Acute neuromuscular and metabolic responses to upper body strength, power, and hypertrophy protocols in resistance trained men

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Abstract

Aim: The purpose of this study was to compare the acute neuromuscular and metabolic responses between strength (S), hypertrophy (H), and power (P) resistance training protocols in the elbow flexors. **Methods:** Fourteen resistance trained men (age: 25 ± 4 years, body mass: 79.5 ± 9 kg, height: 177 ± 4cm) volunteered to participate. They attended four sessions separated by at least one week. On the first session, they performed a one repetition maximum (1RM) test for the standing barbell curl exercise. On the following three sessions, the training protocols were randomized to either a S (11 sets of 3 repetitions, 90% 1RM, 5-minute rest), H (4 sets of 10 repetitions, 75% 1RM, 90-second rest), or P (8 sets of 6 repetitions, 30% 1RM, 3-minute rest). Peak force (PF) and biceps brachii muscle activity (EMG) were quantified before and after each session via maximal voluntary isometric contraction of the elbow flexors. Blood samples were taken before and at 0, 3, 5, 10, 15 and 30 minutes after each session to measure the concentration of blood lactate (BL). **Results:** Higher total volume load (VL) in the S protocol compared to H (577.5±142.2 vs 568.5±133.3, P=0.03, respectively), and S compared to P (577.5±142.2 vs 294.8±67.5, P=0.001, respectively). Additionally, H showed higher VL compared to P (P=0.001). **Conclusion:** This study showed that the equated load between muscular strength and hypertrophy protocols compromised the neuromuscular and metabolic performance after single-joint exercise for upper limbs.

Keywords: fatigue, force, resistance training, strength.

INTRODUCTION

Resistance training (RT) programs are specific to training goals and the individual needs of athletes and recreational practitioners. Manipulation of acute RT variables (e.g. choice and order of exercises, frequency, intensity, volume, rest intervals, velocity) can affect acute metabolic and neuromuscular responses after a training session [1-3].

Despite the current RT scientific literature which has already classified protocols as strength (S), power (P), or hypertrophy (H) [1-4], recent reports have questioned these divisions based on acute responses of the neuromuscular and metabolic systems [5, 6]. Nicholson *et al*., [5] tested the acute biochemical and neuromuscular responses of S and H sessions via a S (4 x 6 repetitions at 85% of 1RM, with 5-minute rest), a H (4 x 10 repetitions at 70% of 1RM, with 90-second rest), and control. They observed an increase in blood lactate (BL) and a reduction in pH after the H compared to S, however, there were no differences between sessions for peak force (PF), rate of force development (RFD), or muscle activity during a maximal voluntary isometric contraction (MVIC) squat test. Additionally, McCaulley *et al*., [6] investigated the acute neuromuscular and metabolic response to S, P, and H sessions with equated relative volume via S: 11 sets of 3 repetitions in the squat exercise at 90% of 1RM with 5-minutes rest; H: 4 sets of 10 repetitions at 75% of 1RM with 90-seconds rest; and P: 8 sets of 6 repetitions of jump squats using body weight with 3-minutes rest. Their BL results were similar to Nicholson *et al*., [5], and H elicited the greatest increase followed by S, while P did not present any variation relative to baseline. They also observed a reduction in PF and RFD after S and H in the MVIC squat test. Finally, they showed that vastus medialis muscle activation decreased immediately after S in comparison to H.

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Additionally, previous studies have primarily manipulated multi-joint lower limb exercises, and different external loads among protocols, with no control of exercise cadence [7]. Probably, for these reasons, several studies have presented differences among RT protocols. Exercises such as the back squat require more complex neural responses, considering the synergism of a higher number of active muscles [2, 8]. Recent research indicates an increased involvement of the hip over the knee extensor muscles when heavier loads are lifted during squat exercise [7, 9]. Therefore, the results observed in single-joint muscles (i.e. vastus lateralis or medialis) might be affected by the different muscle contributions due to different applied loads (i.e. S, H, P). In contrast, single-joint exercise has been used to target specific muscle groups [2, 8], and has been shown to induce greater local muscle activity and local hypertrophic responses than multi-joint exercises [10, 11]. Based on our knowledge, no previous research has compared these RT protocols with upper-body exercises, equated volume load, or similar cadence. Therefore, the purpose of this study was to compare the acute neuromuscular and metabolic responses between S, H, and P protocols in elbow flexion exercise in RT men. The main hypothesis was that S would result in greater muscle activation, and H in greater lactate concentration due to increased stress.

