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Effects of Load-Volume on EPOC After Acute Bouts of Resistance Training in Resistance-Trained Men

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Abstract

Abboud, GJ, Greer, BK, Campbell, SC, and Panton, LB. Effects of load-volume on EPOC after acute bouts of resistance training in resistance-trained men. *J Strength Cond Res* 27(7): 1936–1941, 2013–Recent investigations have shown excess postexercise oxygen consumption (EPOC) to be elevated for up to 48 hours in both untrained and trained subjects after resistance training (RT). The purpose of this study was to investigate the effect of load-volume on EPOC. Eight trained men (aged 22 ± 3 years) participated in 2 randomized RT bouts separated by at least 1 week with total load-volumes of 10,000 and 20,000 kg, respectively. Intensity of RT (85% 1 repetition maximum) did not differ between trials. Exercise energy expenditure and resting metabolic rate (RMR) were measured by indirect calorimetry at 8.5 hours before, 1.5 hours before, and during RT bouts and 12, 24, 36, and 48 hours after exercise. Creatine kinase (CK) was measured before and after RT, and 12, 24, 36, and 48 hours postexercise; ratings of perceived muscle soreness were measured on a similar time course save the immediate postexercise time point. Analysis of variance with repeated measures was used to analyze dependent variables. During the 20,000 kg trial, subjects expended significantly ($p < 0.01$) more energy (484 ± 29 kcal) than the 10,000 kg lift (247 ± 18 kcal). After the 20,000 kg lift, 12 hours postexercise, CK (1,159 ± 729 $U \cdot L^{-1}$) was significantly elevated ($p < 0.05$) as compared with baseline (272 ± 280 $U \cdot L^{-1}$) and immediately postexercise (490 ± 402 $U \cdot L^{-1}$). No significant time or trial differences were found in RMR between the 10,000 and 20,000 kg trials. In conclusion, high-intensity RT with load-volumes of up to 20,000 kg using resistance-trained men does not significantly increase EPOC above baseline RMR.

Key Words weight loss, intensity, weight training

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Introduction

Current evidence suggests that there is minimal benefit to resistance training (RT) for weight loss when compared with caloric restriction (5,13,20,21,28) and that weight loss associated with aerobic training is not enhanced by RT (32). Data indicate that energy expenditure during RT is relatively low even during high-intensity bouts of exercise (6,10,19). Because of the relatively minor amount of energy used compared with aerobic training, this mode of training has not been recommended as an effective method for controlling weight (18).

However, RT can increase excess postexercise oxygen consumption (EPOC) from 1 to 48 hours above resting levels (11,22,23,27,35). Excess postexercise oxygen consumption may be the result of energy-requiring processes such as the replenishment of oxygen stores in muscle and blood, replenishment of adenosine triphosphate and creatine phosphate stores, increased ventilation, increased heart rate, increased body temperature, increased triglyceride or fatty acid cycling, substrate utilization shifts from carbohydrates to fats, glycogen resynthesis, and increased sympathoadrenal activity (2–4,7,31,34). In addition, RT induces muscular protein breakdown (i.e., damage), which in turn invokes a healing response (i.e., synthesis) (9,33). The metabolic costs of protein synthesis are well documented (26); therefore, the degree of muscular damage may be a significant determinant in the EPOC response post-RT.

Thorton and Potteiger (29) report that high-intensity RT (85% 1 repetition maximum [1RM]) produces greater EPOC volume than lower intensity (45% 1RM) when equated for load-volume. However, in an alternative study, Thorton et al. (30) state that intensity did not influence EPOC in overweight African American women. As opposed to investigating the influence of intensity, the purpose of this study was to compare the effects of load-volume on EPOC after 2 bouts of RT. In previous investigations the absolute loads used during RT bouts were not held constant (5,12,13), except in one case in which rest periods were varied (16). In addition, none of the investigations used high-intensity

Table 1. Subject characteristics ($N = 8$).*

Variables	Mean ± *SD*	Range
Age (y)	22 ± 3	20–29
Height (cm)	176.9 ± 5.0	171.0–185.4
Weight (kg)	88.0 ± 8.7	80.1–101.4
BMI ($kg \cdot m^{-2}$)	28.1 ± 2.8	22.9–31.5
Body fat (%)	9.9 ± 4.1	4.6–16.3
Lean body mass (kg)	79.0 ± 6.0	68.7–86.4
1RM bench press (kg)	137 ± 16	112–162
1RM barbell squat (kg)	177 ± 43	134–272
1RM Romanian deadlift (kg)	114 ± 24	67–135
1RM barbell row (kg)	142 ± 34	95–193

*BMI = body mass index; 1RM = 1 repetition maximum.

protocols (≥85% 1RM) with high resistance-trained recreational lifters (5,12,13,27,29,30).

