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# Different Load Distributions Affect Acute Neuromuscular Responses and Muscle Thickness in Resistance-Trained Men

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**Abstract** The aim of the present study was to compare acute neuromuscular responses and muscle thickness of a resistance training session with continuous- vs. grouped-sets. The experimental procedures were performed across three sessions in a crossover and random fashion. During the first session, all subjects were familiarized and the 10RM load was determined for both exercises: biceps curl (BC) and triceps extension (TE). The following two sessions were randomized for continuous- or grouped-sets. For continuous-sets, 8 sets of 10RM for each exercise (BC and TE) were performed sequentially, while for grouped-sets, each exercise was alternated every 4 sets until 8 sets of 10RM for each exercise were completed. Two minutes of rest was used between sets and exercises. Volume load and muscle thickness (biceps brachii, $MT_{BB}$, and triceps brachii, $MT_{TB}$) were measured pre- and post-exercise. Peak force and myoelectric activity (iEMG) were measured for each exercise (BC and TE) and each muscle (biceps brachii and triceps brachii) during a maximal voluntary isometric contraction test. Results demonstrated that volume load was significantly greater in grouped-sets for both exercises ($P<0.001$). $MT_{BB}$ and $MT_{TB}$ increased after both sessions ($P<0.001$), however, there was a greater effect with continuous-sets when compared to grouped-sets ($P=0.001$). Peak force decreased for both exercises and sets ($P<0.05$). iEMG decreased only after continuous-sets for both muscles ($P<0.001$). In conclusion, continuous- and grouped-sets resulted in specific neuromuscular responses and similar muscle thickness for prime movers. Continuous-sets decreased peak force, volume load, and muscle activity, and increased muscle thickness, while grouped-sets decreased peak force and maintained a high volume load.

**Keywords** Neuromuscular fatigue, Muscle edema, Strength

## 1. Introduction

The training division of muscle groups on different days is characterized by split routines. It is a common strategy used by experienced lifters in resistance training programs (RT) designed to reach different goals such as hypertrophy or strength. Split routines are utilized to increase volume load, incorporate more exercises per muscle group, and increase variability in RT sessions. In this way, each session may be more efficient [17, 18, 25].

Some studies have shown that RT to concentric muscular failure is required for maximizing exercise-induced muscle hypertrophy [32]. In order to avoid high levels of neuromuscular fatigue and maintain a high volume load during all sessions (per muscle group), several methods can be proposed to manipulate load and sets (i.e. superset, compound sets, etc.) [27]. These methods are based on increasing rest between sets, changing the exercise order or muscle groups [23]. A method called continuous-sets is common in RT programs, and consists of performing all sets of each exercise sequentially with a fixed rest interval.

According to previous research, performing continuous-sets may alter muscle activation [7], level of neuromuscular fatigue [16], or transient muscle swelling in prime movers [24]. However, performing multiple sets continuously to muscle failure decreases the number of repetitions and volume load. Both methods are commonly used in RT programs, however, to the best of our knowledge there are no studies comparing these different methods in RT

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sessions. Therefore, the purpose of this study was to compare the acute neuromuscular responses and muscle thickness in two different RT sessions with continuous- or grouped-sets. It was hypothesized that both distributions would promote a reduction in muscle activity and increase in muscle thickness due to muscular failure, but grouped-sets would promote greater volume load and peak force compared to continuous-sets based on longer rest intervals between blocks of sets.

## 2. Methods

### Subjects

The sample size was justified by an a-priori power analysis (G*Power) based on a pilot study where the peak force on a maximal voluntary isometric contraction (MVIC) was assessed as the outcome measure with an effect size of 0.75, an alpha level of 0.05, and a power ($1-\beta$) of 0.80 [6]. Sixteen physically active participants volunteered for this study (age 27 ± 6 years, total body mass 81.8 ± 7.8 kg, height 174 ± 5cm, BC 10RM 61 ± 11 kg, and TE 10RM 70 ± 12 kg). All subjects were regularly engaged in RT for more than one year (at least 3 times a week), and familiar with standing biceps curl (BC) and triceps extension (TE) exercises. They had 3±1 years of experience in hypertrophy-type RT, no previous surgery or history of injury with residual symptoms (pain) in the upper limbs within the last year. The University research ethics committee approved this study (#67/2016), and all subjects read and signed an approved informed consent document.