MATERIAL AND METHODS

Subjects

The number of participants was determined using a pilot study conducted previously, all subjects presented same features that were used in the present study, based on a significance level of 5% and a power of 80% based on the peak force from the MVIC test [12]. Fourteen physical active participants were assigned to this study (age: 25 ± 4 years, total body mass: 79.5 ± 9 kg, height: 177 ± 4cm, standing unilateral dumbbell curl 1RM: 19 ± 4 kg). All subjects were regularly engaged in a RT routine for more than one year. Subjects had no previous surgery and no history of injury with residual symptoms within the last year on their upper-limbs and trunk. This study was approved by the University research ethics committee, and all subjects read and signed an informed consent document before participating (#67/2016).

Procedures

Subjects were instructed not to perform any RT procedure 48 hours before each testing session. Except for the first session, all tests were randomized for all subjects and experimental RT protocols. The first session in the laboratory was separated in three parts. First, all subjects read and signed the informed consent, and then anthropometric measures were realized. Finally, all subjects performed a specific warm-up of 8 repetitions at approximately 50% of the estimated 1RM followed by another set of 3 repetitions at 70% of the estimated 1RM, and then 1RM test was performed A 5-min rest interval was allowed between trials. Subjects were instructed to perform the proper technique and cadence for standing unilateral dumbbell curl. Subjects were standing and grasped a dumbbell with a closed, supinated grip, and elbows fully flexed (starting position), then the dumbbell was lowered (eccentric phase) to full elbow extension, then returned to a full elbow flexion (concentric phase), as previously proposed by Haff and Tripplett [13].

The following three sessions were randomly assigned, and the RT protocols were applied (S, H, and P) with a relative volume (total repetitions) equated, and based on McCaulley et al [6]. The S protocol included 11 sets of 3 repetitions at 90% of 1RM with 5-minute rest, and repetition time set to 1.5/1.5-second for muscle action (40 bpm). The H protocol included 4 sets of 10 repetitions at 75% of 1RM with 90-second rest, and repetition time set to 1/1-second for muscle action (60bpm). The P protocol included 8 sets of 6 repetitions at 30% of 1RM with 3-minute rest, and repetition time set to 0.6/0.6-second for

muscle action (90bpm) (Figure 1). Subjects received strong verbal encouragement to ensure maximal effort throughout each protocol. Each set was considered complete when the subject reached concentric muscular failure. All measures were performed at the same time of the day (9AM and 11AM), and all protocols were supervised by a RT specialist.
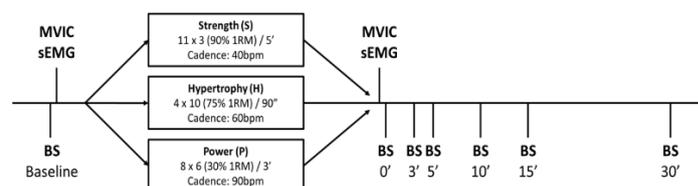
Figure 1: Experimental design. Legend: MVIC= maximal voluntary isometric contraction, sEMG = surface electromyography, BS = blood sample.

Measures

Total Volume Load: The performance was defined by the total volume load, and was calculated for each protocol by the following formula [8, 14]: Total Volume Load = Σ (maximum repetitions x absolute load).

Maximal Voluntary Isometric Contraction (MVIC): Subjects were placed seated on a preacher curl bench with elbows flexed at 90 degrees while unilaterally held a handle attached to a fixed load cell (CEFISE, São José dos Campos, Brazil). Subjects were instructed to start the MVIC as quick as possible and to sustain the maximal contraction for 10 seconds. The load cell was used to define the peak of force (PF). MVIC data were analyzed with a customized Matlab routine (MathWorks Inc., Massachusetts, USA). The PF was filtered with a 4th-order 10 Hz low-pass zero-lag, Butterworth filter. The highest value of the 10 seconds trials was used for analysis. All data were collected before and after each experimental protocol with a sample rate of 100Hz.

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 active 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 parallel to the fibers of biceps brachii (BB) on the line between the medial acromion and the fossa cubit at 1/3 from the fossa cubit [15]. A ground electrode was placed on the dominant side clavicle. The sEMG signals of the BB 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). sEMG 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). sEMG data were analyzed with a customized Matlab routine (MathWorks Inc., Massachusetts, USA). The digitized sEMG data were processed according to the following order: the sEMG was band-pass filtered at 20-400 Hz using a fourth-order Butterworth filter with a zero lag. For muscle activation time domain analysis, RMS (200ms moving window) was calculated during the second and forth seconds to avoid effects of body adjustments and fatigue. Then, the sEMG data was integrated (iEMG) in each condition. For the muscle activation frequency domain, Fast Fourier Transformation (FFT) was used for the 1 second interval. The median frequency (MedF) was calculated for each condition and used for analysis.

