Acute effects of equated volume-load resistance training leading to muscular failure versus non-failure on neuromuscular performance

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ABSTRACT

Background/objective: The aim of this study was to compare the acute effects of resistance training to failure (TF) and non-failure (TNF) with volume-load equalization on neuromuscular performance in recreationally resistance-trained adults.
Methods: Twenty-two trained men (age 21.4 ± 2.3 years) were included in a controlled, randomized, and design cross-over investigation with two experimental conditions and one-week of washout interval between them. The participants performed parallel back-squat adopting TF or TNF with volume, intensity, and rest between sets equalized. Countermovement jump (CMJ) height and peak power (PP) were used as mechanical indicators of neuromuscular performance. The mechanical variables were assessed in five moments (pre-experiment, post 15-s, 10-min, 20-min, and 30-min).
Results: When compared with the TNF condition, TF presented greater decrement on CMJ height ($P < 0.001$) and PP ($P < 0.001$) performance. The CMJ height and PP performance in parallel back-squat exercise following the TNF condition returned to the pre-experiment values 10-min after ($P > 0.05$). On the other hand, the TF condition promoted greater decrement in CMJ and PP performance compared with the pre-experiment and TNF protocol even 20–30 min later ($P < 0.05$).
Conclusion: These findings suggest that TF promotes greater acute impairment on neuromuscular performance even when volume-load is equalized.

Introduction

Resistance training (RT) is considered one of the main conditioning training programs used to improve strength, power, muscular endurance, and muscular hypertrophy.[1] Noteworthy, the peak force, peak power, and movement velocity are considered the main indicators of neuromuscular performance.[2,3] It has been widely known, RT programs improve conditioning for sports performance as well as physical fitness and health status.[1] The magnitude, type of physiological responses, and neuromuscular adaptations to RT depend on adequate control of the so-called acute resistance exercise variables (e.g., intensity, exercise type, order, resting between sets and exercises, movement velocity/time under tension, and volume).[2,3] Other factors that might affect the adaptive, as well as the acute responses to RT is the mechanical and metabolic stress caused by exercise, which has been shown different responses when manipulating the number of repetitions per set leading to concentric muscle failure or not to failure.[4,5]

Conceptually, the training to failure (TF) is defined as the inability to move a load beyond a critical joint angle called "sticking point"[6,7] or the inability to perform a repetition over a full range of motion with a given overload due to fatigue.[8] Such incapacity seems to be associated with a decrease in the total work capacity of

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the neuromuscular system.[9,10] Accordingly, performing consecutive sets leading to muscle failure may affect the ability to stay within a selected repetition range when a specific load is adopted.[7] Thereby, volume manipulation (e.g., reduction of sets and/or repetitions per set) within a session RT might be required for maintaining the total number of repetitions as well as the full range of motion of a given exercise.

Previous studies have compared the acute effects of TF vs. training not to failure (TNF) on physiological and mechanical response associated with neuromuscular performance.[2,4,5,10,11] It has been demonstrated that performing repetitions to muscle failure impairs force production,[9,10] movement velocity[9,11] and consequently, power output will be affected.[4,5,9] In addition, evidence suggests that TF causes a great disturbance in cellular metabolism,[4,5,9,10] leading to high levels of blood lactate and ammonia[4,5,9] as well as depletion of phosphocreatine stores and reduction of adenosine triphosphate pool.[4,5] Overall, the current body of knowledge demonstrated the TF promotes a higher level of fatigue, metabolic, and mechanical stress when compared to TNF.[2,4,5,9,10,12] However, it has been noted in both acute[2,10,11] and chronic studies[12] the non-equalization of variables (e.g., volume-load) might influence the level of mechanical, physiological stress, and neuromuscular system fatigue. Thereby, studies that add a non-equalized RT prescription makes it difficult to isolate the effect of the RT strategy, since it is unknown if the main cause of those changes is related to the RT strategy or to the higher volume-load performed during the RT adopting TF. Thus, to fully quantify and understand the effect of this RT strategy on neuromuscular performance, an equalization of volume-load during the RT session is required.

