Acute Responses of A Drop-Set Session on Muscular Activation and its Applicability in Resistance-Trained Individuals

Bernardo N. Ide[1], Pedro A. B. Fonseca[1], René Brenzikofer[1,2], Leonardo H. F. Carvalho[1,2], Evanisi T. Palomari[3], & Denise V. Macedo[1].

[1]*Department of Biochemistry and Tissue Biology, Institute of Biology, State University of Campinas, Campinas, Brazil,*
[2]*Faculty of Physical Education, State University of Campinas, Campinas, SP, Brazil,* [3]*Laboratory of EMG, Motor Control, and Experimental Electro Thermotherapy, State University of Campinas, Campinas, SP., Brazil.*
Corresponding Author: bernardo_311@hotmail.com

ABSTRACT

We investigated whether performing repetitions to muscular failure (FAIL) during a drop-set would affect muscle activation in trained individuals. Twelve young men performed a drop-set session consisting of 3 sets of two intensity drops (80 to 60 and to 40% of one-repetition maximum [1-RM]) load in a leg press machine. Linear regression between the quadriceps femoris root mean square of surface electromyography (EMG_{RMS}) was employed to observe the initial muscle activation (intercept) and its behaviour over the repetitions (slope). The EMG_{RMS} intercept of the first set decreased (p<0.05) according to load reduction (136.8±4.8 at 80%1-RM to 119.3±5.5 and 110.6±5.5 at 60 and 40%1-RM, respectively). Slopes different from zero ($p<0.05$) were observed at 80 and 60%1-RM during the first set. Remarkably, during the second and third sets, we observed an increased EMG_{RMS} intercept at 60%1-RM ($p<0.05$), leading to non-significant ($p>0.05$) differences compared to 80%1-RM. The maximum initial muscle activation occurred at higher loads only, but low loads performed to FAIL may be necessary for increasing and maintaining muscle activation at higher loads. Understanding these acute responses may support coaches and athletes in optimizing strength training responses during drop-set sessions into their periodization.

Keywords: Surface electromyography; Motor unit recruitment; Intensity threshold; Strength training; Motor control; Muscle hypertrophy.

INTRODUCTION

The potential for further functional and morphological improvements appears to diminish as maximal strength and training status increase (Stone, Plisk et al. 1998). Consequently, trained individuals present lower magnitudes of gains than untrained individuals (American College of Sports 2009), thus requiring the application of advanced training stimuli.

The drop-set is an advanced training method for enhancing muscle hypertrophy in trained individuals (Schoenfeld 2011). The method is proposed to be performed by taking a set to muscular failure (FAIL) at a given load and then immediately reducing the load and performing as many additional reps as possible (Schoenfeld 2011). Nevertheless, a possible limitation of the technique could relate to load reductions. Henneman's size principle ensures that the central nervous system recruits motor units (MUs), starting with the smallest and most excitable, then progressing to the higher and most difficult to excite to maintain or increase force (Henneman, Somjen et al. 1965). Considering that MU recruitment

is necessary for subsequent adaptations, training stimuli aimed at maximizing muscular development would be performed with higher loads (Fry 2004). On the other hand, the concept that high loads are mandatory to induce muscle hypertrophy has been challenged (Mitchell, Churchward-Venne et al. 2012, Fisher, Steele et al. 2017, Schoenfeld, Grgic et al. 2017).

Studies comparing the effects of heavy or light loads have reported similar hypertrophic adaptations when repetitions are performed to FAIL (Mitchell, Churchward-Venne et al. 2012, Fisher, Steele et al. 2017, Schoenfeld, Grgic et al. 2017). Possible explanations may be that during fatiguing contractions, the excitability threshold for recruitment of type II motor units is reduced (Adam and De Luca 2003) or motor units may 'cycle' to maintain force (Westad, Westgaard et al. 2003). Additionally, the increased neural drive to the agonist and synergist muscles and the higher metabolic stress generated by the glycolytic contribution during FAIL may increase motor unit activation (Gandevia 2001, Gorassini, Yang et al. 2002). Despite the drop-set being proposed to be performed by taking a set to FAIL (Schoenfeld 2011), this procedure is not adopted in studies that represent a mischaracterization of the technique regarding its primary objectives (Kassiano, de Vasconcelos Costa et al. 2021).

