Low-Load vs. High-Load Resistance Training to Failure on One Repetition Maximum Strength and Body Composition in Untrained Women

Taylor K. Dinyer,[1] M. Travis Byrd,[1] Matthew J. Garver,[2] Alex J. Rickard,[2] William M. Miller,[3] Steve Burns,[2] Jody L. Clasey,[1] and Haley C. Bergstrom[1]

[1]Department of Kinesiology and Health Promotion, University of Kentucky, Lexington, Kentucky; [2]School of Nutrition, Kinesiology, and Psychological Science, University of Central Missouri, Warrensburg, Missouri; and [3]Department of Health, Science, and Recreation Management, University of Mississippi, Oxford, Mississippi

Abstract

Dinyer, TK, Byrd, MT, Garver, MJ, Rickard, AJ, Miller, WM, Burns, S, Clasey, JL, and Bergstrom, HC. Low-load vs. high-load resistance training to failure on one repetition maximum strength and body composition in untrained women. *J Strength Cond Res* 33(7): 1737–1744, 2019—This study examined the effects of resistance training (RT) to failure at low and high loads on one repetition maximum (1RM) strength and body composition (bone- and fat-free mass [BFFM] and percent body fat [%BF]) in untrained women. Twenty-three untrained women (age: 21.2 ± 2.2 years; height: 167.1 ± 5.7 cm; body mass: 62.3 ± 16.2 kg) completed a 12-week RT to failure intervention at a low (30% 1RM) ($n = 11$) or high (80% 1RM) ($n = 12$) load. On weeks 1, 5, and 12, subjects completed 1RM testing for 4 different exercises (leg extension [LE], seated military press [SMP], leg curl [LC], and lat pull down [LPD]) and a dual-energy x-ray absorptiometry scan to assess body composition. During weeks 2–4 and 6–7, the subjects completed 2 sets to failure for each exercise. During weeks 8–11, the subjects completed 3 sets to failure for each exercise. The 1RM strength increased from week 1 to week 5 (LE: 18 ± 16%; SMP: 9 ± 11%; LC: 12 ± 22%; LPD: 13 ± 9%), week 1 to week 12 (LE: 32 ± 24%; SMP: 17 ± 14%; LC: 23 ± 26%; LPD: 25 ± 13%), and week 5 to week 12 (LE: 11 ± 9%; SMP: 7 ± 9%; LC: 10 ± 7%; LPD: 11 ± 11%) in each exercise, with no significant differences between groups. There were no significant changes in BFFM ($p = 0.241$) or %BF ($p = 0.740$) for either group. Resistance training to failure at 30% 1RM and 80% 1RM resulted in similar increases in 1RM strength, but no change in BFFM or %BF. Untrained women can increase 1RM strength during RT at low and high loads, if repetitions are taken to failure.

Key Words: muscular strength, strength training, exercise performance, failure training

Introduction

Resistance training (RT) is a recommended exercise component commonly used to increase muscular strength and initiate changes in body composition (increased bone- and fat-free mass [BFFM]), muscular hypertrophy, and decreased fat mass) (31). Traditional program guidelines from the American College of Sports Medicine (ACSM) and National Strength and Conditioning Association (NSCA) that promote muscular strength generally recommend an individual to engage in RT 2–4 days per week, completing 2–6 sets of 8–12 repetitions of 70–80% of a one repetition maximum (1RM) for each major muscle group (23,31).

Previous studies (15,20,22,27) have examined RT to failure at low (30–50% 1RM) and high loads (75–90% 1RM) in trained and untrained men and compared 1RM strength increases and body composition changes between groups. For trained men, increases in 1RM strength for low- (30–50% 1RM) and high-load (75–90% 1RM) training groups were observed for free weight training (i.e., back squat and bench press) and machine weight training (22,27). In untrained men completing a single muscle group exercise (forearm flexion or leg extension [LE]), high-load (80% 1RM) groups significantly increased 1RM strength, while low-load (30% 1RM) groups saw little to no change in 1RM strength (15,20). For both low- and high-load RT to failure protocols, increases in muscle thickness, muscle fiber cross-sectional area, and BFFM were reported after 2–12 weeks, with no differences reported between the low- and high-load training groups (15,21,23,28). Thus, engaging in RT to failure may result in positive strength and body composition adaptations, regardless of training load when repetitions are performed to failure.

During the early phases of an RT program (1–6 weeks), the observed strength gains are primarily due to neuromuscular adaptations from an increase in the voluntary motor unit activation of agonist muscle groups and a decrease in the co-contraction of antagonist muscle groups (18,24). Furthermore, different stimuli such as metabolite accumulation, mechanical tension, and specificity of training are believed to be responsible for the neuromuscular adaptations observed in strength increases (18–20,27) and may be due to differences in total volume and time under tension accumulation. Recent studies (15,22,27) have examined total volume and time under tension accumulated during RT to failure at low and high loads and reported total volume for low-load (30–50% 1RM) groups to be greater than or equal to high-load (75–90% 1RM) groups, while time under tension has been reported to be significantly greater in the low-load (30% 1RM) compared with the high-load (80% 1RM)

Address correspondence to Taylor K. Dinyer, taylor.dinyer@uky.edu.