Blood Lactate analysis: All samples were obtained while subjects were seated on the preacher curl bench and each subject's right index finger was cleaned using alcohol prior to each colect. The first drop of blood was discharged to avoid contaminated sample. Blood samples (25 μl)

from the right index finger tips 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, 10-min, 15-min, and 30-min post each protocol. Lactate concentration was analyzed via an electro enzymatic method with a lactate analyzer (YSI 2300 Stat Analyzer; Yellow Springs Instruments, Yellow Springs, OH, USA) previously calibrated by a session using assays of a known concentration. The results were expressed in mmol/l.

Statistical analysis

Normality and homogeneity of variances were confirmed with the Shapiro-Wilk and Levenes tests, respectively. A repeated-measures ANOVAs (protocol x moment [pre- or post-session]) were used to verify differences in all dependent variables (PF, iEMG, and median frequency). A repeated-measures ANOVA (protocol x time) was used to verify differences in blood lactate concentration. A repeated-measures ANOVA was used to measure differences in total blood lactate, and total volume load. Post-hoc comparisons were performed with a Bonferroni (with correction) test. Cohen's d effect sizes (d) were calculated, and were 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 [16]. An alpha of 0.05 was used to determine statistical significance.

RESULTS

Total volume load: There was a significant ($P<0.001$) main effect among protocols. S session was significantly higher than H session ($P<0.001$, $d=0.85$ [moderate effect], Δ%= 1.5%), and P session ($P <0.001$, $d=3.54$ [large effect], Δ%= 49%). Also, H session was significantly higher than P session ($P <0.001$, $d=3.15$ [large effect], Δ%= 48%) (Figure 2a).

Peak Force: There was a significant ($P<0.001$) main effect for conditions and time. There was a significant decrease on PF between pre- and post-session ($P <0.001$, $d=0.90$ [moderate effect], Δ%=24%, and $P =0.002$, $d=1.08$ [moderate effect], Δ%=25%, respectively) for both H and S sessions. There was no significant difference between pre- and post-session for P session ($P>0.05$, $d=0.08$ [trivial effect], Δ%=1.9%) (Figure 2b).
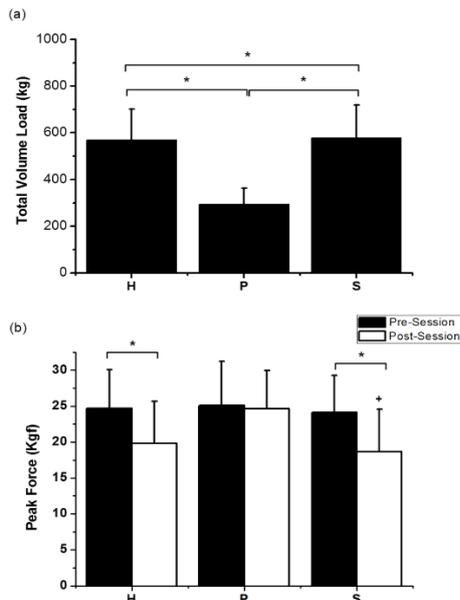
Figure 2: Mean and standard deviation of (a) total volume load, and (b) peak force for all RT sessions. *significant difference between conditions at *P* <0.001; *significant difference between pre- and post-session, *P* <0.05; and + significant difference between S and P, *P*<0.05. Legend: hypertrophy-type session (H), strength-type session (S), and power-type session (P).