### Procedures

Subjects were instructed not to perform any RT for 48 hours prior to each of three testing sessions. All tests were randomized and counterbalanced across subjects for exercise order, and distributions. In the first session, upper limb dominance and anthropometric measures were taken. All subjects were right-arm dominant based on their preferred arm to write. Then, subjects were instructed in the proper technique for the BC and TE. For BC, all subjects were positioned standing in front of a cable-pulley machine and were instructed to use a supinated grip on a straight bar. They lifted the weight stack from complete elbow extension to complete elbow flexion (concentric phase), then returned to full elbow extension (eccentric phase). For TE, they were positioned standing in front of a cable-pulley machine and were instructed to use a pronated grip on the same bar. They lowered the weight stack from complete elbow extension to complete elbow flexion (eccentric phase) then returned to full elbow extension (concentric phase). All subjects underwent 10RM testing (according to guidelines established by the National Strength and Conditioning Association [NSCA] [4]) to determine individual initial training loads for each exercise, and the cadency was self-selected. Three to five minutes rest were used between attempts and 30 minutes between exercises. For both exercises BC and TE, no trunk movement was allowed during the repetitions and partial repetitions were not counted by the researchers.

Two sessions were randomly assigned for each subject, exercise order, and distribution (Figure 1). Initially, a pre-test was conducted with measurements of muscle thickness from biceps brachii ($MT_{BB}$) and triceps brachii ($MT_{TB}$) via ultrasound. Sequentially, all subjects performed three trials of five-second MVICs for both exercises with elbows positioned at 90°, with 10-sec rest between trials. During MVICs, data were collected via a load cell and surface electromyography (sEMG) from elbow flexors (biceps brachii) and elbow extensors (lateral head of triceps brachii).

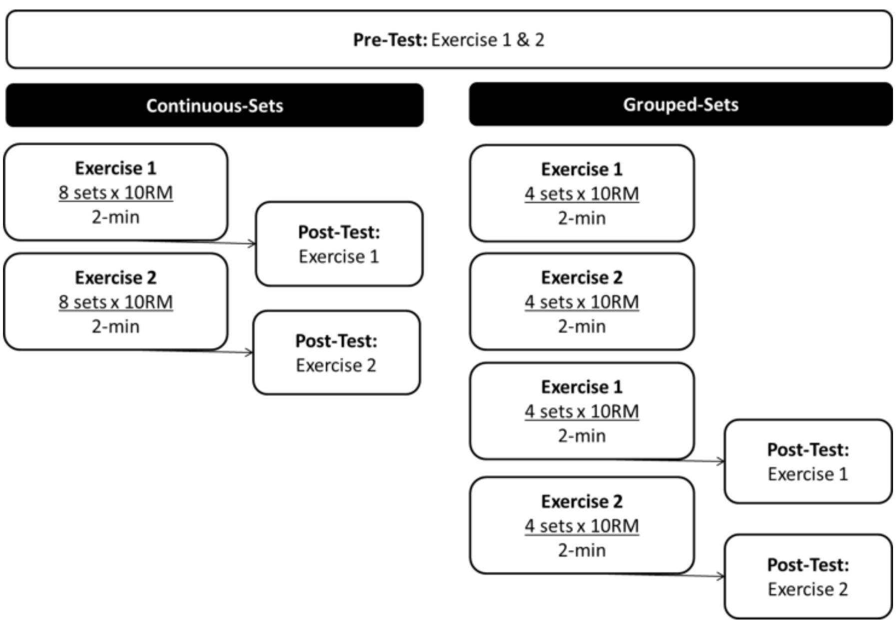


**Figure 1.** Design of the experimental procedures

After the pre-tests, all subjects performed one of two distributions (Figure 1). For continuous-sets, subjects performed eight sets for the first exercise, then eight sets for the second exercise. For grouped-sets, subjects performed four sets of each exercise, then changed exercises until eight sets of each exercise were completed. For both distributions, all sets were performed to concentric failure using 10RM loads, with two minutes rest between sets and exercises. All sessions were directly supervised by research assistants to ensure proper performance of the exercises and experimental procedures. Post-tests were performed for muscle thickness and MVIC immediately after subjects completed eight sets of each exercise, independent of distribution (continuous- or grouped-sets). No injuries were reported and total time of sessions was similar for both distributions.