Methods

Experimental Approach to the Problem

Two RT bouts of equal intensity but different load-volumes were performed. Resting metabolic rate (RMR) was assessed both before (PM baseline and AM baseline to account for circadian shifts) and at 12, 24, 36, and 48 hours postexercise. Rating of perceived muscle soreness (RPMS) and creatine kinase (CK) levels, both indirect indicators of muscle damage, were also measured to determine if any differences in EPOC were because of greater muscular damage.

Subjects

Eight healthy men between the ages of 19 and 29 years volunteered for the experiment. Sample size estimation was based on an effect size of 1.1 from a previous study concerning acute effects of RT on EPOC (11). Subjects had at least 12 months of RT experience with no more than 2 weeks rest at a time, less than a total of 4 weeks off within the last 6 months, or 9 weeks off within the last 12 months. Subjects reported no previous or current use of illegal performance enhancing substances. This study was approved by the Florida State University Institutional Review Board, and all subjects signed a consent form informing them of the aims, procedures, and risks of the study. Subject characteristics are presented in Table 1.

Procedures

The general study design can be viewed in Figure 1. Four to seven days before the initiation of the first trial, subjects arrived at the laboratory for height/weight measurements (Seca Model 707; Columbia, MD, USA), body composition assessment via 3-site skinfold (Beta Technology, Inc., Santa Cruz, CA, USA), to undergo protocol familiarization for all exercises, and for 1RM testing. Subjects self-reported their approximate 8RM for each exercise. This weight was applied to a prediction table (1) to determine the first weight attempted for their 1RM. The load attempted was approximately 10 lbs lighter than predicted; 10 lb increments were used in most cases until a weight was attempted that the subject could not successfully lift. Three minutes of rest were provided between each lift, and limb placements were recorded to be used for better control during future experimental trials. Verbal encouragement was used for all lifts, and the last successful lift was recorded as the 1RM (Table 1).

Subjects were given a food diary log to record their diet 3 days before and 48 hours after the first exercise trial. Subjects were instructed to replicate this diet before and after the second experimental trial. Subjects refrained from RT for 72 hours before and from high-intensity aerobic exercise 48 hours before each trial as this represents adequate time for muscular recovery in trained subjects (9).

On the evening before the first trial, subjects reported to the laboratory at approximately 2000 hours (military time) after a 4-hour fast. Subjects underwent a 30-minute period of supine rest after which $\dot{V}O_2$ was collected to determine RMR and respiratory exchange ratio (RER) during a 30-minute period. A ParvoMedics' TrueMax 2400 metabolic cart

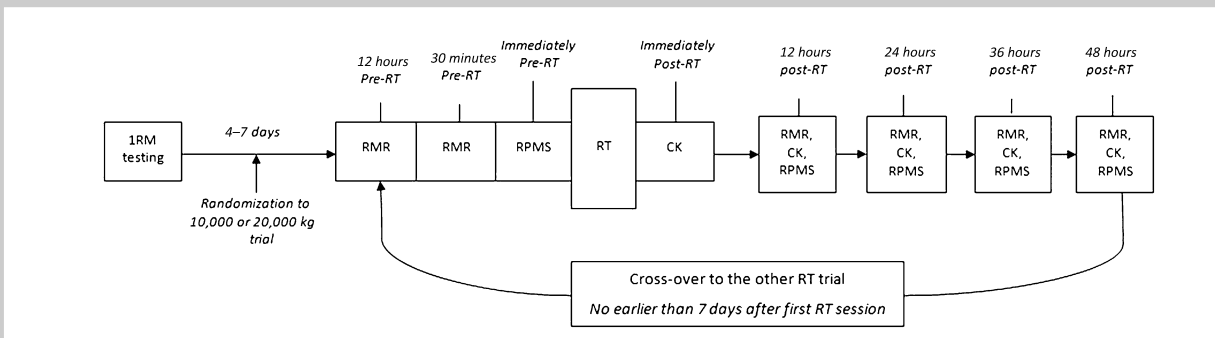

Figure 1. Study design. 1RM = 1 repetition maximum; RMR = resting metabolic rate; RPMS = ratings of perceived muscle soreness; RT = resistance training; CK = creatine kinase.