The present study aimed to investigate neuromuscular activation during a drop-set session with repetitions to FAIL in trained individuals. We hypothesized that the possible decreased neuromuscular activation due to load reduction would be counterbalanced by the fatigue induced by performing repetitions to FAIL. Since longitudinal studies remain equivocal on the utility of drop-set sessions, conceivably understanding the acute responses can help to explore its potential practical applications.

MATERIALS AND METHODS

Subjects

Twelve trained men (age: 23 ± 3 years; body mass: 78.4 ± 10.4 kg; height: 1.74 ± 0.06 m; % of body fat: 11.4 ± 5.0) with 3-9 years of resistance-training experience (1-RM on 45° leg press: 489 ± 111 kg; relative strength [1-RM/body mass] = 6.3 ± 1.1) participated in the study. The inclusion criteria for participants were as follows: 1) having no intake of exogenous anabolic-androgenic steroids

or dietary supplements with potential effects on physical performance; 2) being engaged in strength training programs for at least one year before the experiments; and 3) having no current history of injuries on the lower limbs that could impair the execution of the session. After being advised about the purposes and risks of the study, all subjects signed informed consent forms. The Local Research Ethics Board approved this study.

Study design

We investigated quadriceps femoris electromyography activity during a drop-set session. The protocol was performed on 45° leg press equipment. Since this setup already characterized the proposed drop-set protocol, we used the first set as a control situation. To investigate the effect of the whole session, we compared the electromyographic responses of the second and third sets with those presented during the first. We assessed the fatigue and metabolic stress induced by observing the peak force changes–extracted from the maximum voluntary contraction test–and blood lactate concentrations measured immediately before and after training, as well as 30 min after training.

Participants made four visits to the laboratory 72 hours apart. The first three visits were destined for familiarization with the leg press equipment, range of motion, and frequency of the repetitions. Additionally, for the training load prescription, they performed the 1-RM test. On the fourth day, the volunteers performed the drop-set protocol. During the execution of the protocol, we monitored muscle activation through the amplitude of the surface electromyography signals of the vastus lateralis, vastus medialis, and rectus femoris muscles. We asked the participants to remain absent from strenuous exercise, alcohol intake, tobacco, and ergogenic supplements (such as caffeine) for 48 hours before visits.

Training protocol

The training session was performed on the same 45° leg press equipment used for the 1-RM assessment. Before the beginning of the session, subjects performed a dynamic warm-up consisting of 8 repetitions with 50% 1-RM and 3 repetitions with 70% 1-RM load. The drop-set protocol consisted of three sets with two drops (80 to 60 and to 40% 1-RM load), and repetitions performed to FAIL were defined as the inability to complete a repetition at a given load over a full range of motion without external

International Journal of Strength and Conditioning. 2023

Ide, B. N., Fonseca, P. A. B., Brenzikofer, R., Carvalho, L. H. F., Palomari, E. T., & Macedo, D. V.

assistance. Two min of rest intervals interspersed the sets, and ~10s interspersed the load reductions. Figure 1 illustrates the experimental design of the testing protocol.
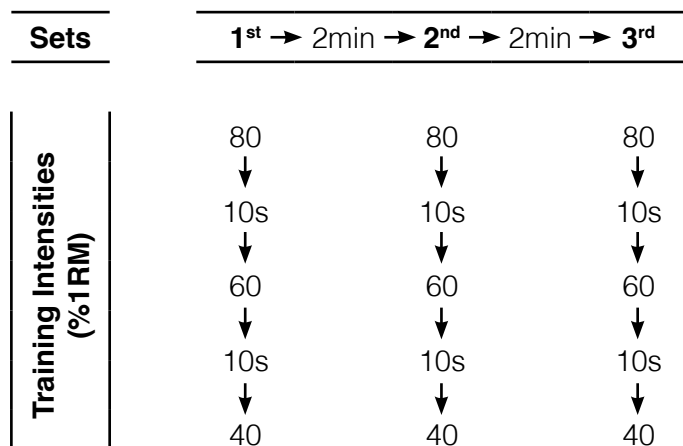
Sets	1st → 2min → 2nd → 2min → 3rd

Training Intensities (%1RM)			
	80	80	80
	↓	↓	↓
	10s	10s	10s
	↓	↓	↓
	60	60	60
	↓	↓	↓
	10s	10s	10s
	↓	↓	↓
	40	40	40

Figure 1. *Experimental design of the proposed drop-set protocol. We imposed two minutes of rest between the sets and approximately 10s between the load reductions. 1-RM = one repetition maximum test.*

We controlled the repetition frequency by a digital metronome set at 60 beats per minute. We instructed the volunteers to synchronize the transition of concentric to eccentric and eccentric to concentric phases with the equipment's audible signals resulting in execution times of ~1s for each phase of the repetitions. The range of motion for the knee and hip joints was ~90° of flexion to full extension at ~0°. Three researchers involved in the study fully monitored the session. We quantified the volume load by multiplying the repetitions by the load (in kg) employed.

