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ORIGINAL ARTICLE

Effect of rest-pause vs. traditional bench press training on muscle strength, electromyography, and lifting volume in randomized trial protocols

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Abstract

Purpose Rest-pause (4-s unloaded rest between repetitions) training effects on one repetition maximum (1 RM), lifting volume, and neural activation via electromyography (EMG) are currently vague in the literature and can benefit strength and conditioning professionals for resistance training programme design. Therefore, this study compared 1 RM, neural activation via (EMG), and volume differences between rest-pause vs. traditional resistance training.

Methods Trained males ($N = 20$) were randomly assigned to either a rest-pause or a traditional training group. Pre- and post-1 RM testing was recorded. Training sessions were completed twice a week for 4 weeks and consisted of four sets of bench press to volitional fatigue at 80% of pre-test 1 RM with a 2-min rest between sets. Total volume completed was recorded on each training day. Neural activation of the pectoralis major was measured on the first and last training days.

Results A two-way repeated-measures ANOVA indicated both groups significantly increased their 1 RMs following the 4-week training protocol ($p < .05$). However, no significant differences were found in 1 RM and neural activation between the two groups ($p > .05$). An independent samples t test indicated that total volume lifted was significantly higher for the rest-pause group (56,778 vs. 38,315 lbs; $p < .05$) throughout the protocol and independently during weeks 2, 3, and 4.

Conclusions While strength and neural activation changes did not differ between groups, both increased 1 RMs and the rest-pause group achieved greater increases in volume than the traditional group. If volume is the focus of training, the rest-pause method should be utilized.

Keywords Neural activation · Mesocycle · Repetition maximum · Electromyography · Volume

Abbreviations

ATP-PCr	Adenosine triphosphate phosphocreatine
ANOVA	Analysis of variance
PCr	Creatine phosphate
EMG	Electromyography
RM	Repetition maximum
RMS	Root mean square

Introduction

Strength and conditioning professionals, athletes, and recreational body builders aim to maximize hypertrophy and strength gains by altering lifting volume and rest periods during training. Several training strategies, including heavy

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weight, eccentric action, slow-motion, breakdowns, and maximal power training, have been used in an effort to produce maximal gains (Keogh et al. 1999). A new technique that has not been extensively studied is the rest-pause method. The rest-pause method incorporates a prolonged pause between individual repetitions within a set (Krol et al. 2007). The prescribed rest period between repetitions has varied among different studies. Keogh et al. (1999) utilized a two second rest period between each repetition for the rest-pause lifting protocol, while Marshall et al. (2012) set the rest period at 20 s after completing a 20-repetition maximum (RM) for the squat exercise.

During periodization, a key goal of resistance training during the hypertrophy phase is to maximize lifting volume. Frequently, hypertrophy phases promote completing sets to volitional fatigue often comprising of 6–12 repetitions (Baechle and Earle 2008). Due to these sets being driven to fatigue, a large amount of the energy should come from creatine phosphate. The adenosine triphosphate–phosphocreatine (ATP-PCr) system can sustain muscle energy requirements for approximately 10 s during high-intensity exercise bouts (McArdle et al. 2014). Inter-set rest periods allow for replenishment of intramuscular creatine phosphate (Keogh et al. 1999; Lawton et al. 2006). Rest periods have extensively been examined and Miranda et al. (2007) concluded that rest periods of 3 min appear to have much more significant increase in volume lifted in comparison to 1-min rest periods. These findings are important, since increases in lifting volume have a positive effect on increasing strength (Pescatello 2014; Robinson et al. 1995).

Keogh et al. (2009) compared variables between rest-pause resistance training and standard heavy weight training sessions. They found that, when using a 6 RM load, rest-pause resistance training averaged 1.33 more repetitions than standard heavy weight training and found that the middle and last repetitions had significant differences in neural activation. More recently, Marshall et al. (2012) concluded that utilizing the rest-pause method was more efficacious for the squat exercise, because it elicited greater neural activation with less post-exercise fatigue in comparison to the traditional methods. While these studies show acute differences in neural activation between rest-pause and traditional resistance lifting sessions, the training effects on neural activation between methods remain unknown.