Blood Lactate Concentration: There was a significant ($P=0.05$) main effect for time. The time-course revealed significant ($P<0.05$) increase in BL immediately after, 3-, 5-, and 10-min after H session when compared to pre-session (Figure 3). Also, a significant ($P <0.05$) increase was observed immediately after, and 3-min after S session. For the P session, there were no significant differences at all moments. Additionally, no differences were observed among conditions at any time moment. The effect size between S and H conditions was: small at pre-session ($d=0.75$), small at immediately after ($d=0.57$), trivial at 3-min ($d=0.29$), moderate at 5-min ($d=0.97$), small at 10-min ($d=0.75$), small at 15-min ($d=0.63$), and trivial at 30-min ($d=0.13$). The effect size between S and P conditions was: trivial at pre-session ($d = 0.33$), moderate at immediately after ($d=1.08$), moderate at 3-min ($d=1.27$), small at 5-min ($d=0.53$), small at 10-min ($d=0.79$), small at 15-min ($d=0.79$), and small at 30-min ($d=0.38$). The effect size between P and H conditions were: trivial at pre-session ($d=0.10$), moderate at immediately after ($d=1.47$), large at 3-min ($d=1.59$), moderate at 5-min ($d=1.31$), moderate at 10-min ($d=1.21$), moderate at 15-min ($d=1.39$), and moderate at 30-min ($d=1.05$).
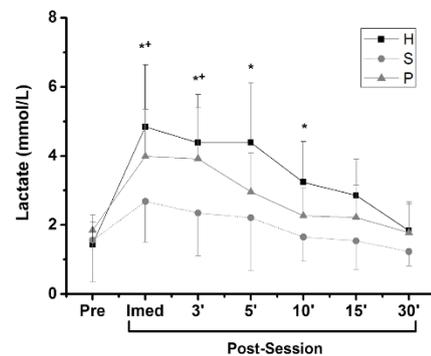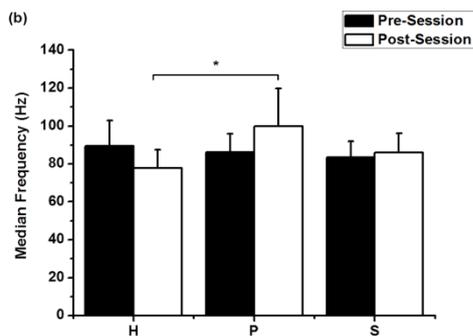
Figure 3: Mean and standard deviation for blood lactate concentration for all RT sessions. *significant difference from pre-session for H session, P < 0.05. +significant difference from pre-session for S session, P < 0.05. Legend: Imed: imediately after-session, hypertrophy-type session (H), strength-type session (S), and power-type session (P).

Integrated electromyography (iEMG): There was no significant interaction of conditions and time for IEMG. The effect size between pre- and post-session to S session was considered moderate ($d=0.81$, Δ%=26%). The effect size between pre- and post-session to H session was considered small ($d=0.41$, Δ%=11%). And, the effect size between pre- and post-session to P session was considered trivial ($d=0.26$, Δ%=10%) (Figure 4a).

Median Frequency (FMed): There was no significant interaction of time, but there was a significant main effect for condition ($P=0.032$). P session presented higher median frequency during post-session when compared to S session at the same time point ($P=0.032$, $d=0.91$ [moderate effect], Δ%=14%). The effect size between pre- and post-session on S session was considered trivial ($d=0.26$, Δ%=3%). The effect size between pre- and post-test on H session was considered moderate ($d=1.01$, Δ%=13%). The effect size between pre- and post-session to P session was moderate ($d=0.87$, Δ%=13%) (Figure 4b).
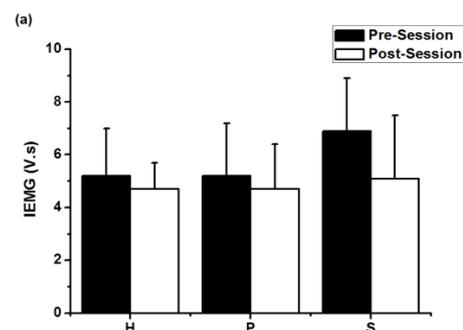
Figure 4: Mean and standard deviation of biceps brachii muscle activation: (a) iEMG, and (b) median frequency, for all RT sessions. *significant difference between conditions at the same time point, P <0.05. Legend: hypertrophy-type session (H), strength-type session (S), and power-type session (P).

DISCUSSION

The results of present study indicated an important effect of the acute RT variables when the total volume load is equated, and the cadency is controlled. It is well recognized that mechanical and metabolic stress imposed during RT is a primary stimulus to adaptive skeletal muscle response [17]. Based on this assumption, our main hypothesis was not corroborated with our results. The main findings of this study presented similarities between S and H sessions, such as a reduction in peak force, similar muscular activity, and high lactate concentration. The P session presented only a high median frequency compared to S and H sessions, which might be affected by the neuromuscular fatigue. Additionally, for the best of our knowledge, this was the first study to analyze single-joint exercises in upper limbs. The choice for single-joint exercise, and cadency was based on better control of the acting muscles, even considering only the biceps brachii for the sEMG analysis.

A specific combination of acute RT variables might be responsible for several responses in neuromuscular system [18-21]. The peak force for all protocols was similar during the pre-session evaluation, and a reduction in force was observed for S and H. The drop in peak force after S and H sessions might be related to both an equalization of the total volume load, and a higher glycolytic stress that can be correlated to the blood lactate concentration.