One repetition maximum test (1-RM)

The 1-RM test was employed to evaluate muscular strength and to define the relative loads employed. The test was performed in the same 45° leg press machine (Tonus Fitness Equipment®, model RT 009) used for the drop-set session and was conducted according to the methods described by Brown and Weir (Brown and Weir 2001).

Surface electromyography (EMG)

Surface EMG data were recorded from the vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF) muscles of the right limb using an eight-channel EMG system (MyosystemBr1, Data Hominis Tecnologia Ltda). After preparation of the skin (shaving, lightly abrading, and cleansing with 70% ethanol), bipolar active surface electrodes were

placed over each muscle. This protocol followed the guidelines of Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM http://www.seniam.org) for electrode placement and orientation. The reference electrode (Bio-Logic Systems Corp® - made of stainless steel, with circular format and 30 mm diameter) was placed on the clavicula of the individuals.

The same investigator placed the electrodes in the same relative position on all participants during the experiment. The surface EMG signal was acquired at a rate of 1000 Hz, pre amplified (20x) and synchronized with the force signal using the same analog-to-digital converter. The data were full-wave rectified and bandpass-filtered between 20 and 500 Hz using a fourth-order Butterworth digital filter. The amplitude of the signal was calculated as the root mean square (EMG_{RMS}) of the concentric phase of each repetition. A synchronized linear potentiometer (Magneto Pot, Spectra Symbol, Salt Lake City, UT, USA) was attached to the equipment and allowed the separation of the concentric and eccentric phases of the signal. The quadriceps femoris EMG_{RMS} signals were considered the averaged EMG_{RMS} values of the three muscles [(VL+VM+RF)/3]. To minimize inter subject changes, the EMG_{RMS} values were normalized to the dynamic warm-up performed with 50%1-RM (Burden 2010).

Muscular activation analysis

The EMG_{RMS} values of each repetition were distributed equally on a 0-100 scale, which represented the % of repetitions to FAIL. The first repetition was always equal to zero, and the last was equal to 100. This procedure allowed the load and number of repetitions to be relativized according to individual values (% of 1RM and % of repetitions to fail). In this way, we evaluated the individuals under comparable, experimental conditions, which allowed the grouping of individual results and the comparison of their neuromuscular responses.

Maximal isometric voluntary contraction (MVC)

The MVC test was performed before and 30 min after training in the same 45° leg press machine used for the training session and the 1-RM test. Peak force was measured by a load cell (Reaccion®, CZCB-500) connected to the equipment calibrated before each subject's session. We acquired the force signal by the auxiliary channel of the electromyography system. During the late offline analysis, the load cell signal was converted to Newtons and smoothed by

a digital fourth-order Butterworth filter using a cut-off frequency of 15 Hz. Before the MVC tests, the subjects performed a set with a fixed load of 40 kg followed by one specific warm-up consisting of 10 isometric voluntary contractions of ~1s separated by ~1s of rest. Throughout the ten isometric contractions, the subjects were instructed to gradually increase their force. The testing protocol consisted of three MVCs of ~3s with 2 min of rest. The relative knee angle was set at 70° (0° for full extension), and during all MVCs, the subjects were instructed to exert force as fast as possible and then relax. We provided real-time biofeedback of the MVC force on a computer monitor and vigorously encouraged the participants to exceed the achieved peak force value. The maximum value of the three attempts was considered for further analysis.

Blood lactate

Approximately 25µL of blood was collected from the fingertip by using a digital puncture and disposable lancets (Roche®) before training, as well as 8- and 30-min post training. Lactate concentrations were measured using the portable lactate analyzer Accutrend® (Roche® Diagnostics, Basel, Switzerland, also marketed as Accusport® by Boehringer Mannheim, Mannheim, Germany).