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training group (15). This may indicate a training status–specific response to volume accumulation, time under tension, and 1RM strength increases at low and high loads when repetitions are taken to failure.

Currently, there is no evidence on the efficacy of RT to failure on maximal strength in trained or untrained women. Women typically self-select RT loads lower than what is recommended by governing bodies (6,10,11), which may suggest adherence to an RT program based on traditional strength prescription guidelines will be low in women (1). In addition, differences in total volume and/or time under tension between lower vs. higher loads may dictate the degree of changes in 1RM strength, which may lead to differences in the stimuli (i.e., metabolite accumulation, mechanical tension, and specificity of training) necessary to elicit increases in 1RM strength. Therefore, the purpose of this study was to examine the effects of RT to failure at a low (30% 1RM) and high load (80% 1RM) on 1RM strength and body composition (BFFM and percent body fat [%BF]) in untrained women. Based on previous studies (15,21,23,28), we hypothesized (a) 1RM strength would increase in both the low- (30% 1RM) and high-load (80% 1RM) groups with no difference in strength increases between the 2 groups; (b) there would be greater total volume accumulation and time under tension for the 30% 1RM group compared with the 80% 1RM group; and (c) there would be an increase in BFFM and a decrease in %BF in both groups (30% 1RM and 80% 1RM), with no difference between groups.

Methods

Experimental Approach to the Problem

This randomized, parallel design study consisted of a 12-week RT to failure intervention at either 30% 1RM ($n = 11$) or 80% ($n = 12$) 1RM. For this study, the terms "low load" and "high load" are used to express RT to failure at 30% 1RM and 80% 1RM, respectively. During pre- (week 1), mid- (week 5), and post-testing (week 12), the subjects completed 1RM testing for 4 different exercises (leg extension (LE), seated military press [SMP], leg curl [LC], and lat pull down [LPD]) and a dual-energy x-ray absorptiometry (DXA) scan to assess body composition. During weeks 2–4 and 6–7, the subjects completed 2 sets to failure for each exercise. During weeks 8–11, the subjects completed 3 sets to failure for each exercise. No RT sessions were conducted during 1RM testing weeks. During weeks 2–4, the subjects lifted at a load corresponding to the 1RM established during pre-testing (30% $1RM_{PT}$ and 80% $1RM_{PT}$), while during weeks 6–11, the load corresponded to the 1RM established during mid-testing (30% $1RM_{MT}$ and 80% $1RM_{MT}$). The subjects were asked to maintain their current physical activity patterns but to refrain from participating in any outside RT.

Subjects

Twenty-three untrained women (mean ± *SD*: age: 21.2 ± 2.2 years [age range: 18–27 years]; height: 167.1 ± 5.7 cm; body mass: 62.3 ± 16.2 kg) completed this study. Untrained was defined as not having participated in a structured (>2 days per week for at least 4 weeks) RT program for the past 2 years. The subjects were included in the study if they were free from any musculoskeletal injuries, not pregnant, and were untrained. The subjects were randomly assigned to the 30% 1RM group ($n = 11$) or the 80% 1RM ($n = 12$) group. This study was approved by the University of Kentucky Institutional Review Board for Human Subjects. All subjects were informed of the risks and benefits of the study before any data collection and then completed a physical activity readiness questionnaire, an ACSM risk stratification, and signed a written informed consent document before beginning the study.

Procedures

One Repetition Maximum Testing. The subjects performed 1RM testing for the LE, SMP, LC, and LPD exercises during weeks 1, 5, and 12 to provide baseline strength measures, prescribe training loads, and assess changes in muscular strength. All exercises were completed using machine weights (FreeMotion Fitness, Logan, UT, USA; Cybex International Inc., Medway, MA, USA) to assist with safe execution of all exercises. Before the 1RM assessments, the subjects completed a standardized warm-up consisting of 2 minutes of jogging or cycling, 10 stationary body mass lunges, 10 leg swings per leg, 10 forward arm circles, 10 backward arm circles, and 10 arm hugs. For each exercise, the machine settings were adjusted to the subject's limb length to ensure proper biomechanics throughout the full range of motion. The subjects were instructed on how to properly perform each machine lift before the lifting attempts. The 1RM attempts were preceded by 3 sets of light-weight warm-ups on each machine. During set 1, the subjects performed 8–10 repetitions at their estimated 50% 1RM. During sets 2 and 3, the load was progressively increased, so subjects could complete 5–6 and 2–3 repetitions, respectively, before the first 1RM attempt. The subjects were given 2-minute rest between warm-ups. The subjects then completed a maximum of five 1RM attempts. A repetition was considered complete when the lift was performed through the full range of motion and controlled through the concentric and eccentric phases of the lift. Weight was added to the barbell until subjects could no longer complete the lift throughout the full range of motion. The subjects were given 3 minutes of rest between each 1RM attempt and between each exercise. All 4 exercise 1RMs were performed on the same day. The lower-body and upper-body exercises were alternated in a randomized order to reduce the fatiguing effect of 1RM attempts.