In practice, adopting the strategy to perform an exercise to failure is a way to increase the amount of work in a given time frame (e.g., block sets of given exercise). In other words, it increases the density of the session. This metric, a product of the volume-load divided by sum the rest interval, has shown a strong relation with acute changes in response to an RT session. For example, RT sessions with higher density lead to greater metabolic stress (i.e., lactate increase).[13] Thereby, it would be expected that RT sessions with high density may lead to a greater decrease in neuromuscular performance. However, to date, this hypothesis has not been tested.

Thus, it is important to note that the acute effects of training strategies provide insight into neuromuscular demand between training sessions, which have important practical implication for RT prescription. In other words, strategies that provide high levels of fatigue (e.g., a longer time under tension, eccentric training) might influence the recovery period needed for the next session, reducing the frequency, which is directly related to the increase or decrease in weekly training volume. Thus, the purpose of this study was to compare the acute effects of RT adopting TF vs. TNF on the neuromuscular performance in trained participants. We hypothesized that even with equalized volume-load in trained participants performing TF, it would present greater impairment on neuromuscular performance when compared with TNF.

Methods

Participants

The sample size calculation was conducted by the software G*Power 3.1 with a power of 0.90, $\alpha = 0.05$, and an effect size of 0.35. The results indicated 16 subjects to perform the study. However, considering possible dropouts, an additional 20% were recruited, resulting in 18 participants. Twenty-two male adults aged from 18 to 25 years old (21.4 ± 2.3 years; 78.1 ± 6.7 kg)

participated in the study. The sampling method was non-probabilistic. All the participants were recreationally trained in RT (i.e., individuals consistently trained from 1 to 5 years, frequency 2–3 sessions per week).[14] The volunteers had no history of muscular or joint injury and did not intake any nutritional ergogenic substance for strength and muscle mass gains in the last six months. This study was approved by the local Ethics and Research Committee (CAAE: 47571415.9.0000.5208) and followed the ethical principles contained in the Declaration of Helsinki (2008). All participants who voluntarily participated in the research signed a free and informed consent term.

Experimental procedures

A controlled, randomized, and crossover design was used to compare the acute effects of two RT strategies (TF vs. TNF) with volume-load equalization on neuromuscular performance. The study was conducted in five sessions with one visit to the laboratory per week (i.e., one-week of washout). In the first session, the participants were familiarized with the Total Quality Recovery (TQR) and Rating of Perceived Exertion Session (sRPE) scales and experimental procedures.

In the following two sessions, participants performed a twelve-repetition maximum test (12 RM) to define intensity-load as previously recommended[15] along with another familiarization with perceptual scales. The 12 RM was conducted in two sessions to assess the reproducibility of the measures.

During the fourth and fifth sessions, the participants underwent two experimental protocols in a randomized order with a washout period (1-week) in-between, according to Fig. 1. The survey coordinator used a number manually generated to determine the participants' allocation in each experimental condition. Thus, the participants performed TF or TNF of the same exercise (parallel back-squat) with volume, intensity, and rest equalized (Table 1).

To evaluate the acute effects of experimental conditions (TF vs. TNF) on neuromuscular performance, the countermovement jump (CMJ) and peak power (PP) in the parallel back-squat (70% of 12 RM) were assessed in the baseline, before (pre-experiment), immediately post-training (15 s), and 10, 20, and 30-min following the experimental sessions (Fig. 1). Additionally, recovery perception level was evaluated by the TQR before each experimental session and internal training load (ITL) was evaluated 30-min after the experimental sessions by session ration of perceived exertion method (sRPE).[16]

Resistance training protocol

The experimental protocol included two resistance exercise sessions, one for each experimental condition investigated. The participants performed two RT strategies (TF and TNF) in the parallel back-squat exercise. The experimental conditions are shown in Table 1. The initial load was defined by the maximum load performed in the 12 RM (using the appropriate technique). Muscular failure was determined by the inability to complete the concentric phase of the movement.

