrected when necessary, ensuring no stopping between eccentric and concentric phases for each test. For a successful repetition, the maximum range of motion was predefined for each exercise. After the 10RM load was determined for a specific exercise, 30 minutes of rest was allowed before the 10RM determination of the next exercise (Gentil et al., 2007). They also received verbal encouragement during all tests. After testing, one hour of rest was given to all subjects.

Following the rest time, all subjects performed two trials of five-second MVICs for both muscles in the same bench press position (90 degrees of elbow joint flexion and 90 degrees of shoulder joint abduction), with one-minute rest between trials. The first MVIC was performed to familiarize the participant with the procedure. After 30 minutes of rest, all exercises were performed at the load obtained during the 10RM tests; therefore, the load for bench press and triceps pushdown was the same during all conditions: pre-test, PE and TR. For Pre-test, subjects performed one set of 10RM for the triceps pushdown and bench press exercise, separated by 30 minutes. For PE, subjects performed one set of 10RM for the triceps pushdown exercise, and immediately followed with one set of as many repetitions as possible of the bench press exercise with the 10RM load. For TR, the opposite order was followed (bench press then triceps pushdown). PE and TR were executed on the same day in random order with 30 minutes rest between conditions. A unidimensional electrogoniometer was positioned on the elbow joint and was used to define the concentric and eccentric phases of each exercise using an acquisition system (EMG832C, EMG system Brasil, São José dos Campos, Brazil) with a sampling rate of 2000 Hz, and a commercially designed software program (DATAQ Instruments Hardware Manager, DATAQ Instruments, Inc., OH, USA). The electrogoniometer data was integrated to sEMG data for each exercise. All measures were performed at the same hour of the day, between 9am and 12pm.

Lactate analysis: Blood samples (25 µl) from the fingertips were collected in heparinized capillary tubes and transferred to microtubes containing 50 µL of sodium fluoride at 1%. All samples were collected at the following times (in minutes): pre-test (baseline), immediately (0-min), 3-min, 5-min, and 10-min post for both TR and PE conditions.

Surface electromyography (sEMG): Participants' skin was prepared before placement of the sEMG electrodes. Hair at the site of electrode placement was shaved, abraded, and the skin was cleaned with alcohol. Bipolar passive disposable dual Ag/AgCl snap electrodes were used which were 1-cm in diameter for each circular conductive area with 2-cm center-to-center spacing. These were placed on the dominant limb over the longitudinal axes of the Pectoralis Major (PM) at the center in the direction of the muscle fibers (sternal portion) (Clemons and Aaron, 1997; Cram et al., 1998), and on the triceps brachii (TB) at 50% on the line between the posterior crista of the acromion and the olecranon at two finger widths lateral to the line (Hermens et al., 2000). A ground electrode was placed on the right patella. The sEMG signals of the PM and TB were recorded by an electromyographic acquisition system (EMG832C, EMG system Brasil, São José dos Campos, Brazil) with a sampling rate of 2000 Hz using a commercially designed software program (DATAQ Instruments Hardware Manager, DATAQ Instruments, Inc., OH, USA). EMG activity was amplified (bi-polar differential amplifier, input impedance = 2MΩ, common mode rejection ratio > 100 dB min (60 Hz), gain x 20, noise > 5 µV), and analog-to-digitally converted (12 bit). EMG signals collected during all conditions were normalized to a maximum voluntary isometric contraction (MVIC) against a fixed bench press resistance.

Rating of perceived exertion (RPE): For assessing the RPE session (CR-10 scale) during the conditions, standard instructions and anchoring procedures were explained during the familiarization session. Subjects were asked to use any number on the scale to rate their overall effort for each condition. A rating of 0 was associated with no effort and a rating of 10 was associated with maximal effort and the most stressful exercise ever performed. Subjects were shown the scale 30 minutes after each condition and asked: "How was your workout?" (Foster et al., 2001a; 2001b).