**Measurements**

*Maximal Number of Repetitions and Volume Load (VL):* The maximal number of repetitions of each set was counted for each experimental condition. Volume load (VL) was calculated for each exercise by the following formula ([28]: VL = Σ sets (number of repetitions x 10RM load).

*Maximal Voluntary Isometric Contraction (MVIC):* Subjects were placed standing with elbows flexed at 90 degrees, and bilaterally held a handle attached to a fixed load cell (EMG832C, EMG system Brazil, Brazil). A supinated grip was used for the standing BC, while a pronated grip was used for the TE. Subjects were instructed to produce force as quickly as possible, and sustain a maximal isometric contraction for 5-sec. Data were analyzed with a customized Matlab routine (MathWorks Inc., Massachusetts, USA). MVIC data were low-pass filtered at 10 Hz using a fourth-order Butterworth filter with a zero lag. The highest value of three MVIC trials was defined as peak force (PF).

The test-retest intraclass correlation coefficient (ICC) calculated through the data collected (three trials) were 0.98 and 0.97 during the pre-test and post-test, respectively.

*Surface Electromyography (sEMG).* Subjects' skin was prepared before placement of the sEMG electrodes. Hair at the site of electrode placement was shaved; the skin was abraded and cleaned with alcohol. Bipolar passive disposable dual Ag/AgCl (Noraxon Dual Electrodes, Noraxon USA Inc, USA) snap electrodes were used which were 1-cm in diameter for each circular conductive area with 2-cm center-to-center spacing. Electrodes 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 distance from the cubit fossa. For the lateral head of triceps brachii (TB), electrodes were placed at 50% of the line between the posterior crista of the acromion and the olecranon at 2 finger widths lateral to the line (5). A ground electrode was placed on the olecranon of the dominant upper limb. The sEMG signals of the BB and TB were recorded by an electromyographic acquisition system (EMG832C, EMG system Brazil, Brazil) with a sampling rate of 2000 Hz using a commercially designed software program (EMG system Brazil, Brazil). The sEMG signal was amplified, and analog-to-digitally converted (12 bit) then analyzed with a customized Matlab routine (MathWorks Inc., Massachusetts, USA). 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, root mean square (RMS) with a moving window (200ms) was calculated from the $2^{nd}$ to $4^{th}$ second to avoid effects of body adjustments and fatigue. Then, the RMS data were integrated (iEMG) for each condition. The iEMG was calculated to the same peak MVIC data.

*Muscle Thickness (MT):* Ultrasound imaging was used to obtain measurements of MT. A trained technician performed all testing using an A-mode ultrasound imaging unit (Bodymetrix Pro System; Intelametrix Inc., Livermore, CA, USA). Following a generous application of water-soluble transmission gel (Mercur S.A. – Body Care, Santa Cruz do Sul, RS, Brazil) to the measured site, a 2.5-MHz linear probe was placed perpendicular to the tissue interface without depressing the skin. Equipment settings were optimized for image quality according to the manufacturer's user manual and held constant across testing sessions. When the quality of the image was deemed to be satisfactory, the image was saved to the computer hard drive and MT dimensions were obtained by measuring the distance from the subcutaneous adipose tissue–muscle interface to the muscle-bone interface per methods used by Abe et al. [1]. Measurements were taken on the right side of the body at two sites with all subjects in a standing position: triceps brachii ($MT_{TB}$), biceps brachii ($MT_{BB}$). For the anterior and posterior upper arm, measurements were taken at 60% distal between the lateral epicondyle of the humerus and the acromion process of the scapula. For each measurement, the examined limb was secured to minimize unwanted movement. To maintain consistency between pre- and post-intervention testing, each site was marked with henna ink. To further ensure accuracy of measurements, at least 3 images were obtained for each site. If measurements were more than 1mm different from one another, a fourth image was obtained and the closest 3 measurements were then averaged.