In the TF condition, each participant performed four sets of 12 repetitions (i.e., intensity zone of 12 RM). For the participants that failed to complete 12 repetitions with the initial load due to fatigue, a reduction of 5% of 12 RM ensure the execution of all 48 repetitions. In the TNF condition, comprised of the same training volume and intensity, as the training to failure, the participants performed eight sets of six repetitions. All the participants were able to complete the training protocol with the initial load in the non-failure training condition. The rest interval between sets was 3-
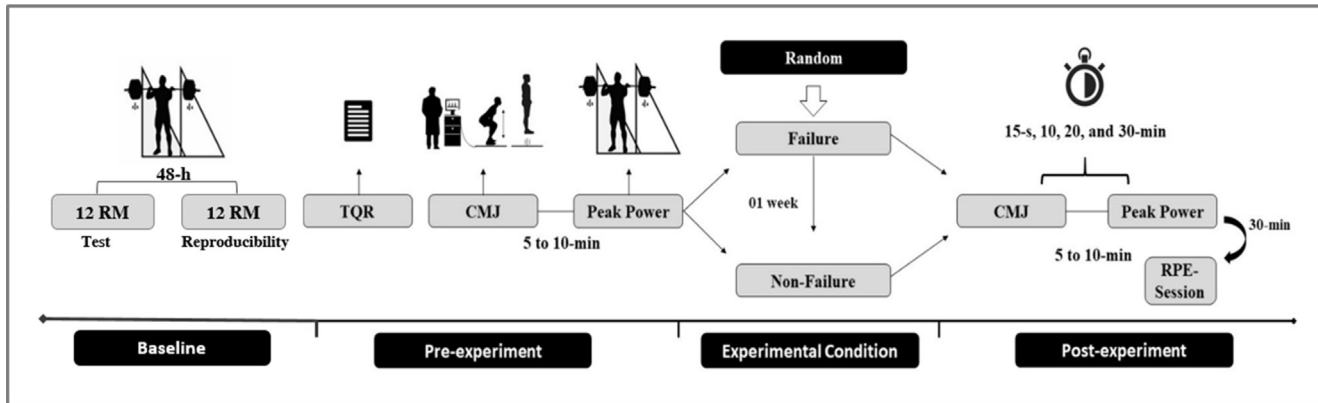
Fig. 1. Experimental design of the investigation.
Note. TQR = total quality recovery; CMJ = countermovement jump; sRPE = session rating of perceived exertion.

Table 1
Descriptive characteristics of resistance training sessions.

	Failure Training	Non-failure Training	*P*-value
Intensity-zone	12 RM	12 RM	–
Load − 12 RM (kg)	85.27 ± 19.29	85.27 ± 19.29	–
Sets x repetitions	4 × 11.9 ± 0.4 [12]	8 × 6 ± 0.0 [12]	0.56
Resting between sets (min)	3	3	–
Volume-load (kg)	4007.5 ± 872.8	4138.9 ± 885.8	0.62
Density (kg.s^{-1})	6 ± 1.3	2.5 ± 0.5	<0.001
Recovery status (AU)	18.95 ± 1.09	18.82 ± 1.14	0.48
RPE-session (AU)	4.0 ± 0.98	3.5 ± 0.6	<0.01

Note. RM = repetition maximum; RPE = Rating of Perceived Exertion; AU = arbitrary units.

min for both interventions. Thus, the relative magnitude of the training-load, number of sets and repetitions, and inter-set recoveries were equalized. Moreover, the density of the resistance exercise session was calculated by the division among stimulus (load) and rest interval.

Right before the training, the participants completed a standardized parallel back-squat warm-up that consisted of two sets of 12 repetitions at 50% and 80% at 12 RM, respectively. During the execution of the parallel back-squat, participants' feet were slightly wider than shoulder-width and toes pointed forward or slightly outward. The bar was placed in the upper portion of the trapezius muscle, slightly above the posterior portion of the deltoid muscle. The participants were instructed to hold the bar comfortably and slightly wider than the width of the shoulders. Finally, the participants squatted down until the thighs were parallel with the floor (90-degree angle) pushing the hips backward and flexing their knees and returned to the initial position. Two work metrics were calculated: volume-load and density. The volume-load was obtained from the number of total repetitions x load (kg). The density of the session was derived from the volume-load (kg) divided by the sum of the recovery interval in seconds.[13]

Additionally, the procedures occurred at the same time of the day (4 p.m.−7 p.m.) to avoid circadian rhythm effects. Pre-test instructions were provided to reduce possible external bias. Participants were asked to keep their sleep behavior, avoid alcohol consumption, and vigorous activities 24-h before each of the following visits. In addition, it was requested the participants to avoid caffeine consumption 3-h prior to the experimental condition and consume a light meal 2-h before the experiment. These data were self-reported before each experimental condition.