Data analyses

Performance was defined by the volume load and was calculated for each exercise by following formula (Tran & Docherty, 2006): Volume Load=Σ(maximum repetitions x load). Then, the total volume load lifted was calculated to all conditions (Pre-test, TR and PE). Lactate concentration was analyzed via an electro enzymatic method with a lactate analyzer (YSI 2300 Stat Analyzer; Yellow Springs Instruments, Yellow Springs, OH, USA). They were expressed in mM. sEMG data were analyzed with a customized Matlab routine (MathWorks Inc., Massachusetts, USA). All sEMG data were defined by the electrogoniometer data, characterizing both the concentric and eccentric phase of each repetition. The first and last repetitions were removed from the data to ensure anybody adjustment or change in exercise cadence. The digitized sEMG data were band-pass filtered at 20-400 Hz using a fourth-order Butterworth filter with a zero lag. For muscle activation time domain analysis, RMS (150ms moving window) was calculated during the MVIC and the sEMG data. The sEMG data was then normalized to the RMS average of the two peak MVICs, and integrated (iEMG) for each condition and muscle. Then, two different analyses were performed via the iEMG data: (1) the fatigue analysis for each exercise set, for both conditions, where the iEMG was compared between the first and the last repetition for all muscles independently; (2) iEMG analysis from the first three repetitions for each condition and muscle ($iEMG_{3repts}$).

Statistical analyses

Normality and homogeneity of variances were confirmed with the Shapiro-Wilk and Levenes tests, respectively. To test differences in total volume load lifted, RPE and $iEMG_{3repts}$ one-way ANOVAs were used. To test differences in muscle activity (iEMG), a 3x3 repeated-measures ANOVAs (condition x repetition [first or last]) were used. A 2x5 repeated-measures ANOVA (condition x time) was used to measure differences in lactate. Post-hoc comparisons were performed with a *Bonferroni* test. Cohen's *d* effect sizes (*d*) were calculated by following the formula: *d = (Mean Group1 – Mean Group2)/Standard Deviation*. The effect size was evaluated based on the following criteria: <0.35 trivial; 0.35-0.80 small; 0.80-1.50 moderate; and >1.5 large, for recreationally trained subjects (Rhea, 2004). Test-retest reliability (ICC) was calculated and evaluated based on the following criteria: < 0.4 poor; 0.4 - < 0.75 satisfactory; ≥ 0.75 excellent (Rosner, 2010). An alpha of 0.05 was used to determine statistical significance.

Results

All ICCs ranged between 0.82 and 0.98 (excellent) for all dependent variables.

Maximal number of repetitions: For bench press, there was a significant ($p < 0.001$) main effect for condition. Pre-test (10 ± 0 reps) and TR (10 ± 0 reps) were significantly greater than PE (8 ± 2 reps) ($p < 0.001$, d = 1.41, Δ% = 20%). For triceps pushdown, there was also a significant ($p < 0.001$) main effect for condition. Pre-test (10±0 reps) and PE (10±0 reps) were significantly greater than TR (8 ± 2 reps) ($p < 0.001$, d = 1.41, Δ% = 20%).

Total volume load lifted: There was a significant (p = 0.028) main effect for condition. Pre-test was significantly greater than PE (p = 0.031, d = 1.04, Δ% = 22.5%) but not different than TR (Figure 1a).

Lactate analysis: There was no significant (p = 0.07) interaction of conditions and time, but there was a significant ($p < 0.001$) main effect for time. All post values were significantly greater than pre-test for both conditions ($p < 0.05$) (Figure 1b). The effect size between conditions (TR vs PE) was considered small at 0-min (d = 0.57), and 3-min (d = 0.47), but trivial at 5-min (d = 0.08), and 10-min (d = 0.019).