**Statistical analyses**

Normality and homogeneity of variances were confirmed with the Shapiro-Wilk and Levene's tests, respectively. Multiple 2x2 repeated-measures ANOVAs (condition [continuous- and grouped-sets] × time [pre- vs post-test]) were used to test differences of all dependent-variables (PF, iEMG, VL, and MT). A 2x8 repeated-measures ANOVA (condition [continuous- and grouped-sets] × sets [1 to 8]) was used to test differences in number of repetitions. Post-hoc comparisons were performed with a *Bonferroni* correction. Furthermore, the magnitudes of the differences were examined using the standardized differences based on Cohen's *d* (Effect Size Calculator, UCCS) by means of effect sizes (*d*) [19]. The effect sizes were qualitatively interpreted using the following thresholds: trivial ($ES<0.35$); small ($0.35<ES<0.80$); moderate ($0.80<ES<1.50$); and large ($ES\geq1.5$), for recreationally trained subjects[20]. An alpha of 0.05 was used to determine statistical significance.

## 3. Results

*Maximal Number of repetitions:* There was a progressive reduction in the maximal number of repetitions performed during continuous-sets ($P$<0.05; $d$=0.96 [small effect]; Δ%=49%). However, for grouped-sets, there was a progressive reduction in the maximal number of repetitions performed from the 1st to the 4th set ($P$<0.05; $d$=0.81 [small effect]; Δ%=36%), and from the 5th to the 8th set, with no difference between 1st and 5th set ($P$<0.05; $d$=0.93 [small effect]; Δ%=55.6%) (Table 1).

*Volume Load:* There was a significant difference in continuous- versus grouped-sets for BC exercise (3292±809 kgf vs. 3692±891 kgf, respectively; $P$<0.001; $d$=0.46 [small effect]; Δ%=10.8%), and for TE exercise (4114±927 kgf vs. 4636±1035 kg, respectively; $P$<0.001; $d$=0.41 [small effect]; Δ%=8.9%).

*Peak Force:* For BC exercise, there was a significant decrease in peak force in continuous-sets ($P$<0.001; $d$=1.01 [moderate effect]; Δ%=15.1%), and grouped-sets ($P$<0.001; $d$=0.95 [moderate effect]; Δ%=14.4%) (Figure 2A). For TE exercise, there was a significant decrease in peak force for continuous-sets ($P$<0.001; $d$=0.91 [moderate effect]; Δ%=13.3%), and grouped-sets ($P$=0.004; $d$=0.87 [moderate effect]; Δ%=13.8%) (Figure 2B). There was no significant difference between continuous- versus grouped-sets for both exercises and pre- vs. post-test ($P$>0.05).

*Muscle Activation (iEMG):* There was a significant decrease in BB activity for continuous-sets ($P$=0.023; $d$=0.89 [moderate effect]; Δ%=29.72%), but no difference for grouped-sets ($d$=0.08 [trivial effect]; Δ%=4.2%) (Figure 2C). There was a significant decrease in TB activity for continuous-sets ($P$=0.007; $d$=1.27 [moderate effect]; Δ%=26.4%), but no difference for grouped-sets ($d$=0.31 [trivial effect]; Δ%=10.6%) (Figure 2D). There was no significant difference between continuous- versus grouped-sets for both exercises and pre- vs. post-test ($P$>0.05).

*Muscle Thickness:* There was a significant increase in $MT_{BB}$ after continuous-sets ($P$<0.001; $d$=1.66 [large effect]; Δ%=19.3%), and grouped-sets ($P$<0.001; $d$=1.07 [moderate effect]; Δ%=14.1%). For the post-test, there was greater $MT_{BB}$ to continuous-sets when compared to grouped-sets ($P$=0.001; $d$=0.47 [small effect]; Δ%=5.3%) (Figure 2E). For $MT_{TB}$ there was a significant increase after continuous-sets ($P$<0.001; $d$=1.74 [large effect]; Δ%=16.4%), and grouped-sets ($P$<0.001; $d$=1.01 [moderate effect]; Δ%=10.5%). For the post-test, there was greater $MT_{TB}$ for continuous- versus grouped-sets ($P$<0.001; $d$=0.68 [small effect]; Δ%=6.4%) (Figure 2F).