Measurements

Recovery status

The status of perceived recovery was assessed using the TQR scale.[17] Before each experimental session, the subjects were presented to a scale ranged between 6 and 20 (6 = very poorly recovered/extremely tired; 20 = very well recovered/highly energetic) and they were asked: "how do you feel?". The participants were previously familiarized with the TQR scale and received standardized instructions.

Back-squat peak power (PP)

PP in the parallel back-squat exercise was measured using a Smith machine (Righetto®, São Paulo, Brazil). The participants were instructed to perform three repetitions at the concentric maximal velocity with a load corresponding to 70% of 12 RM. A momentary pause, which lasted approximately 2 s, was interposed between the eccentric and concentric phases of parallel back-squat exercise to minimize the contribution of the rebound effect and allow for more reproducible, consistent measurements.[18] An interval of 30-s was provided between attempts. The highest PP value obtained in the three attempts was considered for analysis. The PP was determined using a linear transducer (T-Force, Dynamic Measurement System; Ergotech Consulting S.L., Murcia, Spain) that was attached to the smith machine bar.[10,19] The intraclass coefficient correlation (ICC), the coefficient of variation (CV), standard error measurement (SEM) and minimal difference detectable (MDC) were used to determine the test-retest reproducibility of the squat PP measurement [ICC = 0.99 (0.97−0.99); CV = 1.2% (0.85−1.5); SEM = 0.6; MDC$_{90}$ = 1.5 (−1.2 to 4.2)]. Noteworthy, PP has been used in other studies to indicate neuromuscular performance during or after resistance exercise.[4,5]

CMJ

The participants performed three maximal CMJ with 30-s of resting between trials. All volunteers were encouraged to perform a maximum effort and "jump as high as possible". Additionally, they were instructed to position their hands on the hips, to perform a downward movement followed by a complete extension of the legs keeping knees and hips fully extended until landing to ensure the validity of the test. When these criteria were missed, the jumps were repeated. Jump height was determined on a contact platform (Jump System Pro; Cefise, Nova Odessa, Brazil) and the highest CMJ was registered for analysis. The test-retest reproducibility of CMJ measure was ICC = 0.91 (0.81–0.96); CV = 2.8% (1.6–4.1); SEM = 0.1; MDC_{90} = 0.2 (−0.2 to 0.8). Notable, CMJ has been the main indicator used to demonstrate improvements or impairments in neuromuscular performance during or after exercise sessions.[10,20]

12 Repetitions maximum (12 RM)

The 12 RM intensity zone was determined following protocols of the maximum number of repetitions to failure, in the parallel back-squat exercise, using similar procedures to the maximum repetition protocols adopted in previous studies.[11,21,22] Accordingly, a warm-up (2 × 15−20 reps with 50% of the predicted 12RM, adopting 120-s intervals between sets) before 12 RM test was performed. To obtain the reproducibility of the load in the 12 RM, the test-retest was conducted in two sections separated by 48-h. In each section, the participants performed two attempts with an interval of 10-min between sets. Verbal encouragement was given throughout the 12 RM test. The test was finished when the voluntary concentric failure occurred (i.e., the inability to perform a full range movement because of fatigue). The highest load achieved between the two sessions was considered for the 12 RM test (85.27 ± 18.29 kg). The test-retest reproducibility values of the 12RM was ICC = 0.99 (0.98−0.99); CV = 1.6% (1.0−2.2); SEM = 0.1; MDC_{90} = 0.4 (−0.3 to 1.2).

Internal training load

The internal training load was assessed using the sRPE method.[16] Approximately 30-min after finishing each experimental session, the participant was asked to provide a rating of the overall intensity of the exercise bout, the sRPE. The participants were instructed to report the scale ranged from 0 to 10, where 0 is total rest and 10 represents maximal effort, considering their general state of fatigue of the training session. Participants were previously familiarized with the RPE scale and received standardized instructions. The internal training load is presented in arbitrary units obtained by multiplying the training volume [load (kg) x total of repetitions] by the intensity value obtained in the RPE-session.