Muscle activity: For bench press, there was no significant interaction (p = 0.081), however, there was a significant ($p < 0.001$) main effect for repetition in all conditions. Pectoralis major muscle activity in the last repetition was significantly greater than the first repetition (pre-test: p = 0.006, *d* = 0.97, Δ% = 23.4%; PE: p = 0.016, *d* = 1.05, Δ% = 35.1%; and TR: p = 0.005, *d* = 0.90, Δ% = 31.8%) (Figure 2a). Also, triceps brachii muscle activity in the last repetition was significantly greater than the first repetitions (pre-test: p = 0.001, *d* = 1.20, Δ% = 24.8%; PE: p = 0.005, *d* = 1.43, Δ% = 37.3%; and TR: p = 0.006, *d* = 1.23, Δ% = 28.5%) (Figure 2b). For triceps push-down, there was no significant interaction (p > 0.05), however, there was a significant (p < 0.001) main effect for repetition in all conditions. Triceps brachii muscle activity, in the last repetition, was significantly greater than the first repetition (pre-test: p = 0.006, *d* = 0.81, Δ% = 19%; PE: p = 0.016, *d* = 0.58, Δ% = 16.6%; and TR: p = 0.005, *d* = 1.13, Δ% = 30.1%) (Figure 2c). There were no significant main effects (p > 0.05) for muscle or exercise in $iEMG_{3repts}$.

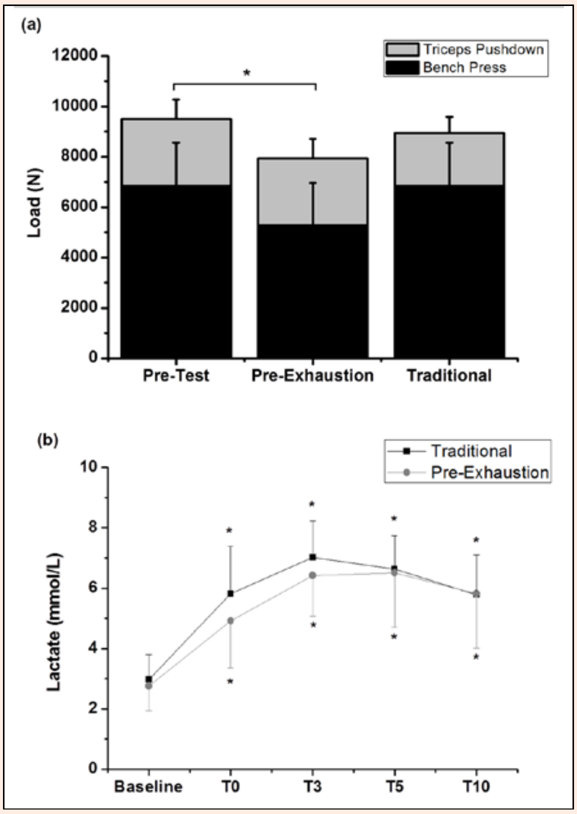

Figure 1. **Mean and standard deviation values for (a) total volume load lifted; and (b) blood lactate concentration by condition.***Significantly greater than baseline, p < 0.05.

Session RPE: There was no significant (p > 0.05) main effect for condition. There were no significant differences between PE (9.3 ± 0.7) and TR (8.8 ± 1.6): p = 0.15, *d* = 0.4, Δ% = 5.4%.

Discussion

The main results of this study demonstrated that both sequences resulted in similar performance and neuromuscular fatigue, metabolic responses, and perception of effort; however, exercise order decreased number of repetitions performed, regardless of the relative amount of muscle mass involved.