To our knowledge, no studies have compared maximal strength, lifting volume, and neural activation changes between rest-pause and traditional resistance training that mirrors a hypertrophy mesocycle. Therefore, the purpose of this study was to compare changes in 1 RM bench press, lifting volume, and peak pectoralis major neural activation after 4 weeks of either rest-pause or traditional resistance training. It is hypothesized that the rest-pause training group will have a greater increase in 1 RM bench press, complete more lifting volume, and have a greater change in pectoralis major neural activation than the traditional training group.

Methods

Participants

Male participants ($N = 20$) participated in the study which met the required sample size power analysis. Participants were randomly assigned to one of the two groups ($N = 10$ per group) by the primary investigator for the 1 RM on the first day between the rest-pause and traditional protocols. Descriptive statistics of the participants in each group are presented in Table 1. All participants had a minimum of 1-year experience performing the bench press resistance exercise and had been actively participating in resistance training for the past 6 months prior to beginning the study. This study was approved by the university Institutional Review Board (#15-089) prior to data collection. All participants gave their informed consent prior to their inclusion in the study and that details that might disclose the identity of the participants under study have been omitted. Participants were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. Participants refrained from caffeine usage 24 h prior to testing.

Instrumentation

The height of each participant was measured to the nearest millimeter using a stadiometer (SECA, Hanover, MD). The mass of each participant was measured to the nearest 0.1 kg using a calibrated scale (Health-O-Meter® Professional, Northbrook, IL). A Pro Elite Strength Systems Smith machine was used for bench press solely for safety of participants during the unracking and reracking process between repetitions for the rest-pause group (Salt Lake City, UT). The traditional group also used the Smith machine for consistency. A metronome was used to keep pace with each phase of repetitions completed by both the traditional and rest-pause group. The eccentric phase had a

Table 1 Descriptive statistics for study participants

Group	Ht. (cm) M (±SD)	Wt. (kg) M (±SD)	Age (years) M (±SD)	80% TL (kg) M (±SD)
Rest-pause (*n* = 10)	178.5 (5.2)	81.5 (8.5)	23.0 (2.0)	88.2 (21.0)
Traditional (*n* = 10)	175.4 (4.6)	77.8 (10.4)	23.1 (2.6)	83.9 (17.6)

TL training load

contraction time of 2 s, while the concentric phase of the pectoralis major had a 1-s contraction. EMG (electromyography) data were measured using a DELSYS Trigno Wireless EMG System (Natick, MA).

Procedures

Participants completed a total of ten sessions that included the pre/post-test, and a 4-week protocol that consisted of two training session a week (Table 2). A 4-week protocol was used to mimic a standard training mesocycle (Baechle and Earle 2008). The weekly training sessions were spaced by a minimum of 48 h but did not exceed 96 h. The pre- and post-training tests consisted of a 1 RM test for the bench press exercise (sessions 1 and 10). The eight lifting sessions over the 4 weeks consisted of four sets to volitional fatigue using 80% of each participant's 1 RM. Hand grip for bench press followed the National Strength and Conditioning Association guidelines with hands slightly wider than shoulders, and a closed pronated grip (Baechle and Earle 2008). Participants walked on a treadmill for 3–5 min at a self-selected pace, followed by bench pressing with an intensity that could be performed for approximately 15 repetitions for a standardized warmup. A 2-min rest period was provided between sets for both training groups. Both groups completed the same training protocol with the exception of the rest-pause group which utilized a four second unloaded pause between each repetition. The participants' arms were fully extended during the racking/unracking process. Total lifting volume was measured as the product of number of repetitions and weight lifted in kg on each day of the training programme. Pectoralis major neural activation was recorded using the EMG system during sets one and four during the second and ninth sessions (Table 2, i.e., first and last training sessions). At the start of the first and eighth training sessions, surface electrodes were placed on the skin over pectoralis major of the dominant hand side. This location is at the most superior part of the pectoralis major on the medial sternum lateral to the supra sternal notch (Krol et al. 2007). Electrode placement was placed one-third of the distance from the super sternal notch and the anterior axillary line. Hair was shaved from the chest and skin was exfoliated with redux paste prior to placement of the sensors to reduce signal impedance. A Certified Strength and Conditioning Specialist collected all data and ensured proper technique throughout all repetitions.