Statistical analysis

We created specific routines in MATLAB 2019a (The MathWorks, Inc, Massachusetts, USA) for all the analyses. Data normality was verified using the D'Agostino-Pearson test. The EMG signal amplitude data were analyzed by analysis of covariance (ANCOVA). Analysis of variance (ANOVA) with repeated measurements and the Tukey post-test were used for multiple comparisons. The Kruskal–Wallis test and Dunn test were used for multiple comparisons of non-normally distributed data. For simple comparisons, we choose the Wilcoxon test for non-normal distributions. Unless otherwise specified, data are expressed as the mean ± standard deviation (SD). Differences were considered significant at $p<0.05$.

RESULTS

Muscle activation in the first set of sessions

Figure 2 presents the adjusted lines of the EMG_{RMS} behavior in the first set and repetitions performed in each load.
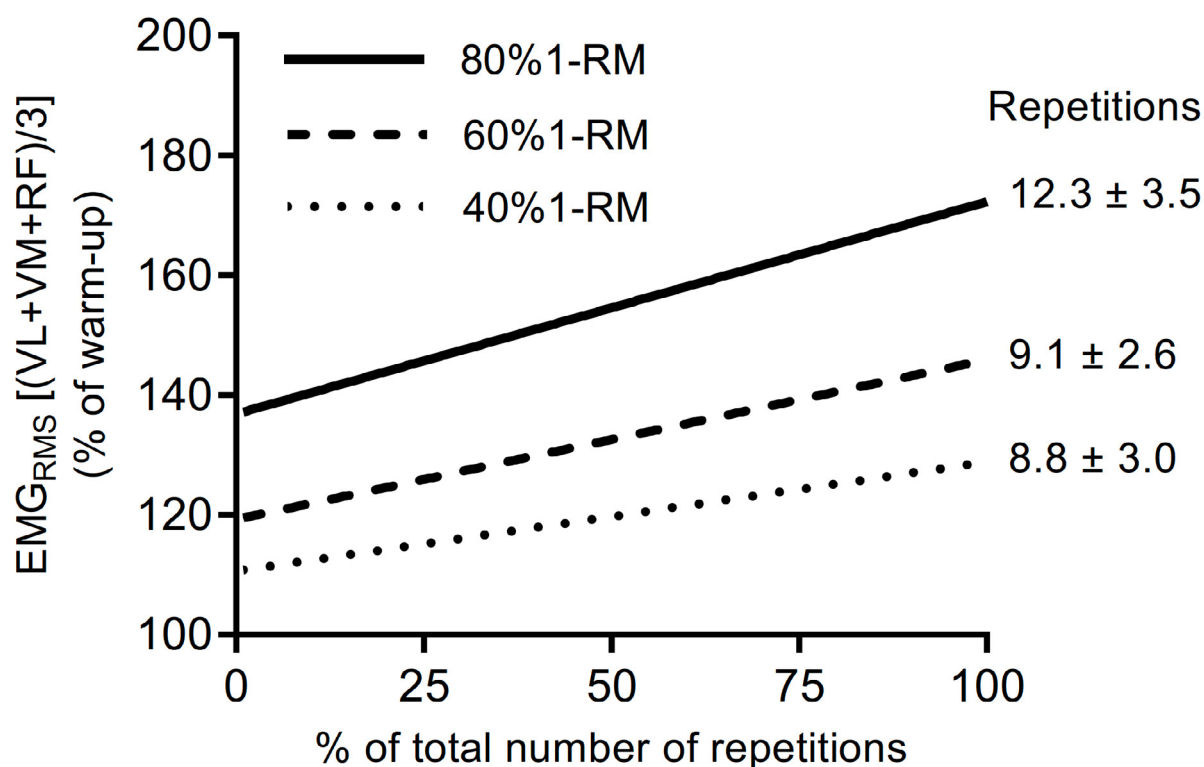
The intercept behavior (% of warm-up) indicates the

Figure 2. *Linear regressions of EMG_{RMS} at 3 loads (80, 60, and 40% 1-RM) during the first set. The number of repetitions is expressed as the mean ± SD. 1-RM = one repetition maximum test.*

International Journal of Strength and Conditioning. 2023

Ide, B. N., Fonseca, P. A. B., Brenzikofer, R., Carvalho, L. H. F.,
Palomari, E. T., & Macedo, D. V.

load's reduction effects on neuromuscular activation decreasing significantly from 136.8 ± 4.8 at 80%1-RM to 119.3 ± 5.5 and 110.6 ± 5.5 at 60 and 40%1-RM, respectively. The slopes significantly differed from zero, indicating an increased rate of muscle activation during repetitions, observed at 80 and 60%1-RM loads only (see Table 1). This first set configuration allowed an average of ~30 repetitions.

