Original Article

Neuromuscular and metabolic responses of the pre-exhaustion method in highly-trained individuals

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ABSTRACT

Several studies investigated the pre-exhaustion resistance training (PERT), no study investigated the responses after the pre-fatigue of two auxiliary muscles. The purpose of this study was to evaluate the neuromuscular and metabolic effects of PERT in highly-trained individuals. Twenty-one men (24.90 ± 4.54 years) who were experienced in resistance training were randomly distributed into two groups. In the conventional resistance training (CRT), three sets of each exercise were performed separately (front raise [FR], triceps-forehead [TF] extensions, and bench press [BP]), with an interval of 45 seconds between the sets. In the PERT method, the exercises were performed in sequence (FR, TF, and BP), with an interval of 2 minutes 15 seconds between the sets. The electromyography (EMG), signal was acquired during the execution of the FR, TF, and BP exercises, and the muscles anterior deltoid, triceps brachii long head, and pectoralis major (clavicular head and sternal head). Lactate levels were measured before workout and at the end of each set in each method. There was no difference in the EMG activation of PMC and PMS muscles when compared to the PERT and CRT methods. Clavicular portion, PERT/CRT: 1st 42.1±7.1/42.1±6.6µV, 2st 45.9±5.5/43.5±6.2 µV, 3rd 45.5±5.7/43.9±6.1µV. Sternal portion, PERT/CRT: 1st 36.2±9/35±5.7µV, 2st 38.3±8.9/35.3±6µV, 3rd 36.8±7.1/35.1±5.1µV. However, lactate accumulation was significantly higher in PERT when compared CRT. PERT/CRT 1st 7.6.0±1.8/5.7±1.5 mmol.l^{-1}; 2st: 9.5±1.5/8.4±2 mmol.l^{-1}; 3rd:10.0±2.1/9.4±1.8 mmol.l^{-1}, when compared to CRT. The PERT was more effective, producing greater

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metabolic stress, demonstrating to be a high-intensity method that leads to muscle adaptation. **Keywords:** RESISTANCE TRAINING, ELECTROMYOGRAPHY, METHODS OF TRAINING, LACTATE, ACTIVATION.

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INTRODUCTION

According to the recommendations of prescription of resistance training (RT) for healthy adults by the American College of Sports Medicine(ACSM, 2009), single-joint exercise should be performed after multiple-joint exercise. However, the current scientific literature says that the order of prescription of exercises should be determined, taking into account the proposed objectives (Simao et al., 2012).

The reverse order of exercises, in which single-joint exercise is performed before multiple-joint exercise (Sforzo & Touey, 1996), has aroused the interest of some research groups. Previous studies that used this order showed changes in the number of repetitions (Simão et al., 2005), muscular power(Spineti et al., 2010), and muscular strength (Fisher et al., 2014).

Following this same order of execution, the pre-exhaustion resistance training (PERT) method, which has two forms of execution, has also aroused interest in the scientific community (Artur et al., 2017; Augustsson et al., 2003; Tan, 1999). In the first form, the individual performs the single-joint exercise for the same muscular group, which will later be exercised during a multiple-joint exercise, for example, chest fly followed by bench press (BP) (Gentil et al., 2007). The second form of execution is characterized by a synergic muscle fatigue through the completion of a single-joint exercise (triceps forehead [TF]), followed by a multiple-joint exercise (BP) for the agonist muscle (Guarascio et al., 2016; Soares et al., 2016).

Some of the studies that evaluated the two PERT methodologies found low agonist muscle activation (Augustsson et al., 2003; Brennecke et al., 2009; Gentil et al., 2007). However, not all the studies identified significant differences in electromyography (EMG) activation of synergic muscles (Brennecke et al., 2009; Gentil et al., 2007). Unlike the above-mentioned studies (Guarascio et al., 2016), managed to identify significant differences in EMG activation in the agonist muscles, after the fatigue of the synergic muscle. On the other hand, by using the same methodology, the authors did not identify a significant difference in activation of agonist and synergic muscles, and found no significant difference in lactate levels when comparing PERT and conventional resistance training (CRT) (Soares et al., 2016).

However, none of the studies cited above sought to study the effects of PERT, on the EMG activation of the pectorals and their synergic muscles (triceps brachii and anterior deltoid). The hypothesis of this study was that the pre-exhaustion of the anterior deltoid (AD) and triceps brachii (TB) muscles could lead to higher EMG activation of the pectoralis major muscles (PM) (Artur et al., 2017) and an increased metabolic stress. Thus, the evaluation of the metabolic effects and EMG findings from the application of PERT can provide information to assist in the continuation of the process of muscular adaptation (Schoenfeld et al., 2015), even in individuals in advanced stages of RT. Therefore, the objective of this study was to evaluate the neuromuscular and metabolic effects of PERT in highly-trained individuals.