**Table 1.** Mean ± standard deviation, delta percentage, and effect size ($d$) of the maximal number of repetitions performed in each set for continuous- and grouped-sets

| Set | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| **Biceps Curl Exercise** | | | | | | | | |
| CS | 10±0 | 9.3±1.3 | 7.4±1.8 | 5.6±1.6 | 5.6±1.5 | 5.7±1.3 | 5.3±1.3 | 5.1±1.0 |
| GS | 10±0 | 9.8±0.5 | 8.0±1.6 | 6.4±1.8 | 9.9±0.3* | 6.4±2.0 | 5.4±1.7 | 4.4±1.4 |
| Δ% | - | 5.1 | 7.5 | 12.5 | 43.4 | 10.9 | 1.8 | 13.7 |
| $d$ | - | 0.50[S] | 0.35[S] | 0.48[S] | 3.97[L] | 0.41[S] | 0.06[T] | 0.57[S] |
| **Triceps Extension Exercise** | | | | | | | | |
| CS | 10±0 | 10±0 | 8.6±1.6 | 7.1±2.3 | 6.5±1.9 | 6.1±1.6 | 5.8±1.6 | 5.7±1.2 |
| GS | 10±0 | 9.9±0.3 | 8.8±1.5 | 7.0±2.1 | 9.8±0.5$^+$ | 8.2±1.8$^\#$ | 6.2±2.3 | 5.6±2.0 |
| Δ% | - | 1.0 | 2.2 | 1.4 | 33.6 | 25.6 | 6.4 | 1.7 |
| $d$ | - | 0.47[S] | 0.12[T] | 0.04[T] | 2.37[L] | 1.23[M] | 0.20[T] | 0.06[T] |

**Legend**: CS – continuous-sets condition; GS – grouped-sets condition; T - trivial effect; S - small effect; M - moderate effect; L - large effect.

*Significant difference between conditions from the corresponding set, $P$<0.001; $^+$Significant difference between conditions from the corresponding set, $P$=0.001; $^\#$Significant difference between conditions from the corresponding set, $P$=0.003. *Significant difference between distributions in the corresponding set ($P$<0.001), +Significant difference between distributions in the corresponding set ($P$=0.001), #Significant difference between distributions in the corresponding set ($P$=0.003).