Muscle activation in the whole session

Table 1 presents the intercepts and slopes of the EMG_{RMS} linear regression analysis.

Curiously, the addition of the second and third sets led to higher EMG_{RMS} intercept values at 80 and 60%1-RM loads than those found in the first one. The EMG_{RMS} intercept at 40%1-RM remained significantly lower than those at 80 and 60% 1-RM in all sets. EMG_{RMS} slopes were not significantly different from zero in the second and third sets at all loads except for the 40%1-RM load in the third set.

Table 2 shows the number of repetitions and the volume load of the session.

Only one volunteer was unable to perform a complete repetition with 80%1-RM in the second and third sets; another was unable to perform a complete repetition with the same load in the third

set. The total volume load of the second and third sets decreased significantly by ~45 and 53%, respectively. However, the inclusion of 2 more sets doubled the volume load performed in the first.

Peak force and blood lactate

The peak force data (Fig. 3A) showed a significant decrease of approximately 24% (5171 ± 1015 N Pre to 3949 ± 854 N Post). The blood lactate concentrations (Fig. 3B) showed significant increases at 8 (14.7 ± 2.1 mmol/L) and 30 min post training (7.7 ± 2.4 mmol/L) compared to pre training (2.0 ± 0.8 mmol/L).

DISCUSSION

The present study investigated neuromuscular activation of trained individuals during a drop-set session performed to FAIL. To assess the behaviour of muscular activation during the experimental protocol, we developed two innovative methodological procedures: a) applying a linear regression model to the EMG_{RMS} values extracted from repetitions and b) using the first set as the control. The linear regression models to EMG_{RMS} values allowed us to observe the initial muscle activity (intercept) and its behaviour throughout the repetitions (slope). The relativization of the repetitions

Table 1. Comparisons of intercepts and slopes throughout the sets and intensities.

Load (%1-RM)	Set 1 Intercept	Set 1 Slope	Set 2 Intercept	Set 2 Slope	Set 3 Intercept	Set 3 Slope
80	136.8 ± 4.8	35.4 ± 8.13[&]	147.9 ± 9.2	22.2 ± 14.9	142.0 ± 9.3	27.5 ± 15.3
60	119.3 ± 5.5*	26.6 ± 9.2[&]	142.1 ± 7.9[#]	10.9 ± 13.1	143.3 ± 8.5[#]	8.1 ± 13.9
40	110.6 ± 5.5*	18.2 ± 9.2	113.2 ± 7.4*[$]	14.5 ± 12.3	106.6 ± 7.7*[$]	22.0 ± 12.7[&]

1-RM = one repetition maximum test; *Significant difference to 80%1-RM of the same set; [$]Significant difference to 60%1-RM of the same set; [#] Significant difference to 60%1-RM of the first set; [&]Significant difference from zero. Data are expressed as the mean ± SD.

Table 2. Repetitions and volume load (repetitions x load) were performed throughout the sets.

Load (%1-RM)	Set 1 Repetitions	Set 1 Volume load (kg)	Set 2 Repetitions	Set 2 Volume load (kg)	Set 3 Repetitions	Set 3 Volume load (kg)
80	12.3 ± 3.5	4761 ± 1829	4.4 ± 2.1*	1654 ± 887*	4.3 ± 2.5*	1611 ± 994*
60	9.1 ± 2.0	2645 ± 778[#]	6.5 ± 2.0[*]	1906 ± 734	5.3 ± 1.4*	1537 ± 433*
40	8.8 ± 3.0	1767 ± 790#	7.8 ± 2.5	1520 ± 585	6.6 ± 2.3	1284 ± 525
Total	30.3 ± 6.7	9173 ± 1539	18.7 ± 4.7†	5080 ± 196†	16.3 ± 4.0†	4432 ± 604†