Table 2. Mean ± *SD* of metabolic measurements for the 10,000 and 20,000 kg trials ($N = 8$).

Variable	10,000 kg trial	20,000 kg trial
Energy expended (kcal)	247 ± 18	484 ± 29*
$\dot{V}O_2$ (ml·kg^{-1}·min^{-1}) across trial	12.9 ± 1.8	12.3 ± 1.8
Respiratory exchange ratio across trial	1.03 ± 0.02	1.00 ± 0.02

*$p \leq 0.01$, significantly different from 10,000 kg trial.

(ParvoMedics, Sandy, UT, USA) was used to collect all metabolic data.

After the baseline evening RMR was taken, subjects slept overnight in the laboratory. Resting metabolic rate was once again determined the following morning before the exercise protocol at 0600 hours. Blood was drawn after the morning baseline RMR measurement to determine CK levels (8). After the blood draw and 30 minutes before exercise, subjects were fed a Balance Bar Gold containing 22 g of carbohydrates, 15 g of protein, and 7 g of fat. Trial order was randomized, and RPMS for 4 muscle groups were collected immediately before RT using a visual analog scale (25). During the exercise trials, indirect calorimetry was used to determine energy expenditure. Blood was also collected immediately postexercise. Subjects returned to the laboratory for the next 2 evenings at 2000 hours to have blood drawn and for RMR and RPMS measurements, and then stayed overnight for morning measurements. Subjects repeated these procedures with the alternate load-volume no earlier than 7 days after the initial exercise trial.

Creatine Kinase Analysis

Before RT, and immediately after, 12 , 24 , 36 , and 48 hours postexercise, subjects had approximately 25 ml of blood drawn from an antecubital vein using sterile venipuncture techniques. The blood was collected in EDTA-coated tubes and centrifuged for 10 minutes. Two clear non-hemolyzed serum samples were separated and stored at −80° C. Creatine kinase was determined by manual assay (Pointe Scientific, Inc., Detroit, MI, USA) (17).

Resistance Protocols

Each RT bout consisted of 4 exercises performed on a non-counterbalanced Smith Machine so that range of motion could be controlled for easily. A bench press, squat, bent-over row, and Romanian deadlift were used. One trial required lifting a total load-volume of 10,000 kg and the other a total load-volume of 20,000 kg. During pilot testing, the regression coefficients for RMR 24 hours after 10,000 and 20,000 kg trials were $\beta = 0.977$ (95% confidence interval [CI]: −1.984 to 4.194) and $\beta = 0.971$ (95% CI: −2.886 to 5.578), respectively.

The loads were divided between the 4 exercises as follows: 35% to squats, 30% to bench press, 20% to bent-over rows, and 15% to Romanian deadlift. For each set, subjects lifted approximately 85% of their 1RM for 6–8 repetitions. If 6 repetitions could not be completed at any point, the load was reduced by 10% for the subsequent set.

During each lifting session, 3 testers were present; one to monitor the metabolic cart, one to ensure proper range of motion, and one to monitor proper lifting form. Subjects were instructed to perform the concentric portion of each lift with maximal speed and ensure a controlled eccentric descent, although a specific time interval was not dictated. The tester monitoring lifting form, present during every lifting session, monitored the lifting speed to aid speed consistency without the use of a metronome. A set was stopped if subjects broke

Table 3. Mean ± *SD* for AM metabolic measurements ($N = 8$).*

Trial	Variables	AM baseline	After 24-h EPOC	After 48-h EPOC
10,000 kg	RMR (ml·kg^{-1}·min^{-1})	3.3 ± 0.3	3.4 ± 0.4	3.4 ± 0.3
	RMR (L·min^{-1})	0.30 ± 0.04	0.30 ± 0.05	0.30 ± 0.04
	30-min energy expenditure (kcal)	36 ± 5	36 ± 6	37 ± 5
	RER	0.89 ± 0.10	0.86 ± 0.04†	0.89 ± 0.05
20,000 kg	RMR (ml·kg^{-1}·min^{-1})	3.5 ± 0.8	3.4 ± 0.3	3.5 ± 0.6
	RMR (L·min^{-1})	0.32 ± 0.09	0.30 ± 0.05	0.31 ± 0.05
	30-min energy expenditure (kcal)	39 ± 11	36 ± 5	38 ± 6
	RER	0.90 ± 0.11	0.87 ± 0.08†	0.90 ± 0.08

*EPOC = excess postexercise oxygen consumption; RMR = resting metabolic rate; RER = respiratory exchange ratio.
†$p < 0.05$, significantly different from 48 hours.