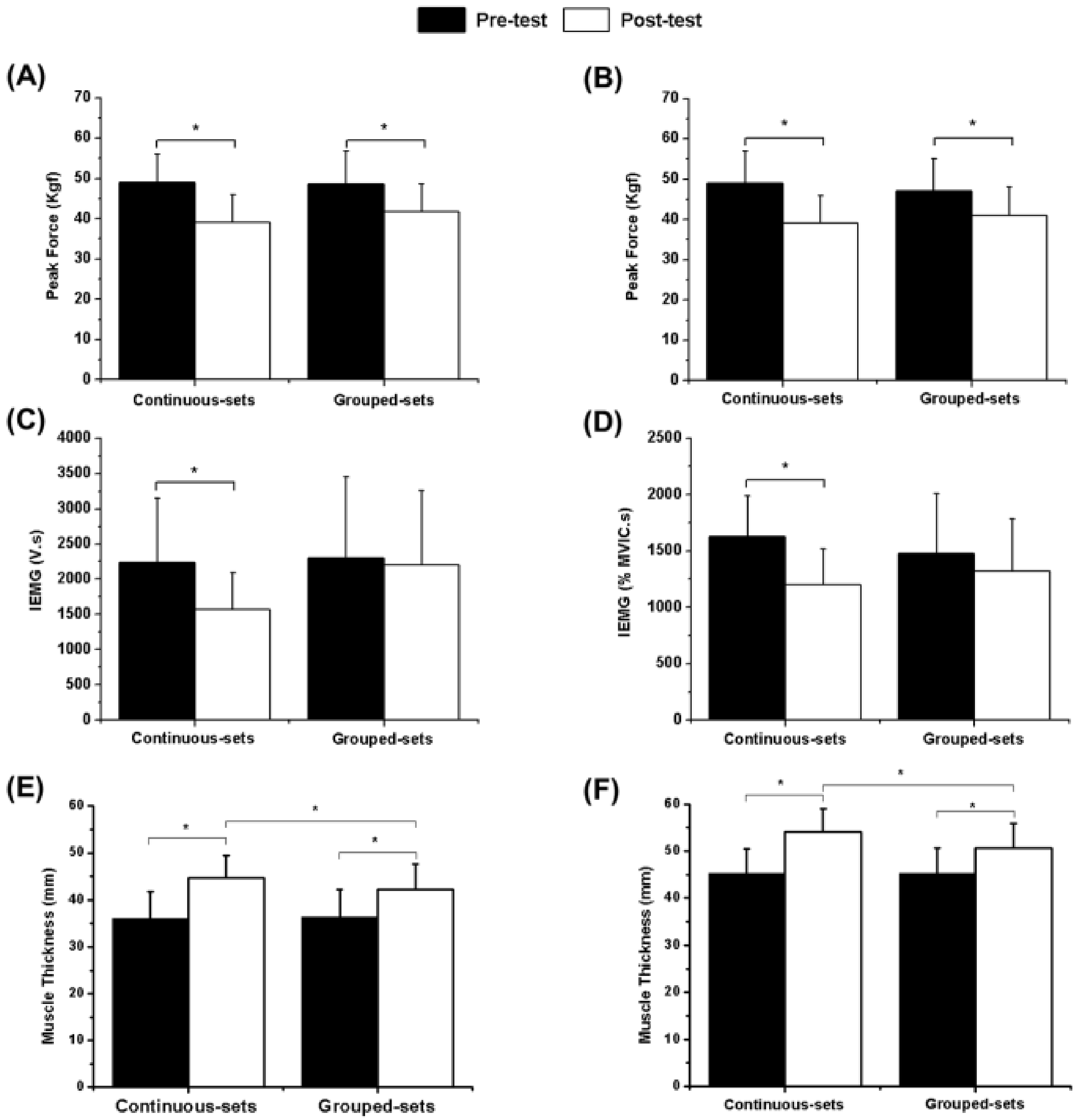


**Figure 2.** Mean ± standard deviation of peak force performed on (A) biceps curl exercise, and (B) triceps extension exercise; muscle activity of the (C) biceps brachii, and (D) triceps brachii; and muscle thickness of the (E) biceps brachii and (F) triceps brachii for all experimental conditions.*Significant difference, $P<0.05$

## 4. Discussion

The current study aimed to compare acute neuromuscular responses and muscle thickness between two different RT sessions with continuous- or grouped-sets. The findings were that acute neuromuscular responses and muscle thickness increased significantly between continuous- and grouped-sets in a single RT session. The results of the present study are partially in accordance with the main hypotheses. Continuous- and grouped-sets demonstrated similar reductions in peak force after a single RT session. Continuous-sets presented a reduction in the maximal number of repetitions and volume load when compared to grouped-sets. Muscle activity was reduced only after continuous-sets. Finally, muscle thickness was greater after continuous-sets versus grouped-sets.

Several studies have demonstrated a progressive decrease in the maximal number of repetitions with continuous-sets, even with long rest intervals between sets and exercises [19, 26, 35, 36]. Willardson and Burkett [36], Scudese et al., [26], and Ratamess et al., [19] reported a reduction in the maximal number of repetitions performed during the bench press exercise (80%1RM, 3RM, and estimated 10RM, respectively) from 2nd to 5th set with 2 minutes rest between sets. In general, reduction in the maximal number of repetitions was observed in previous studies with similar results (continuous-sets: 49%, and grouped-sets: 43%). However, based on characteristics of grouped-sets, a higher volume load was observed (~10%,) when training was divided into two moments (4sets+4sets), and separated by longer recovery times. This result is in accordance with previous studies that demonstrated a time-efficient strategy with the use of alternate exercises aiming to sustain the maximal number of repetitions over multiple sets [13, 14, 16, 21]. It is well accepted that a combination of central and peripheral fatigue is responsible for the reduction in strength over multiple sets [3], and the rest interval is the main acute variable responsible for removing its deleterious effects [33, 34]. Previous studies have indicated that an increase in the rest interval between sets promotes removal of byproducts from the glycolytic system, restores adenosine triphosphate and phosphocreatine, and increases intracellular pH [22, 33, 34]. Therefore, grouped-sets presented higher volume load when compared to continuous-sets, and maintenance of the maximal number of repetitions across multiple sets. Even with different effects of the recovery interval between conditions, peak force was reduced in both conditions because all sets reached muscular failure.