Table 2 Training protocol

Week	Sessions	Rest-pause	Traditional
Week 1	1	1 RM max (pre)	RM max (pre)
	2	4 sets to fatigue[a] 80% 1 RM (2-min rest)	4 sets to fatigue[a] 80% 1 RM (2-min rest)
	3	4 sets to fatigue 80% 1 RM (2-min rest)	4 sets to fatigue 80% 1 RM (2-min rest)
Week 2	4	4 sets to fatigue 80% 1 RM (2-min rest)	4 sets to fatigue 80% 1 RM (2-min rest)
	5	4 sets to fatigue 80% 1 RM (2-min rest)	4 sets to fatigue 80% 1 RM (2-min rest)
Week 3	6	4 sets to fatigue 80% 1 RM (2-min rest)	4 sets to fatigue 80% 1 RM (2-min rest)
	7	4 sets to fatigue 80% 1 RM (2-min rest)	4 sets to fatigue 80% 1 RM (2-min rest)
Week 4	8	4 sets to fatigue 80% 1 RM (2-min rest)	4 sets to fatigue 80% 1 RM (2-min rest)
	9	4 sets to fatigue[a] 80% 1 RM (2-min rest)	4 sets to fatigue[a] 80% 1 RM (2-min rest)
	10	1 RM Max (post)	1 RM Max (post)

[a]EMG recorded during first set and fourth set

Data processing

The EMG signals during all lifts were band-pass filtered with cut-off frequencies of 20–450 Hz. The signals were then full-wave rectified and smoothed using a root-mean-square (RMS) filter with a moving window of 250 ms (Allen et al. 2013). During the 1st and 8th training sessions, the RMS signals during the last repetition of the last set were normalized to the RMS peak values during the first repetition of the first set for each participant (i.e., percent change from peak first repetition). The total lift included both eccentric and concentric phases.

Statistical analysis

An alpha of 0.05 and power of 0.80 were used for all statistical procedures. Separate 2 (groups: traditional and rest-pause) × 2 (time; before and after 4 weeks of training) analysis of variance (ANOVA) for repeated measures was used to assess the differences in 1 RM and neural activation in the dominate pectoralis major between rest-pause vs. traditional training groups. Effect sizes for the repeated-measures ANOVA were calculated using partial eta squared. Independent samples *t* tests were used to assess total volume changes over the 4-week training protocol and to compare volume differences between the two groups for each of the 4-weeks. Effect sizes for the independent samples *t* tests were calculated using eta squared.

Results

Descriptive characteristics of the sample are indicated in Table 1. A two-way repeated-measures ANOVA indicated both groups significantly increased their 1 RM from pre-test to post-test, $F(1,18) = 37.45$, MSE = 98.96, $p < .001$,

Table 3 Descriptive statistics for 1 RM and muscle activity

Variable	Rest-pause M (±SD)	Traditional M (±SD)
1 RM (kg)		
Pre-training	110.5 (26.5)	104.8 (22.6)
Post-training*	119.3 (26.5)	113.4 (21.7)
Peak EMG (%)		
Pre-training	32.1 (54.6)	44.2 (50.0)
Post-training	19.9 (34.1)	53.8 (54.9)

EMG electromyography

* $p < .05$ for post-training vs. pre-training 1 RM scores. EMG data represent the percent change in RMS signal from the 1st and 4th sets during the 1st (pre-training) to the 8th (post-training) sessions for both groups

Table 4 Descriptive statistics for volume (kg) and repetition totals

Variable	Rest-pause M (±SD)	Traditional M (±SD)
Week 1 volume	4797.6 (1851.8)	3697.4 (905.3)
Week 2 volume	6035.9 (2202.5)*	4051.5 (825.6)
Week 3 volume	6880.5 (2712.3)*	4371.6 (963.8)
Week 4 volume	7097.6 (2517.9)*	4.865,4 (1032.2)
Total volume	24,811.7 (9016.8)*	16,985.9 (3392.4)
Week 1 average repetitions	52.4 (12.9)	44.2 (5.7)
Week 2 average repetitions	67.9 (16.0)*	48.9 (5.6)
Week 3 average repetitions	76.8 (19.5)*	53.1 (9.3)
Week 4 average repetitions	80.0 (18.2)*	59.5 (11.9)
Total average repetitions	277.1 (60.5)*	205.7 (27.3)

* $p < .05$ between rest-pause vs. traditional training group

$\eta_p^2 = 0.68$; Table 3). However, there was no significant difference in the amount of 1 RM change between the traditional and rest-pause training groups following the 4-week lifting protocol, $F(1,18) = 0.01$, MSE = 98.96, $p = .938$, $\eta_p^2 = 0.00$.