Statistical analyses

The normality of the data was analyzed by the Shapiro-Wilk test. Data with normal distribution are presented as mean and standard deviation (SD). Non-parametric data are presented as median and 25 e 75% percentile (25−75). We used a paired *t*-test to compare the perceptual response and density between the experimental conditions. The Wilcoxon test was used to analyze the difference in TQR. Levene's test was used to analyze homoscedasticity. The data sphericity was verified by the Mauchly's test and whether the assumption was violated the Greenhouse-Geisser correction was adopted.

A two-way repeated measure analysis of variance (ANOVA) verified the interaction effect between the conditions (TF vs. TNF) vs. time (pre-experiment, 15-s, 10, 20, and 30-min) for neuromuscular performance (PP and CMJ). The Bonferroni post-hoc test was

used to identify possible differences. Percent delta (Δ%) from pre-to post-experiment was calculated as follow: Δ% = ([post-pre]/pre) *100. The partial eta-squared (ηp^2) was adopted as the effect size of the variance. The Cohen effect size ("d") was used to analyze the magnitude of the differences and were defined as small (<0.2), medium (<0.5), or large (>0.8) [23]. Importantly, as we did not perform a prior sample size estimation, we calculated the effect size (ES) as a post-hoc analysis for every dependent variable. Statistical power was >0.80 for all analysis, and the significance level was set at 5%. The analysis was performed in the Statistical Package for the Social Sciences (SPSS) 20.0 version (Chicago, USA).

Results

Volume-load, perceived recovery status, and internal training load

The volume-load was equalized between the two experimental conditions (TF = 4007.5 ± 872.8 kg; TNF = 4138.9 ± 885.8 kg). The results showed no statistically significant difference between TNF and TF for the total repetitions ($F_{(2,20)}$ = 0.33, P = 0.56) and volume load ($F_{(2,20)}$ = 0.25, P = 0.62) (Tables 1 and 2). Wilcoxon test showed that perceived recovery status was similar among experimental conditions (P = 0.48), whereas sRPE (P = 0.01) higher in the TF condition (Table 1). Paired *t*-test show that the internal training load ($t_{(21)}$ = 2.65; P = 0.01) also was higher in the TF condition (Fig. 2).

Density

TF condition presented a statistically significant difference when compared with TNF (Table 1), (TF = 6.0 [1.3] vs. TNF = 2.5 [0.5]; $t_{(21)}$ = 21.872; P < 0.001; 95% CI = 3.1 to 3.7).

CMJ performance

Fig. 3 shows CMJ performance before and after experimental conditions. Significant interaction effect (condition vs. time) in CMJ ($F_{(2.8,59.4)}$ = 3.825; P = 0.01; ηp^2 = 0.15), as well time ($F_{(2.6,56.4)}$ = 18.491; P < 0.001; ηp^2 = 0.47) and condition ($F_{(1,21)}$ = 23.392; P < 0.001; ηp^2 = 0.52) were observed. Specifically, CMJ performance decreased following 15-s, 10-min, 20-min, and 30-min in the TF condition when compared with the pre-experiment value (P < 0.001). On the other hand, following the TNF condition, CMJ performance decreased only in 15-s after RT session (P = 0.02; 95% CI = 0.5 to 2.8), returning to pre-experiment values after 10-min (P = 0.07; 95% CI = −0.0 to 2.1). Although both conditions reduced performance in CMJ immediately after, TF reduced longer when compared to TNF condition (P < 0.001; 95% CI = −1.5 to −0.6) (Table 3).

Peak power performance

Significant interaction effect (condition vs. time) for PP performance ($F_{(2.3,49.4)}$ = 4.188; P = 0.01; ηp^2 = 0.16), as well as time ($F_{(2.3,48.3)}$ = 19.822; P < 0.001; ηp^2 = 0.48) and condition ($F_{(1,21)}$ = 23.666; P < 0.001; ηp^2 = 0.53). The PP performance decreased from the pre-experiment following 15-s, 10-min, 20-min following TF condition (P < 0.05), returning to baseline values after 30-min (P = 0.20; 95% CI = −3.8 to 35.0) (Fig. 3). In the TNF condition, PP performance was reduced only immediately after RT session (15-s) (P = 0.001). After 10-min, the performance in the PP returned to the pre-experiment (P = 0.15; 95% CI = −3.6 to 41.5) (Table 3).