Table 4. Mean ± *SD* for PM metabolic measurements ($N = 8$).*

Trial	Variables	PM baseline	After 12-h EPOC	After 36-h EPOC
10,000 kg	RMR ($ml \cdot kg^{-1} \cdot min^{-1}$)	3.7 ± 0.4	3.8 ± 0.6	3.9 ± 0.6
	RMR ($L \cdot min^{-1}$)	0.33 ± 0.05	0.33 ± 0.07	0.34 ± 0.04
	30-min energy expenditure (kcal)	40 ± 5	41 ± 8	42 ± 8
	RER	0.89 ± 0.10	0.87 ± 0.10	0.87 ± 0.09
20,000 kg	RMR ($ml \cdot kg^{-1} \cdot min^{-1}$)	3.6 ± 0.4	3.7 ± 0.4	3.8 ± 0.6
	RMR ($L \cdot min^{-1}$)	0.32 ± 0.06	0.33 ± 0.05	0.34 ± 0.07
	30-min energy expenditure (kcal)	39 ± 7	40 ± 6	42 ± 8
	RER	0.86 ± 0.11	0.88 ± 0.11	0.88 ± 0.11

*EPOC = excess postexercise oxygen consumption; RMR = resting metabolic rate; RER = respiratory exchange ratio.

form and the repetition would not be counted. The subjects continued to perform sets until the load-volume for each respective trial was reached. Two-minute rest periods were given between sets.

Studies using load-volumes ranging from 3,000 to 6,000 kg do not report significant elevations in EPOC beyond 90 minutes (24,34). Greater load-volumes of approximately 11,000 kg and higher have been shown to increase RMR for up to 48 hours postexercise (11,35). The lower load-volume chosen for this study was similar to those used in the protocol by Dolezal et al. for one muscle group (11). The higher load-volume was similar to those used by both Gillette et al. (14) and Melby et al. (22); however, these studies used a lower intensity.

Statistical Analyses

The study followed a 2 × 6 and 2 × 5 within-subjects design with repeated measures in regards to CK and RPMS, respectively. A 2 × 3 design was used for metabolic measurements (nighttime baseline measure, after 12 hours, and after 36 hours), and a separate 2 × 3 design was used for alternate time points (morning baseline, after 24 hours, after 48 hours). Within-group differences were also examined. Repeated-measures analysis of variance was used to analyze the variance of experimental treatments. A Tukey HSD post hoc test was used to identify significant differences between mean values. Pearson product-moment correlations were used examine the relationship between CK and RMR. Significance for all tests was set at $p < 0.05$. Statistical analysis was performed using SPSS for Windows version 15.0 and 16.0 (SPSS, Inc., Chicago, IL, USA).

Results

All 8 subjects who initially volunteered completed the study. Data for the 2 exercise bouts are presented in Table 2. The exercise duration was significantly longer ($p \leq 0.01$) for the 20,000 kg protocol (90.3 ± 16.1 minutes) compared with the 10,000 kg protocol (43.6 ± 7.9 minutes). Energy expended in kilocalories for each protocol was also significantly different ($p < 0.01$). Mean oxygen consumption was significantly greater ($p \leq 0.01$) during both the 10,000 and 20,000 kg trials when compared with their respective morning baselines. Mean $\dot{V}O_2$ and RER did not differ both the between trials.