MATERIAL AND METHODS

Participants

Twenty one trained male volunteered to participate in this study (age: 24.90 ± 4.54 years; body weight, 79.08 ± 12.83 kg; body fat, 15.38% ± 5.54%; height, 1.77 ± 6.00 m; and training duration, 3.53 ± 0.52 years). The inclusion criterion was the ability to BP 1.3 times the lean body mass (Rauch et al., 2017). Subjects were excluded from participation if they were currently taking any medications, anti-inflammatory drugs, or performance enhancers. No medical disorders, diseases, or musculoskeletal injuries were reported among the subjects. Lastly, the subjects were required to continuously train for at least 3 years before the commencement of the experimental protocol.

All volunteers were informed about the experimental procedures in the study and possible risks and discomfort. The experiment was conducted in compliance with the Declaration of Helsinki and was approved by University Ethics Committee for Human Studies of UFLA, with opinion CAAE, approved the project: 38090314.0.0000.5148.

Experimental Procedures

The evaluations were performed in five stages in the Laboratory of Human Movement Studies of the Department of Physical Education, Federal University of Lavras (UFLA). The first stage was a physical assessment of the individuals and the 1RM test in the FR exercise. In the second stage (48 h after the first session), the 1RM test was performed in the TF exercise. In the third stage (after 48 h of the second session), the 1RM test was performed in the BP exercise. After the randomization of samples per lot, in which subjects with odd numbers performed the CRT and those with even numbers performed PERT. In the four stage, the training methods were applied. Stage 5 was conducted 168 h after the previous stage, consisting in the inversion of the implementation of the training methods. The participants did not perform any resistance exercises for 72 hours before the test, and all the experimental sessions were conducted after every 168 h.

Anthropometric assessment

To characterize the sample, stature and body mass data were obtained using a scale with a stadiometer (Welmy, Santa Bárbara D'Oeste, SP, Brazil). Body composition was determined using the sevenfold protocol of Jackson and Pollock (Jackson & Pollock, 1978) using a scientific Adipometer caliper (Cescorf, Porto Alegre, Brazil), and the percentage of body fat (%bf) estimated using the Physical Test 7.0 software.

Maximum dynamic strength tests

To determine the reference value for each exercise, a maximal repetition test (1RM) was used, and the evaluation was performed in three non-consecutive days. Before beginning the test, the participants performed a 5-minute general warm-up by cycling at 60 rpm on a stationary bicycle (Movement, São Paulo, Brazil). Specific warm-up consisted of two sets of the same exercise. The volunteers performed eight repetitions with an estimated load at 50% 1RM in the first set and three repetitions with an estimated load at 70% 1RM in the second set, with a 2-minute interval between each set. After an interval of 3 minutes the 1RM test was initiated, with the initial load in the test based on the values obtained during the specific warm-up sessions. The load increments in each attempt were approximately 2.5% to 5% of the previous load. A maximum of three attempts were made to establish the 1RM load, with a rest interval of 3 to 5 minutes between the attempts (Brown & Weir, 2001). During all attempts verbal encouragement was provided. In all the 1RM tests, the speed was controlled using a digital metronome (BOSS model DB30, Hamamatsu, Japan), where 1:2 tempo, 1-second concentric phase and 2-second eccentric phases, was established.

On the first day, the volunteers performed the 1RM test for the front raise (FR) exercise. After a 48-hour interval, a TF extension test was performed, and finally, after 48 h, BP was performed.

Randomization of participants

Before starting the implementation of the training protocols, the participants were randomized by drawing lots, where each individual received a number (1 to 21). Next, those with odd numbers were assigned to first perform the CRT method, and those with even numbers were assigned to perform the PERT method. After an interval of 168 h, the subjects with even numbers performed CRT; and the odd numbers, PERT.

Conventional resistance training

In the CRT protocol, three sets of each exercise were performed with an interval of 45-second rest between each set and between exercises. First, the front raise (FR) exercise was performed, followed by the TF exercise and, finally, BP. A tempo of 1:2 (1 second for the concentric phase and 2 seconds for the eccentric phase) was set for all the exercises. The recovery interval was equalized, so no significant difference was found between the protocols. All the exercises were performed with an intensity of 70% 1RM.

Pre-exhaustion resistance training

In the PERT protocol, three sets with a routine of three different exercises (FR, TF, and BP) were performed without rest between them, at a tempo of 1:2 (1-second concentric phase and 2-second eccentric phase). The complete set was executed until concentric failure of the FR exercise, followed by the TF and BP exercises. After a complete set, an interval of 2 minutes 15 seconds of rest was held; the same interval was used between the protocols. All the exercises were performed at an intensity of 70% 1RM.