Table 2
Repetitions and intensity (load) in the back squat performed in training to failure (TF) and training non-failure (TNF). Data are presented as mean and standard deviation (SD).

	1st set	2nd set	3rd set	4th set	5th set	6th set	7th set	8th set
TNF - Load (kg)	86.2 ± 18.5	86.2 ± 18.5	86.2 ± 18.5	86.2 ± 18.5	86.2 ± 18.5	86.2 ± 18.5	86.2 ± 18.5	86.2 ± 18.5
TF - Load (kg)	86.2 ± 18.5	84.8 ± 18.4	83.0 ± 17.7	82.1 ± 17.9	–	–	–	–
TNF - Rep (n)	6.0 ± 0	6.0 ± 0	6.0 ± 0	6.0 ± 0	6.0 ± 0	6.0 ± 0	6.0 ± 0	6.0 ± 0
TF - Rep (n)	12.0 ± 0	11.9 ± 0.5	11.7 ± 0.7	11.6 ± 0.8	–	–	–	–

Note. TF = training to failure; TNF = training non-failure; Rep = repetitions.
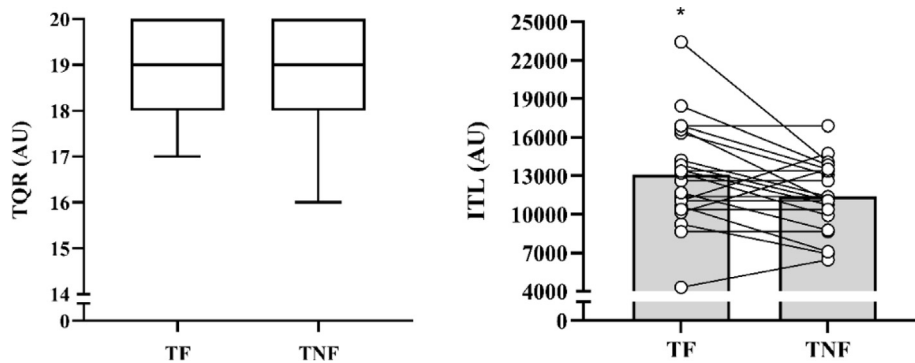

Fig. 2. Perceived recovery status (median and 25–75) and internal load according to the experimental condition.
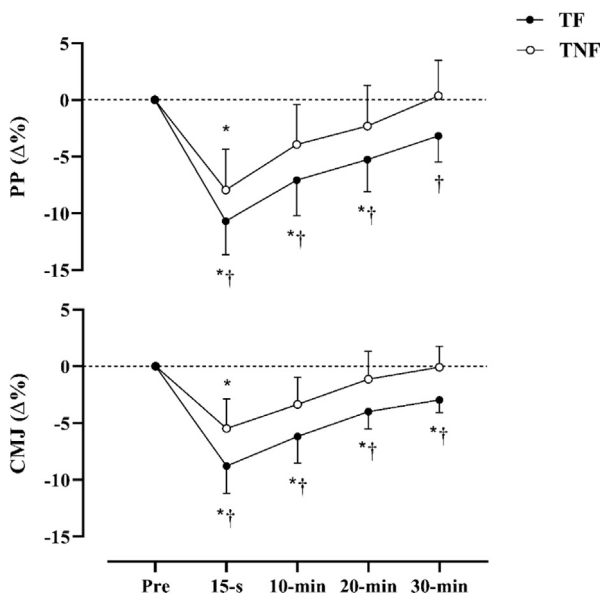*Note.* * = significant difference; AU = arbitrary units.

Fig. 3. Neuromuscular response before and after experimental conditions (TF and TNF).
Note. * = difference when compared to pre; † = difference when compared to TNF; TF = training to failure; TNF = training non-failure; CMJ = countermovement jump; PP = peak power.

Table 3
Neuromuscular performance in TF and TNF conditions. Data are presented as mean and standard deviation (SD).