Muscle activation (iEMG) of the biceps brachii and triceps brachii decreased after continuous-sets, and remained unchanged after grouped-sets. Previous studies have reported reductions [2] and maintenance [12, 15] of muscle activity after multiple sets. They are in agreement with the present study regarding continuous-sets, even with different load strategies and exercises (single-joint [11, 28], and multi-joint [29, 30]). McCaulley et al., [15] did not observe differences in IEMG after 4 sets of 10 repetitions at 75% of 1RM in the squat exercise. On the other hand, Ahtiainen et al., [2] reported a significant reduction in iEMG after 4 sets of 12RM of leg press, 2 sets of 12RM of squats, and 2 sets of 12RM of knee extensions. However, all these studies used continuous-sets, making it difficult to compare with the grouped-sets condition in the present study. In addition, the present study design (agonist/antagonist) may have contributed to stimulating reciprocal inhibition, and reducing muscle activation in both muscles and distributions.

Results of the present study directly demonstrate characteristics of each condition. Grouped-sets allowed more time for recovery between groups of sets, while continuous-sets induced a higher level of neuromuscular fatigue, due to less recovery time between sets. Therefore, byproducts of glycolysis can directly impact excitation-contraction coupling and action potential velocity, or indirectly inhibit output from Type III (quimioceptors) and IV (mechanoreceptors and nociceptors) afferents [9, 31] primarily after maximal voluntary contractions. Therefore, training strategies that aim to achieve a high degree of neuromuscular fatigue and muscle damage could choose continuous-sets, based on reduced recovery intervals between sets [8]. In this way, grouped-sets allow greater recovery between blocks of sets enabling maintenance of the load across sets of a single session.

In regards to muscle thickness, continuous-sets presented greater values for both muscles when compared to grouped-sets. Transient edema in specific muscles is maximized, particularly after exercises until muscle failure and continuous-sets [8, 10]. Therefore, muscle thickness (MT) can be considered as a potential marker for metabolic stress including metabolite accumulation and muscle damage [8]. Additionally, during muscle contraction, the veins and capillaries are compressed, while the arteries continue to deliver blood to the working muscles causing a flow of plasma into the muscle cells. Therefore, it is possible that the shorter rest intervals in continuous-sets caused muscle transient edema when compared to grouped-sets.

We recognize that this study has some limitations. Firstly, the total time of each session could be useful to understand the metabolic effect of each distribution, however all subjects performed both conditions in similar times (Continuous-Sets:~38-min and Grouped-Sets:~42-min). Secondly, measurements of lactate removal, hormonal responses, and muscle damage could be useful to fully understand the differences between continuous and grouped-sets. Finally, the present study design may have affected the results between distributions. However, the main idea was to evaluate and report acute differences between distributions in order to allow professionals to choose the best option for specific situations. Also, the number of sets and intensity used was chosen to match the practices of recreationally trained individuals aiming to increase hypertrophy. Therefore, the results of the present study cannot be generalized to other population or training goals.

## 5. Conclusions

In conclusion, acute neuromuscular responses and muscle edema differed significantly when the sets of a single RT session were distributed differently (continuous- or grouped-sets). Continuous-sets resulted in a reduction in peak force, maximal number of repetitions, volume load, and muscle activity, but had the greatest increase in transient edema. On the other hand, grouped-sets showed a similar reduction in peak force but allowed greater volume load, and maintained muscle activity.

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