Surface electromyography

The EMG signal was captured throughout the implementation of the protocols (CRT and PERT). A Miotool 400 Electromyographer (Miotec Equipamentos Biomédicos Ltda, Porto Alegre, Brazil) was used to record the signal, using 3M 2223BR disc-shaped, 1-cm-diameter electrodes, with an AgCl capture surface. The electrodes were placed on the body of the evaluated subjects in accordance with the points proposed by (Merletti & Di Torino, 1999), maintaining a distance of 2 cm parallel to the muscle fibers. Procedures to avoid possible interference in EMG signal were followed before placing the electrodes, especially skin trichotomy and asepsis of the site with alcohol-soaked cotton. All channels of the electromyographer were duly calibrated before the recording (Da Silva et al., 2014). The EMG data were normalized by the peak of contraction for each muscle in each one of the exercises.

Sampling of blood lactate

For the analysis of blood lactate level, a prick was performed in the earlobe using lancets (Accu-Chek Safe-T-Pro Uno, Roche, Hawthorne, USA), with the first drop being discarded and then 25 µl of blood collected for lactate analysis in the pre-workout condition by using reactive strips (Accusport Boehringer Mannheim (BM) - lactate, Roche). Blood was also collected 1 minute after at the end of each set in both protocols to compare the methods. A portable analyzer (Accusport BM-lactate, Roche) was used for lactate analysis, and it was previously validated(Bishop, 2001).

Statistical analysis

All group data are reported as mean ± standard deviation (SD) and 95% confidence intervals (CI). Data analyses were performed using the SPSS 23 statistical software (IBM, Chicago, USA). Data were subjected to the Kolmogorov-Smirnov test with Lilliefors correction normality test; the logarithmic transformation (base 10) was performed for dependent variables that did not show a normal distribution. The descriptive analysis was presented with both mean and standard deviation (SD). The homogeneity of variances was determined by Box's M test. Intragroup and intergroup comparisons were performed using general linear models (GLM) multivariate analysis of covariance (MANCOVA). This utilized two factors, the time factor for intragroup comparison and the group factor for intergroup comparison. Statistical significance was set at p values of <0.05.

RESULTS

General sample characteristics are presented in table 1. All 21 participants completed the study.

Table 1. General sample characteristics

Characteristics	Mean (SD)	
Age (years)	24.90	(4.54)
Weight (kg)	79.08	(12.83)
Height (cm)	177.00	(6.00)
LM (Kg)	66.15	(10.2)
FM (Kg)	12.15	(6.16)
1RM	----	----
BP (Kg)	93.6	(18.6)
TT (Kg)	38.2	(9.8)
FE (Kg)	26.0	(5.3)

LM: lean mass; FM: fat mass; rep.: repetitions; s: seconds; kg: kilograms; BP: Bench Press; TF: Triceps Forehead; FE: Front Elevation; 1RM: 1 Maximum Repetition.

The result of the EMG analysis in the Pectoralis major Clavicular portion (PMC) and Pectoralis major Sternal portion (PMS) muscles during the BP exercise showed no significant difference in the comparison between the methods and when a comparison between the sets of each method was performed. The lactate analysis revealed significant differences between the methods (PERT x CRT) and when comparing the sets of each method, with higher values after the completion of the PERT method, as shown in table 2.

Table 2. Results of EMG activity and blood lactate on 3 different sets and comparison of those results between PERT and CRT. Mean (SD)

	PERT (n=21)			CRT (n=21)			Homosc.		Time factor		Group factor	
	1st set	2nd set	3rd set	1st set	2nd set	3rd set	M	p	F	P	F	p
PMC (%)	42.1 (7.1)	45.9 (5.5)	45.5 (5.7)	42.1 (6.6)	43.5 (6.2)	43.9 (6.1)	1.3	0.204	2.5	0.089	1.4	0.240
PME (%)	36.2 (9.0)	38.3 (8.9)	36.8 (7.1)	35.0 (5.7)	35.3 (6.0)	35.1 (5.1)	1.3	0.204	0.3	0.726	2.3	0.129
LAC(mmol/l)	7,6 (1,8)*	9,5 (1,5)*,#	10,0 (2,1)#	5,7 (1,5)	8,4 (2,0)#	9,4 (1,8)#	1,3	0,204	10.4	0.001	15.1	0.001

*: p<0.05 for the same set in intragroup comparisons.
#: p<0.05 for comparison with 1st set.
PERT: pre-exhaustion resistance training; CRT: conventional resistance training; PMC: pectoralis major clavicular portion; PMS: pectoralis major sternal portion; LAC: blood lactate.