A two-way repeated-measures ANOVA was performed to view differences neural activation using EMG. There were no differences in neural activation from pre-test to post-test, $F(1,18) = 0.01$, MSE = 0.002, $p = .917$, $\eta_p^2 = 0.001$, and no significant differences were found between the rest-pause group and the traditional group before and after the 4-week training protocol, $F(1,18) = 0.79$, MSE = 0.119, $p = .387$, $\eta_p^2 = 0.042$ (Table 3).

Descriptive statistics for volume and repetitions are shown in Table 4. The independent samples t test indicated that total volume lifted was significantly higher for the rest-pause group (M = 24,811.7 kg, SD = 9016.8 kg, $n = 10$) in comparison to the traditional training group (M = 16,985.9 kg, SD = 3392.4 kg, $n = 10$), $t(18) = 2.56$, $p = .019$, $d = 0.27$. When volume was compared each week, the rest-pause group had significantly higher volume during weeks two ($t = 2.66$, $p = .016$, $d = 0.31$), three ($t = 2.75$, $p = .013$, $d = 0.30$), and four ($t = 2.58$, $p = .018$, $d = 0.27$) in comparison to the traditional training group. No significant differences were found at week 1 ($t = 1.69$, $p = .109$, $d = 0.14$).

Discussion

To the authors' knowledge, this is the first study that compared changes in 1 RM, lifting volume, and neural activation between rest-pause and traditional bench press resistance training. Our hypothesis that rest-pause training would yield larger increases in bench press 1 RM, total lifting volume, and pectoralis major neural activation compared to traditional resistance training was partially supported. Rest-pause training resulted in a significantly greater total lifting volume than the traditional resistance training which supports our original hypothesis (Table 4). However, the differences in bench press 1 RM and pectoralis major neural activation were not different between groups rejecting our original hypothesis.

Although the change in bench press 1 RM was not different between groups, both groups significantly increased their post-training 1 RM (Table 3). The outcome of both groups increasing strength was expected due to the intensity (80%) that was used throughout the training programme by both groups. The intensity used in this study was near the recommended intensity (≥85% of 1 RM) for strength training (Rhea et al. 2002). The lack of between-group strength differences is notable, because the volume was significantly higher in the rest-pause group than the traditional group. Numerous studies have investigated the effects of volume differences in 1 RM changes. Studies that have used intensity ranges from 70 to 75% of 1 RM over 10–13 weeks have not shown significant changes in 1 RM (Hass et al. 2000; Ostrowski et al. 1997). However, Rhea et al. (2002) found that high volume training had significantly higher 1 RM changes than low volume training at 80–90% 1 RM for 12 weeks. The results of these studies appear to indicate that volume's effect on strength adaptations is dependent upon it being conducted at higher intensities. Although the current study used an intensity similar to Rhea et al. (2002), strength gains were not comparable. An explanation for this may be due to the briefer training programme (4-weeks) used in the present study. While the current study was intended to emulate a hypertrophy phase during periodization, future studies should compare rest-pause and traditional training after longer training programmes (i.e., 12 weeks).

The rest-pause group lifted significantly more total volume during the resistance training programme than the traditional group. A possible reason for these findings could be that the pauses used within a set by the rest-pause group allowed for some replenishment of creatine phosphate (PCr). While studies have shown that full PCr re-synthesis after high intense bouts may require ≥170 s (Bogdanis et al. 1995; Dawson et al. 1997; Harris et al. 1976; Hakkinen et al. 1998; Seynnes et al. 2007), DiPrampero and Margaria (1969) found a half-life of 30–40 s for PCr re-synthesis. In the current study, the average time to complete a set during rest-pause training was 56.9 s of which 30.8 s was time spent resting. It is plausible that some PCr replenishment occurred at this time. This could have delayed fatigue and led to the greater volume observed during rest-pause training. Furthermore, Keogh et al. (1999) also found that rest-pause training achieved more volume than the traditional training. Our study found that rest-pause training averaged 2.26 more repetitions than the traditional training, while Keogh et al. (1999) found that rest-pause training averaged 1.33 more repetitions than traditional training. A noteworthy difference between the rest-pause protocols of the current study and Keogh et al. (1999) is that the current study used 4 s pauses and Keogh et al. (1999) used 2 s pauses. The longer between repetition rests of the current study may have led to the greater volume disparity between rest-pause and traditional training. To our knowledge, optimal between repetition rest periods for rest-pause training are unknown and future studies should investigate optimal between repetition rest periods.