No significant differences in RMR were observed across time or between conditions. Data from metabolic measurements made in the AM and PM can be seen in Tables 3 and 4, respectively. The only significant changes ($p < 0.05$) were observed was between the 24- and 48-hour RER. As expected, PM baseline RMR trended higher as compared with the AM

Table 5. Mean ± *SD* for indirect indicators of muscle damage ($N = 8$).*

Protocol	Variable	Preexercise	Immediately postexercise	After 12 h	After 24 h	After 36 h	After 48 h
10,000 kg	CK ($U \cdot L^{-1}$)	309 ± 295	398 ± 344	729 ± 524	561 ± 400	492 ± 326	330 ± 189
	RPMS	0.2 ± 0.2	N/A	0.3 ± 0.4	0.5 ± 0.7	0.5 ± 0.4	0.3 ± 0.2
20,000 kg	CK ($U \cdot L^{-1}$)	272 ± 280	490 ± 402	1,159 ± 729†	981 ± 653	774 ± 588	506 ± 357
	RPMS	0.3 ± 0.3	N/A	1.2 ± 1.3	1.2 ± 1.5	2.1 ± 2.2	1.5 ± 1.8

*CK = creatine kinase; RPMS = ratings of perceived muscle soreness measured by a visual analog scale.
†$p < 0.05$, significantly different from baseline and immediately postexercise measurements.

measurement but was not significantly different ($p > 0.05$). Data regarding indirect indicators of muscle damage are presented in Table 5, with the only significant difference ($p < 0.05$) in the 20,000 kg trial between 24 hours CK and before and after exercise measurements.

Discussion

The primary finding of this study was that high-intensity RT with load-volumes of 10,000 and 20,000 kg do not significantly affect RMR in highly trained recreational male lifters. The study is unique with regard to the training experience of the subjects, evidenced by training duration history and high 1RM measurements, and the lifting intensity, which was held constant between trials.

As subjects in this study were well adapted to RT, the training stimulus needed to elicit increases in EPOC arguably needed to be much higher compared with that used in previous research (11,22,23,27,35). Two studies using intensities of 70% 1RM report significant increases in RMR. Melby et al. (22) had subjects perform 6 sets of 10 different exercises for a total of 60 sets. The repetition range for this protocol was 8–12 repetitions per set. This amounts to approximately 600 repetitions performed during the course of the exercise bout. The range of load-volume lifted by these subjects was 15,000–38,000 kg. Gillette et al. (14) used a similar protocol having subjects complete 5 sets of 10 different exercises for a total of 50 sets. The repetition range was also 8–12 meaning approximately 500 repetitions were performed. The mean load-volume lifted by these subjects was approximately 25,000 kg. The load-volume difference between these studies and the higher load-volume in this study (20,000 kg) is relatively minor compared with the difference in effect size regarding EPOC. However, the subjects in this study completed their trials with a drastically lower number of repetitions, a mean of 199. If subjects in this study performed a similar number of repetitions the load-volume would have been close to 50,000 kg. Perhaps, this would have been the threshold to induce a significant EPOC response. In other words, perhaps repetition volume is also significant in addition to load-volume or intensity in elevating RMR postexercise. Hackney et al. (15) support this contention because RMR was elevated up to 72 hours postexercise in trained individuals with a lower load-volume than this study but a higher repetition volume, although this was observed when the eccentric component of the lift was emphasized. Both Dolezal et al. (11) and Hackney et al. (15) focused on longer eccentric contractions, which may have caused greater protein degradation (9), and therefore higher EPOC levels were needed for skeletal muscle protein repair. The independent effects of repetition volume, as opposed to load-volume, and contraction type should be further investigated.

Hackney et al. (15) report that higher EPOC is observed in untrained subjects as compared with trained (15). This is not surprising as many acute energetically costly responses to RT, particularly the sympathoadrenal response (34), are downregulated as individuals become better adapted. In addition, untrained individuals experience a far greater degree of muscular damage in response to RT (9). As protein synthesis required for repair is energetically expensive, it is logical that untrained subjects will show greater and longer alterations in EPOC post-RT. Judging by training history, strength levels, and CK responses, subjects in this study had most likely reached a higher level of adaptation than the ones in previous studies and therefore were less sensitive to the metabolic effects of recovery from RT.

Practical Applications

Although most practitioners understand that aerobically oriented exercise can provide a greater caloric expenditure during exercise, RT is often promoted as an effective modality for weight loss because of its potential increases in RMR for hours or days postexercise. However, as an individual becomes better adapted to RT, the increase in EPOC is so minor that it may not be practically important. Although RT is an important component in any weight loss program to attenuate the loss of fat-free mass and therefore better preserve RMR, it is unlikely that the total energetic cost (during and after exercise) of a typical duration workout will be adequate for significant weight reduction in highly trained recreational lifters without caloric restriction and/or additional aerobic or high-intensity interval training.

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