Strength-type sessions (S) were studied using 4 to 20 sets, one to six repetitions, between 70 to 100% 1RM, and rest intervals of 3 to 5-min. The S session allows a high amount of load to be lifted, and, it also induces a drop in the peak force (~25%)[5, 6, 22, 23]. Despite all differences in our procedures, it was observed 7 to 30% in the reduction of peck force that corroborates with previously studies [5, 6, 22, 23]. On the other hand, the effects observed in force and total volume load of the present study cannot be only attributed to neural adjustments, as shown by IEMG and median frequency. For hypertrophy-type sessions (H) were studied using 3 to 5 sets, ~10 repetitions maximal or 70 to 80% 1RM, and rest intervals of 90 seconds to 3 minutes [1-4, 24]. The reduction of ~24% on peak force after a H session is in accordance with previous studies (~16 to 48%)[5, 6, 22, 23]. In addition, the S and H session presented high values for total volume load when compared to the P session. Considering that the volume load was equated for all sessions, the P session presented the lowest physical stress when compared to S and H sessions. The results from blood lactate concentration showed low glycolytic stress to P session corroborating with the total volume load, and high time under tension.

The muscle activation (IEMG and median frequency) of the biceps brachii was not changed for H and S sessions, except for the median frequency in the P session when compared to H session. The absent of reductions in IEMG, and median frequency might indicate no changes

in output from central nervous system to muscle fibers [25]. However, it was observed an increase in blood lactate concentration for all sessions immediately after each session, which might mean a low relation between neurophysiological and metabolic alterations.

Finally, the glycolytic metabolism was highly affected in both H and S sessions, when compared to P session. Lactate is a metabolite formed in anaerobic glycolysis, and its concentration is increased in the bloodstream during high-intensity exercises [26]. In the current study, the analysis of blood lactate concentration post-exercise (pre- to 10-min) and the observed peak values indicates a relevant reliance on glycolysis as an energy pathway in H and S. The magnitude of blood lactate concentration after the P session was the lowest among sessions. It is known that the products of anaerobic glycolysis, such as blood lactate and H^+ protons can reduce the conduction velocity of action potentials [5, 25]. Changes in median frequency are highly influenced by the conduction velocity of action potentials [25]. However, it is also known that the use of high movement velocities lead to an increase on motor unit activation, and consequently, the recruitment of fast twitch fibers [15, 27, 28], therefore, a shift to higher frequencies may occur [29]. The present study showed a moderate but not significant increase on median frequency after the P session (~4%), not corroborating the study of Linnamo *et al.*, [29]. Additionally, the combination of acute variables oriented to P session lead to the lowest amount of load lifted and blood lactate concentration, which might mean less physiological stress in this type of session.

We recognize that this study has some limitations. The differences on the amount of load lifted may have promoted different magnitudes of muscle damage and neuromuscular fatigue. We measured the muscle activation of only one elbow flexors (biceps brachii). Finally, our results cannot be generalizable to other conditions, populations, or athletes.

The peak force for all protocols was similar during the pre-session evaluation, and a reduction in force was observed only for S and H. The S and H session presented high values for total volume load when compared to the P session. The muscle activation (IEMG and median frequency) of the biceps brachii was not changed for all RT sessions, except to the median frequency in the P session. The glycolytic metabolism was highly affected in both H and S sessions, when compared to P session.

CONCLUSION

This study showed that the equated load between muscular strength and hypertrophy protocols compromised the neuromuscular and metabolic performance after single-joint exercise for upper limbs (elbow flexors). In this way, the maximum strength protocol may be prescribed in order to induce both acute metabolic and neuromuscular stress similarly to the hypertrophy protocol. However, even with equated loads, the power protocol presented important differences compared to strength and hypertrophy, such as a small drop in the peak force and lactate production. In this way, resistance training protocols, with equated load, might affect both metabolic and neuromuscular acute responses differently, as well as possible recovery time and chronic adaptations.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors' Contribution

Daniel Alves Correa (Data collect, and Data Analysis), Charles Ricardo Lopes (Main Idea, Data Analysis, Article Writting, Final Review), Antônio Cláudio Paulodetto (Data collect, and Data Analysis), Enrico Gori Soares (Data collect, and Data Analysis), Willy Andrade Gomes (Data collect, and Data Analysis), Josinaldo Jarbas da Silva (Data collect,

and Data Analysis), Lee E. Brown (Article Writting, Final Review), Paulo Henrique Marchetti (Main Idea, Data Analysis, Statistical Analysis, Article Writting, Final Review).

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