When between-group weekly volume was analysed, the rest-pause group reported significantly higher volume in weeks 2, 3, and 4 but not in week 1 (Table 4). In the current study, only 1 of the 20 recruited participants had experience using rest-pause training and he was randomly placed in the rest-pause training group. One limitation to the current study is possibly an insufficient amount of time for familiarization for the rest-pause group which could explain the lack of between-group volume difference. Furthermore, some participants indicated rarely training on a Smith machine. The weekly comparisons of our study show that it may take 1 week to familiarize participants to the rest-pause method. Future studies should use a familiarization week and extend the training protocol beyond 4 weeks. It is interesting that despite the lack of between-group difference in week 1, a linear regression line indicated that nine additional training sessions would have been needed for the traditional group to match the volume lifted in week 4 of the rest-pause group (rest-pause volume week 4 = 7093.2 kg, predicted the traditional volume week 13 = 7202.1 kg). This further shows the impact using the rest-pause method to achieve greater volume.

To the authors' knowledge, this is the first study that compared chronic neural activation changes in the pectoralis major between rest-pause and traditional training. Rest-pause and traditional bench press training did not produce different pectoralis major activity; however, pectoralis major activity was increased following the traditional resistance training (44 vs. 54%) but reduced following rest-pause training (32 vs. 20%; Table 3). While the rest-pause protocol was different, Marshall et al. (2012) viewed neural activation for the squat exercise using three different protocols. Marshall et al.'s (2012) rest-pause protocol used 80% of a 1 RM for the squat exercise with neural activation in six leg muscles being significantly higher when performing a 20-s inter-set rest interval until 20 repetitions were completed in comparison to completing four sets of five repetitions using both a 3-min rest and 20 s rest between sets (Marshall et al. 2012). Normalization methods included a percent change by averaging amplitudes of repetitions 1–4, 5–8, 9–12, 13–16, and 17–20. Furthermore, Keogh et al. (1999) found greater neural activation of the pectoralis major and triceps brachii during the middle and later repetitions during 1 set to failure between a traditional and rest-pause bench press protocol. However, normalization procedures used a 110° maximal voluntary isometric contraction and lifting intensities were with a 6 RM load. The results of the current study, Keogh et al. (1999), and Marshall et al. (2012), show inconsistent normalization procedures when viewing neural activation. The current study indicated no significant differences in neural activation changes between the rest-pause and the traditional training groups following 4 weeks of training (Table 3). Therefore, the hypothesis for neural activation was not supported. However, the rest-pause group had lower muscle activation after 4 weeks of training (12% less), while the traditional training group actually increased muscle activation (10% greater, Table 3). The authors believe that the lack of significance is likely due to the large standard deviation between the two groups.

Since the current studies' protocols were performed to volitional fatigue, it can be argued that central fatigue could have a potential role. Brooks et al. (1996) state that painful afferent inputs from the joints and muscles can negativity affect a participants' willingness to continue repetitions and physiological signals can lead to psychological inhibition. However, it is very difficult to obtain direct data on central nervous system function during exercise. Furthermore, muscular fatigue appears to be peripheral failure due to fatigue of muscles compared to the central nervous system which is likely far superior to skeletal muscles maintaining function (Brooks et al. 1996).

The results of the current study indicate that utilizing a rest-pause method is conducive for eliciting greater volume increases, which is suggested during hypertrophy phases (Baechle and Earle 2008). No significant differences were found in neural activation between the two training groups likely due to a large standard deviation between groups. Finally, no significant differences were found between 1 RM changes, though both groups significantly increased their post-test 1 RMs following the training protocol. Future studies should use a longer training period as this may reveal differences in strength gains and neural activation changes between rest-pause and traditional resistance training. The rest-pause training method can be a successful tool to incorporate into strength and conditioning experts' training programmes where hypertrophy increases during a mesocycle are the key goal within the training macrocycle. Finally, all 20 participants that began the testing protocol finished indicating 100% adherence for the two training regimens. This indicates with minor instruction and coaching, the rest-pause protocol can be just as safe a traditional resistance training. Finally, future studies should replicate a rest-pause training protocol and measure hypertrophy increases compared to the traditional training to volitional fatigue. Furthermore, studies examining changes in neural activation patterns should use a consistent normalization method, since there is no census defined. No external funding was received for the current study.