	TF		TNF	
	CMJ (cm)	PP (W)	CMJ (cm)	PP (W)
Pre	30.0 (4.1)	439.6 (71.2)	30.1 (3.6)	439.0 (72.9)
Post 15-s	27.4 (3.8)*†	391.6 (64.3)*†	28.5 (3.6)*	402.2 (65.0)*
10-min	28.1 (3.8)*†	407.2 (65.2)*†	29.1 (3.6)	420.1 (67.9)
20-min	28.9 (4.2)*†	414.9 (63.3)*†	29.8 (3.8)	427.5 (71.6
30-min	29.1 (3.9)*†	424.0 (61.8)†	30.1 (3.7)	438.6 (66.6)

Note. * = difference when compared to pre; † = difference when compared to TNF; TF = training to failure; TNF = training to non-failure; CMJ = countermovement jump; PP = peak power.

Discussion

The purpose of this study was to compare the acute effects of TF vs. TNF with volume-load equalization on neuromuscular performance in recreationally resistance-trained adults. As hypothesized, TF promoted greater impairment on neuromuscular performance, higher internal training load, and higher density in the session than the TNF condition until 30-min after the RT session. Moreover, following the TNF condition, the neuromuscular performance returned to the pre-experiment level in less than 10-min. Thereby, the main finding of this study is that volume-load does not appear to be determinant for acute decrement on neuromuscular performance following RT sessions.

In crossover experimental studies is essential to remain in the same physiological conditions before each session. For example, perceived recovery indicates how recovered the participant is related to the last session. The findings showed no difference in the TQR score between experimental conditions, which means the participants present the same physiology condition in the experimental sessions avoiding residual effects of fatigue (muscular or mental).

Regarding CMJ performance, TF induced greater jump height decrement (ranging from −3.0 ± 2.5% to −8.8 ± 5.5%) than TNF condition. In fact, it is widely reported that RT adopting TF causes greater acute fatigue and mechanical/metabolic stress when compared with TNF strategy (i.e. repetitions in reserve)[2,10,11] even when the total volume-load was equalized.[4,5] Consequently, the ability to apply force is reduced and neuromuscular performance is impaired. Accordingly, Sanchez-Medina and González-Badillo[11] showed that loss of CMJ height (%) was linearly increased as the number of repetitions in reserve approached to muscle failure. In addition, the authors found a strong correlation between the CMJ height decrement and intra-set mean propulsive velocity during back-squat exercise (r = 0.92).

The decrease in jump height and peak power output observed immediately after exercise protocols in the present study (TF = 10%; TNF = 5%) is relatively smaller compared to previous findings.[10,11] These differences might be attributed to methodological differences. In the study of Pareja-Blanco et al.,[10] the participants

sequentially performed two exercise protocols (bench press and full back squat) before the CMJ evaluation. Additionally, in both studies mentioned before,[10,11] the participants performed a 3-repetition test with maximum intentional velocity (1 m s^{-1}) 20 s before CMJ evaluation. Thus, the two exercise protocols in the same session and the execution of three repetitions with the maximum effort of 20 s before CMJ may justify the higher percentage of jump height loss compared to the protocols of the present study that involved only back squat exercise.

In the present study, mechanistic processes were not assessed but previous studies demonstrated that compromised neuromuscular performance is related to both central (e.g. reduced motor drive) and peripheral mechanisms.[4,24,25] Specifically, decrement in neuromuscular performance generally was accompanied by increased muscle lactate and ammonia blood levels following the TF.[4,5,9,24] The increased lactate is a signal of the high demand for anaerobic glycolysis and increased blood ammonia, which is likely associated with a concomitant decrease in intramuscular ATP levels.

On the other hand, an acute impairment in the central motor drive following contraction to exhaustion may lead to a lower ability to produce muscle power.[8,25] Under highly-fatigue condition, neural adjustments such as neural drive and electromyography power spectrum may be compromised.[8,26] As maximal power generation demands a high level of neural drive,[27] TF to fully activate contracting musculature may affect the rate of force development. Thereby, the complex interaction of peripheral and central fatigue provides an important rationale for the impaired neuromuscular performance, but the exact mechanism goes beyond the scope of our investigation.

Considering that in our study as well as in the others mentioned above the volume-load was equalized, it is supposed that other variables associated with the set manipulation and repetitions that lead to muscle failure are determinant to cause acute neuromuscular fatigue. Those effects might be explained by the different time under tension (TUT) between the conditions. Essentially, TUT refers to how long a muscle is under strain during a set.[28] The TF condition of this study was performed with sets of 12 repetitions, while the sets in the TNF condition consisted of six repetitions.