1-RM = one repetition maximum test; *Significant difference from the first set. [#]Significant difference (p<0.05) to 80%1-RM of the same set; †Significant difference (p<0.05) from the total of the first set; Data expressed as the mean ± SD.
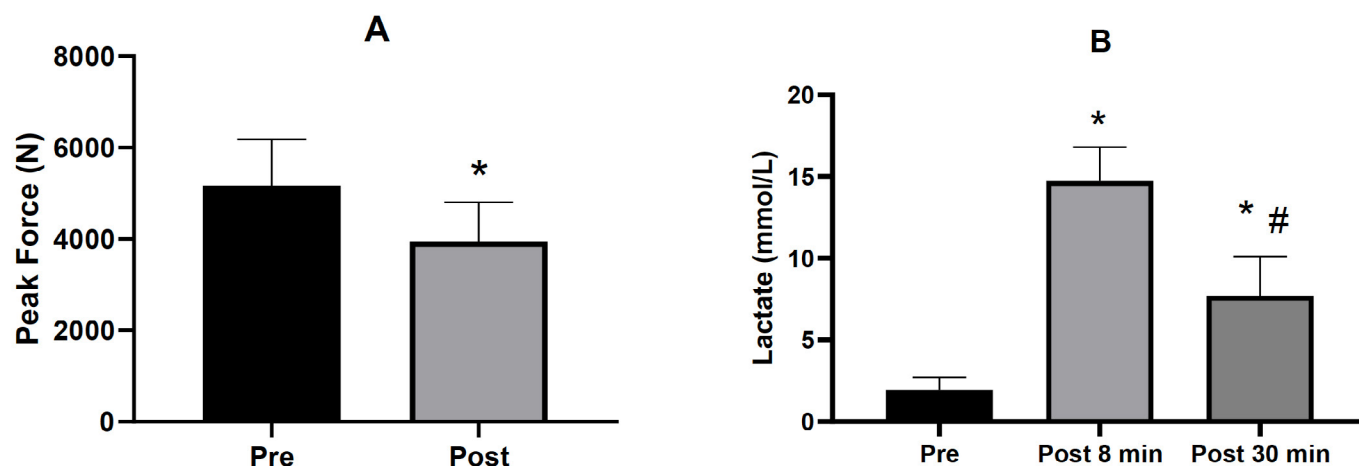
Figure 3. *Peak force (A) and blood lactate (B) before and after sessions. *Significant difference compared to Pre. #Significant difference to Post 8 min; Data are expressed as the mean ± SD.*

allowed us to monitor the longitudinal neuromuscular activation throughout the nine phases of the session. The experimental approach using the first set as the control efficiently overcame the limitations imposed in studies that compare the drop-sets with traditional resistance training protocols equalizing their volume loads (Kassiano, de Vasconcelos Costa et al. 2021).

As expected, the load reductions in the first set decreased the initial muscle activation by 12.8% and 7.3% at 60 and 40%1-RM loads, respectively (Table 1 and Fig. 2). The slopes significantly different from zero may indicate an increased action potential firing rate and neural drive for the active muscles at each load to sustain the repetitions to FAIL (Gandevia 2001). The high number of movements and volume loads observed at all loads reinforces this interpretation.

Worthy of attention was the change in the activation pattern observed in the second and third sets. The EMG_{RMS} responses remained high during all repetitions performed at 80 and 60% 1-RM loads without changes in the activation rate (slope ~0; see Table 1). In contrast, the EMG responses during the 40%1-RM load were significantly lower in all sets, suggesting a possible load threshold for a significant increase in the initial muscle activity during repetitions to FAIL. Sustained, low-load dynamic activities may be important to induce substitution and rotation between motor units (Bawa and Murnaghan 2009). Although this condition has only been confirmed by spectroscopy and phosphorus-31 magnetic resonance analysis (Dankel, Mattocks et al. 2017), we may speculate that the 40%1-RM load was essential for maintaining higher activation at 80 and 60%1-RM loads of the subsequent sets. In addition, lower loads may also increase the hypertrophic response in type I fibers (Fry 2004).

In summary, we show herein that our drop-set session induced a higher time under tension and increased muscle activation; these conditions considered essential for optimizing muscle strength and hypertrophic responses in trained individuals (Schoenfeld 2013, Dankel, Mattocks et al. 2017). Despite a possible study limitation in using a multiarticular exercise and not monitoring the activation of all muscle groups participating in the movements, we have shown herein that the neuromuscular activation responses were dependent on the magnitude of the loads and the addition of more sets. This knowledge may support coaches and athletes interested in optimizing strength training responses incorporating multiple drop-set sessions into their periodization.