Conclusions

The current study found that utilizing a rest-pause protocol allows for significantly higher volume lifted in comparison to the traditional bench press training and yields similar increases in 1 RM. Strength and conditioning specialist and trainers could utilize this method during a mesocycle within a macrocycle to maximize volume increases during an off-season training programme. However, neural activation might not increase or decrease using the rest-pause training method. This suggests that if increasing volume is the goal of the athlete, recreational weightlifter, or bodybuilder, the rest-pause method should be used vs traditional lifting techniques.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Allen CC, Dean KA, Jung AP, Petrella JK (2013) Upper body muscular activation during variations of push-ups in healthy men. Int J Exerc Sci 6(4):278–288

Baechle TR, Earle RW (2008) Essentials of strength training and conditioning. Champaign, Illinois

Bogdanis GC, Nevill ME, Boobis LH, Lakomy HK, Nevill AM (1995) Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man. J Physiol 482(2):467–480

Brooks GA, Fahey TD, White TP (1996) Exercise physiology: human bioenergetics and its applications, 2nd edn. Mayfield Publishing Company, Houston

Dawson B, Goodman C, Lawrence S, Preen D, Polglaze T, Fitzsimons M, Fournier P (1997) Muscle phosphocreatine repletion following single and repeated short sprint efforts. Scand J Med Sci Sports 7:206–213

DiPrampero PE, Margaria R (1969) Mechanical efficiency of phosphagen (ATP + CP) splitting and its speed of resynthesis. Pflugers Arch 308:197–202

Hakkinen K, Newton RU, Gordon SE et al (1998) Changes in muscle morphology, electrographic activity, and force production characteristics during progressive strength training in young and older men. J Gerontol 53(6):415–423

Harris RC, Edwards RN, Hultman E, Nordesjo LO, Nulind B, Sahlin K (1976) The time course of phosphorylcreatine resynthesis during recovery of the quadriceps muscle in man. Pfluger Arch 367:137–142

Hass CJ, Garzarella L, Hoyos DD, Pollock ML (2000) Single versus multiple sets in long-term recreational weightlifter. Med Sci Sports Exerc 32(1):235–242

Keogh JWL, Wilson GJ, Weatherby RP (1999) A cross-sectional comparison of different resistance training techniques in the bench press. J Strength Cond Res 13(3):247–258

Krol H, Sobota G, Nawrat A (2007) Effect of electrode position on emg recording in pectoralis major. J Hum Kinet 17:105–112

Lawton TW, Cronin JB, Lindsell RP (2006) Effect of interrepetition rest intervals on weight training repetition power output. J Strength Cond Res 20(1):172–176

Marshall PWM, Robbins DA, Wrightson AW, Siegler JC (2012) Acute neuromuscular and fatigue responses to the rest-pause method. J Sci Med Sport 15:153–158

McArdle WD, Katch FI, Katch VL (2014) Exercise physiology, nutrition, energy, and human performance, 8th edn. Baltimore, Maryland

Miranda H, Fleck SJ, Simao R, Barreto AN, Dantas EHM, Novaes J (2007) Effect of two different rest period lengths on the number of repetitions performed during resistance training. J Strength Cond Res 21(4):1032–1036

Ostrowski KJ, Wilson GJ, Weatherby R, Murphy PW, Lyttle AD (1997) The effect of weight training volume on hormonal output and muscular size and function. J Strength Cond Res 11(1):148–154

Pescatello LS (2014) ACSM's guidelines for exercise testing and prescription. Philadelphia, Pennsylvania

Rhea MR, Alvar BA, Ball SD, Burkett LN (2002) Three sets of weight training superior to 1 set with equal intensity for eliciting strength. J Strength Cond Res 16(4):525–529

Robinson JM, Stone MH, Johnson RL, Penland CM, Warren BJ, Lewis RD (1995) Effects of different weight training exercise/rest intervals on strength, power, and high intensity exercise endurance. J Strength Cond Res 9:216–221

Seynnes OR, Boer MD, Narici MV (2007) Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. J Appl Physiol 102(1):368–373