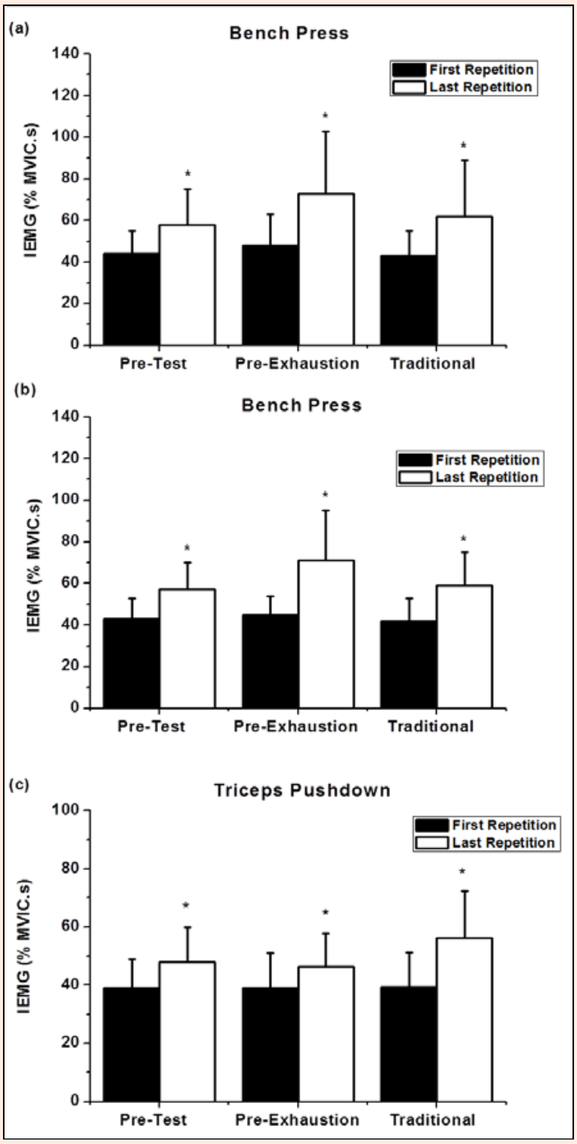

Figure 2. **Mean and standard deviation values for IEMG (a) bench press (pectoralis major activation); (b) bench press (triceps brachii activation); and (b) triceps pushdown (triceps brachii activation) by condition.** *Significantly greater than the first repetition, p < 0.05.

Regarding maximal repetition performance, the current results demonstrated a decrease (~20%) for both sequences during the second exercise, corroborating previous studies (Augustsson et al., 2003; Brennecke et al., 2009; Gentil et al., 2007; Monteiro et al., 2005; Silva et al., 2009). Additionally, Gentil et al.(2007) and Brennecke et al.(2009) considered the acute effects of performing an isolation exercise for the pectoralis major prior to completion of a compound chest exercise. Both studies reported a significantly greater number of repetitions for the compound exercise when it was not preceded by an isolation exercise. Therefore, these results may be explained by the possible influence of residual neuromuscular fatigue in the pectoralis major during the chest press exercise when preceded by an isolated exercise.

The total volume load lifted is most commonly calculated by the product of load and number of repetitions (Tran and Docherty, 2006). This is an approximation of mechanical work (force×distance) with the assumption that all repetitions are performed through the same range of motion (Tran and Docherty, 2006). Total load lifted may be considered a superior method of calculating volume compared to purely counting total repetitions because it recognizes that load is a contributing factor to volume (Tran and Docherty, 2006). Whereas in the present study, only the second exercise was affected by some level of neuromuscular fatigue independent of exercise order, total load lifted presented differences only between the pre-test and PE conditions. Even though, maximal repetitions were not signicantly different between sequences, the total load lifted was less than when triceps pushdown was the second exercise compared to when bench press was the second exercise. Considering that each lost repetition results in a loss of the total volume load lifted, the bench press resulted in a greater loss when compared to the triceps pushdown (two repetitions x 680 N vs. two repetitions x 260 N, respectively), consequently reducing the total work output (Gentil et al., 2007). The assumption that a PE sequence elicits a greater level of neuromuscular recruitment for the non-fatigued fibers, and may allow additional repetitions and/or volume was not corroborated by the present study. In addition previous studies also reported similar findings (Brennecke et al., 2009; Gentil et al., 2007).