ACKNOWLEDGEMENTS

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

REFERENCES

1. Adam, A. and C. J. De Luca (2003). "Recruitment order of motor units in human vastus lateralis muscle is maintained during fatiguing contractions." J Neurophysiol 90(5): 2919-2927.
2. Adams, G. R. and M. M. Bamman (2012).

International Journal of Strength and Conditioning. 2023

Ide, B. N., Fonseca, P. A. B., Brenzikofer, R., Carvalho, L. H. F.,
Palomari, E. T., & Macedo, D. V.

"Characterization and regulation of mechanical loading-induced compensatory muscle hypertrophy." Compr Physiol 2(4): 2829-2870.

3. American College of Sports, M. (2009). "American College of Sports Medicine position stand. Progression models in resistance training for healthy adults." Med Sci Sports Exerc 41(3): 687-708.

4. Bawa, P. and C. Murnaghan (2009). "Motor unit rotation in a variety of human muscles." J Neurophysiol 102(4): 2265-2272.

5. Brown, L. E. and J. P. Weir (2001). ASEP Procedures recommendation I: accurate assessment of muscular strength and power. 4: 1-21.

6. Burden, A. (2010). "How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research." J Electromyogr Kinesiol 20(6): 1023-1035.

7. Dankel, S. J., K. T. Mattocks, M. B. Jessee, S. L. Buckner, J. G. Mouser and J. P. Loenneke (2017). "Do metabolites that are produced during resistance exercise enhance muscle hypertrophy?" Eur J Appl Physiol 117(11): 2125-2135.

8. Fisher, J., J. Steele and D. Smith (2017). "High- and Low-Load Resistance Training: Interpretation and Practical Application of Current Research Findings." Sports Med 47(3): 393-400.

9. Fry, A. C. (2004). "The role of resistance exercise intensity on muscle fibre adaptations." Sports Med 34(10): 663-679.

10. Gandevia, S. C. (2001). "Spinal and supraspinal factors in human muscle fatigue." Physiol Rev 81(4): 1725-1789.

11. Gorassini, M., J. F. Yang, M. Siu and D. J. Bennett (2002). "Intrinsic activation of human motoneurons: possible contribution to motor unit excitation." J Neurophysiol 87(4): 1850-1858.

12. Haun, C. T., C. G. Vann, B. M. Roberts, A. D. Vigotsky, B. J. Schoenfeld and M. D. Roberts (2019). "A Critical Evaluation of the Biological Construct Skeletal Muscle Hypertrophy: Size Matters but So Does the Measurement." Front Physiol 10: 247.

13. Henneman, E., G. Somjen and D. O. Carpenter (1965). "Functional Significance of Cell Size in Spinal Motoneurons." J Neurophysiol 28: 560-580.

14. Kassiano, W., B. D. de Vasconcelos Costa, J. P. Nunes, A. F. Aguiar, B. F. de Salles and A. S. Ribeiro (2021). "Are We Exploring the Potential Role of Specialized Techniques in Muscle Hypertrophy?" Int J Sports Med 42(6): 494-496.

15. Mitchell, C. J., T. A. Churchward-Venne, D. W. West, N. A. Burd, L. Breen, S. K. Baker and S. M. Phillips (2012). "Resistance exercise load does not determine training-mediated hypertrophic gains in young men." J Appl Physiol (1985) 113(1): 71-77.

16. Schoenfeld, B. (2011). "The use of specialized training techniques to maximize muscle hypertrophy." Strength & Conditioning Journal 33(4): 60-65.

17. Schoenfeld, B. J. (2013). "Potential mechanisms for a role of metabolic stress in hypertrophic adaptations to resistance training." Sports Med 43(3): 179-194.

18. Schoenfeld, B. J., J. Grgic, D. Ogborn and J. W. Krieger (2017). "Strength and Hypertrophy Adaptations Between Low- vs. High-Load Resistance Training: A Systematic Review and Meta-analysis." J Strength Cond Res 31(12): 3508-3523.

19. Stone, M. H., S. S. Plisk, M. E. Stone, B. K. Schilling, H. S. O'Bryant and K. C. Pierce (1998). "Athletic Performance Development: Volume Load---1 Set vs. Multiple Sets, Training Velocity and Training Variation." Strength & Conditioning Journal 20(6): 22-31.

20. Westad, C., R. H. Westgaard and C. J. De Luca (2003). "Motor unit recruitment and derecruitment induced by brief increase in contraction amplitude of the human trapezius muscle." J Physiol 552(Pt 2): 645-656.