DISCUSSION

The objective of this study was to evaluate the neuromuscular and metabolic effects of PERT in highly trained individuals. One of the main novelties of this study was the form of realization of the PERT method with the pre-fatigue state of the AD and TB muscles, before exercising the agonist muscles (PMC and PMS). The main results of this study revealed that 1) the time factor indicated no statistically significant change in the EMG signal in the agonist muscles; 2) the group factor showed no statistically significant difference in the EMG signal in the agonist muscles between the protocols used (CRT × PERT); 3) the analysis of blood lactate level indicated that the factor time led to a higher accumulation of lactate in sets 2 and 3 of the protocols, compared with set 1; and 4) the PERT protocol promoted a higher accumulation of lactate when compared with CRT.

Our EMG findings agree with previous studies (Artur et al., 2017; Augustsson et al., 2003; Brennecke et al., 2009; Gentil et al., 2007; Soares et al., 2016), in which the authors could not identify any significant difference in the activation of the agonist muscles between the protocols. However, studies observed a significant difference in the neuromuscular activation of TB, when comparing PERT and CRT (Gentil et al., 2007), (Brennecke et al., 2009) and (Artur et al., 2017). Moreover, a study, Identified a greater activation of the TB in comparison with PM during the completion of the BP exercise (Gentil et al., 2007). However, it should be noted that a higher synergic muscle activation is not the main objective of PERT.

Recently researchers evaluated the activation of the PM alone during BP and after 10RM triceps extension (PERT) and identified significant differences in EMG activation of the agonist muscles (PM) after fatigue of the TB (Guarascio et al., 2016), corroborating the hypothesis of Tan (Tan, 1999). However, this difference in the outcome may be related to the time interval between the application of the protocols (72 h), not allowing residual fatigue to affect the results (Schoenfeld et al., 2016). Nevertheless, several factors are known to influence muscle activation such as the level of training, speed of execution of the movement and width of the grip, the angle of execution of movements, and electrode positioning in relation to the muscle (Soares et al., 2016).

The lactate levels showed a significant difference between the protocols (PERT $\times$ CRT), and a significant difference in comparing the second and third sets. These results show that the PERT protocol can increase metabolic stress owing to the form of implementation of the protocol (three exercises in sequence without rest between them), demonstrating a higher muscular contraction period (Mangine et al., 2015) that leads to the high-energy demand of the skeletal muscle, mainly by type IIa and IIx muscle fibers, inducing greater production of lactate through anaerobic glycolysis (Campos et al., 2017; Chatel et al., 2016).

The only study found in the scientific literature that evaluated and compared the lactate kinetics between the PERT and CRT protocols (Soares et al., 2016). However, they found no significant difference in the protocols. Nevertheless, some factors may have determined the difference between their assessments in comparison with our study. For example, we performed an equalization of the load and volume through the 1RM test in the three exercises proposed, 48 h before the application of the methods, and determination of the intensity. The number of exercises performed was higher than that in the aforementioned study (3 exercises in our study against 2 exercises in the previous study), signaling a greater volume of training (Angleri et al., 2017), which led to increased metabolic stress and, consequently, to the results obtained. We also emphasize that in this study, the short time interval between the implementation of the protocols (30 min) directly influenced the metabolic response, and it was not possible to restore normal lactate levels with a partial recovery affecting the final result (Ferreira et al., 2017; Schoenfeld et al., 2016).

One study evaluated and compared the metabolic impact between two different orders of execution of the exercises, multiple joint compared with single joint. At the end of the study, the authors found significant differences in the accumulation of lactate between the orders of execution, with the highest values found after performing multiple-joint exercises (Arazi et al., 2015). Although not investigating the PERT method, this study assessed the influence of multiple- and single-joint exercises, percentage of loads and interval times similar to ours, showing that multiple-joint exercises produce a higher metabolic stress when compared with single-joint exercises (Wirtz et al., 2014). A recent study (De Souza et al., 2017) compared lactate kinetics between three RT methods (traditional, agonist-antagonist, and super-set training). The results showed that the highest accumulation of lactate occurred after the implementation of the super-set method, with no significant difference between the other protocols, confirming that advanced methods can produce more lactate due to increased muscle stress, which may lead to greater muscle development when compared with the conventional RT training. Thus, our study corroborates other studies that also evaluated lactate kinetics during RT (Arazi et al., 2015; Soares et al., 2016; Wirtz et al., 2014). Recently, a study showed that the accumulation of lactate has a positive effect on many physiological conditions, as a fuel for many cells of our body and even the central nervous system, discarding the idea that lactate is a waste product and the main cause of muscle fatigue (Proia et al., 2016).

CONCLUSION

We can say that the PERT method did not provide greater muscle activation of the agonist muscles (PMC and PMS) when the fatigue of the auxiliary muscles was performed. This result may have been obtained due to the advanced level of training of the individuals involved in the study. However, additional studies should be performed to investigate other muscle groups, such as those in the dorsal region, given the differences in the biomechanical factors of the movement, with possible different results from other studies performed with this protocol, besides implementing a study.

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