Lactate plays a key role in carbohydrate energy between muscle and other cells (Brooks, 2000). Production of lactate in muscle during intense exercise is beneficial in removing pyruvate, sustaining a high-rate of glycolysis, and regenerating cytosolic NAD+, which is the substrate of the glyceraldehyde-3-phosphate dehydrogenase reaction. An added benefit of lactate production concerns metabolic proton buffering. Given the need for lactate production to provide sufficient NAD+ to support sustained high substrate flux through glycolysis, it is beneficial to combine glycolysis and lactate for balance of net substrates and products for the glycolytic energy system (Baker et al., 2010). No previous studies have measured the contribution of glycolytic via between different sequences. The current study found that blood lactate production increased as a result of resistance exercise regardless of exercise sequence, and that lactate concentration may represent a similar glycolytic pathway in both conditions. However, considering the practical differences between conditions (TR and PE), the time course of lactate presented a small effect size till 3-min, and then decreased to trivial (3 and 10-min). Although, the metabolites resulting from the hydrolysis of ATP used during exercise were not analyzed, the current results indicate that both sequences (with 20 seconds of rest) were insufficient for PCr resynthesis due to high glycolytic pathway stress for energy production. Charro et al. (2010) observed a positive relationship between the total volume load lifted and lactate response when the load was equalized, corroborating the results of the present study.

The amplitude of the sEMG signal (expressed by iEMG) is a measure of the voluntary drive to the muscle (Gardiner, 2011; Marchetti and Duarte, 2011). During submaximal actions, iEMG usually increases considerably due to the recruitment of extra motor units and an increase in firing frequency (Zwarts et al., 2008). Based on the iEMG data, our results showed an increase in muscle activation in the last repetition when compared to the first in both sequences. This could be related to neuromuscular fatigue until concentric failure. However, a similar muscle activation result was observed in the triceps brachii at the start of the second exercise in both sequences, which might represent low interference of the previous exercise resulting in similar activation of the pectoralis major. In contrast, the current findings did not corroborate previous studies (Brennecke et al., 2009; Gentil et al., 2007) that reported significantly greater activation of triceps muscles during a multi-joint exercise when preceded by a single-joint exercise with rest interval less than 20s. This finding suggests that bench press exercise required greater triceps brachii contribution when the pectoralis major was pre-exhausted. This study is the first to analyze the effects of a PE sequence by using the triceps brachii as a "target muscle."

Finally, the session RPE is an important subjective tool to estimate resistance training intensity and is often used during training sessions (Foster et al., 2001a; 2001b). Previous studies have examined the influence of exercise order on session RPE (Belleza et al., 2009; Monteiro et al., 2005; Silva et al., 2009; Simao et al., 2005; 2007), however all of them utilized several exercises or muscle groups while we used a specific sequence of synergistic muscles. The present study did not observe any differences in session RPE between sequences. However, an important consideration is that both sequences were performed to concentric failure and similar total volume load lifted, which may have equated the effort perception by subjects (Lodo et al., 2012).

We recognize that this study has some limitations. We did not control skinfold of the sEMG detection area, that is considered to be a low-pass filter, and there may have been some inherent differences in the tightness between subjects. We also used a healthy, non-athletic population, and our results are not generalizable to other conditions, populations, or athletes.

Conclusion

Exercise order decreased the number of repetitions performed, regardless of the relative amount of muscle mass involved. However, lactate, neuromuscular fatigue, and session RPE were not impacted. This lack of difference in total volume load lifted between PE and TR sequences might explain, at least in part, the similar metabolic and perceptual responses. Therefore, exercise order may be prescribed based on the priority of the RT training goal, irrespective of sequence or muscle group.

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Key points

- The effects of different exercise order schemes (e.g. PE and TR) on muscle activity and strength performance indicated that similar responses were observed when comparing these schemes.
- Strength and conditioning coaches should consider these results when prescribing resistance training programs.
- The primary target (e.g. muscle group) of the training session should trained first, when fatigue level low, in order to maximize training outcomes.

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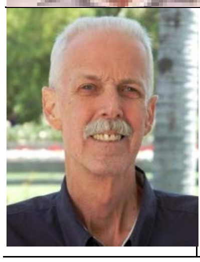

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