Although the duration of eccentric and concentric phases in the back-squat was not controlled in our study, the greater number of repetitions may have been determinant to increase the TUT per set during training at muscle failure condition, increasing fatigue.[29–31] Additionally, during maximal repetition protocols, the movement velocity is reduced as the number of repetitions in reserve decreases.[2,9] Therefore, this reduction of velocity results in an increased TUT. Indeed, TUT has been considered the main determinant of neuromuscular fatigue when training load is properly equalized.[31]

In addition, the TF condition presented a higher density when compared to TNF. Since RT sessions with higher density induce greater internal responses (i.e., accumulation of metabolites),[13] the present study points out to the fact that higher densities associated with maximal repetitions negatively affect neuromuscular performance. In this sense, although the recovery interval between the sets was equal (i.e., 3 min), in the TF condition, participants performed the same amount of work (volume-load equated) when compared to TNF, but in a smaller interval of the time (i.e., duration of the experimental session). This fact may have induced a momentary reduction of neural input, contributing to a decrease in CMJ and squat performance after TF.[32]

Regarding ITL, participants reported higher score of RPE after TF than in the TNF condition. As perceptual responses (e.g., RPE) are likely to be dictated by central commands,[33] increased ITL in the TF condition associated with higher density reinforces the explanation

for a possible decrease in input to the muscles compromising the neuromuscular function (CMJ and power output in the back-squat exercise). Accordingly, it was previously reported that sRPE was correlated to CMJ height decrement following different sets of resistance exercise.[34] However, it is necessary to investigate the effects of different densities and ITL on the neuromuscular performance associated with neural drive assessment.

Importantly, some questions raised about the necessity to perform training to muscle failure.[7,35,36] It is important to maintain neuromuscular performance throughout the RT session in high volume-load situations without severe raising in metabolic stress. The maintenance of neuromuscular performance might lead to increased volume-load, which may favor gains in strength and hypertrophy.[37] In the present study, we found that intra-set PP was lower after TF than TNF condition. Moreover, previous studies demonstrated that TF requires a greater recovery time[2,38] which may not be attractive for the practitioners that aim to accelerate neuromuscular recovery within and between the sessions. For instance, a fast recovery between RT sessions might be essential to increase the weekly training frequency of the same muscle group, which may increase muscle hypertrophy.[3]

From a practical perspective, RT to muscle failure induces large acute neuromuscular decrement in performance when compared with the non-failure condition, even when volume-load is equalized. Thus, TUT and rest distribution between sets seem to influence the level of acute fatigue. Therefore, these findings discourage the use of exercises that lead to muscle failure in situations that frequency, volume of training, movement velocity, and power are needed to be maintained throughout the session.

Although our data add a relevant contribution to the current body of knowledge regarding the RT strategy leading to muscular failure, some limitation of our investigation should be pointed out. First, TUT and density (i.e. total recovery time) were not equalized. Considering that both variables may affect the work and rest ratio and mediate the neuromuscular response during the RT, future investigations should equalize them. Moreover, the lack of reproducibility of the experimental conditions was not performed to ensure that the greater neuromuscular decrement following RT leading to muscular failure not occurred by random factors. Finally, the lack of electromyography to analyze the muscle activation during the RT session and neuromuscular assessment should provide valuable information about neural responses. Although the absence of this measure limits our data interpretation, the applied nature of our study still provides interesting data to strength and conditioning professionals and practitioners of RT.

Conclusion

Our study showed that training to muscular failure or non-failure with equalized volume produced distinct neuromuscular responses (CMJ height decrement and reduced intra-set PP). Performing an RT session to failure promote greater neuromuscular decrement compared with the pre-experiment and non-failure protocol even 20–30 min later. The volume does not appear to be determinant for monitoring acute fatigue in exercises leading to failure. These findings discourage the frequent use of RT adopting TF and high density, especially when the objective is to increase the training frequency of the same muscle group, maintaining the volume-load and neuromuscular performance.

Declaration of competing interest

The author's state have no conflicts of interest directly relevant to the content of this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jesf.2020.01.004.

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