Body Composition Assessment. The BFFM (kg) and %BF were used to determine changes in body composition measures from pre- to mid-, pre- to post-, and mid- to post-testing. To assess body composition, a total body DXA scan (GE Lunar Prodigy; GE Lunar Inc., Madison, WI, USA) was performed on weeks 1, 5, and 12. The machine was calibrated before each day's use. The subjects were asked to remove jewelry, eyeglasses, and metal during the scanning procedure. The subjects were instructed to refrain from eating, and from drinking caffeine at least 4 hours before the scan and to maintain normal hydration levels on the day of testing. All scans were analyzed by a single trained investigator using the Lunar software version 13.10.z.

Resistance Training to Failure Sets. The RT protocol consisted of 9 weeks of RT to failure at either 30% $1RM_{PT}$ or 80% $1RM_{PT}$ (weeks 2–4) and 30% $1RM_{MT}$ or 80% $1RM_{MT}$ (weeks 6–11) on all 4 resistance exercises (LE, SMP, LC, and LPD). Failure was defined as the point in which the subject could no longer complete the concentric phase of the lift with proper form (19). During weeks 2–4 and weeks 6–7, the subjects completed 2 sets of repetitions to failure on each lift. During weeks 8–11, a third set was introduced for each lift to mimic progressive overload commonly seen within strength cycles (31). The subjects completed training 2 times per week during the RT to failure weeks and did not complete any RT training sessions on the weeks 1RM assessments were performed. Before each training day, the subjects completed the same standardized warm-up as previously described. Before completing the set to failure at the prescribed load, the subjects in both groups (30% 1RM and 80% 1RM) completed 5 repetitions of the exercise at their 30% 1RM load. The subjects in the 80% 1RM group received 2 additional warm-up sets of progressive loads closer to the prescribed training load. It is recommended all RT exercises be completed in a slow and controlled manner to use the full range of motion and proper form (8,31). Thus, cadence was controlled between subjects with a 2-second concentric phase and a 2-second eccentric phase set to a metronome. The subjects were instructed to perform the concentric and eccentric portions of each lift to the metronome, so each phase lasted approximately 2 seconds, with little to no pause at the end of each phase. Both groups received 90 seconds of rest between sets and 2 minutes of rest between exercises. At least 48 hours separated training days, and sessions occurred at the same time of day (±2 hours) and day of the week (±1 day) throughout the 12 weeks.

The total repetitions completed were recorded for each subject after each exercise set. The total volume of exercise for each lift was calculated by multiplying the weight lifted (kg) by the number of repetitions completed. To determine total volume for the 9-week training program, total volume accumulated per day combined for all lifts was summed from each subject, for each week, to establish an overall 9-week volume. In addition, time under tension was calculated by multiplying the total number of repetitions completed for all lifts throughout the 9-week training program by 4 seconds (2-second eccentric phase + 2-second concentric phase).

Statistical Analyses

Independent-samples *t*-tests were used to determine whether there were any differences between groups (30% 1RM vs. 80% 1RM) for the pre-test scores of 1RM strength on each lift (LE, SMP, LC, and LPD), BFFM, and %BF. The 1RM strength was examined with a 2 (group: 30 and 80% 1RM) × 3 (time: pre-, mid-, and post-training) × 4 (exercise: LE, SMP, LC, and LPD) mixed factorial analysis of variance (ANOVA) with follow-up two-way and one-way repeated-measures ANOVAs and Bonferroni-corrected independent and dependent pairwise comparisons (3 comparisons; Bonferroni-corrected $p \leq 0.017$). The analyses of BFFM and %BF included separate 2 (group: 30 and 80% 1RM) × 3 (time: pre-, mid-, and post-training) mixed factorial ANOVAs with follow-up one-way repeated-measures ANOVAs and Bonferroni-corrected pairwise comparisons (3 comparisons; Bonferroni-corrected $p \leq 0.017$). The analyses of total volume and time under tension included separate 2 (group: 30 and 80% 1RM) × 2 (time: pre-to-mid and mid-to-post 1RM testing) × 4 (exercise: LE, SMP, LC, and LPD) mixed factorial ANOVAs with follow-up two-way and one-way repeated-measures ANOVAs and Bonferroni-corrected independent and dependent pairwise comparisons. All analyses on 1RM strength, BFFM, %BF, total volume, and time under tension were conducted using absolute values. The analyses were conducted using Statistical Package for the Social Sciences software (v.21.0. IMB SPSS Inc., Chicago, IL, USA), and an alpha level of $p \leq 0.05$ was considered statistically significant for the ANOVA analyses.

Results

Table 1 includes the baseline mean (±*SD*) descriptive information, 1RM values, and body composition values for the subjects by group. There were no group differences for any pre-testing measures (1RM strength, BFFM, and %BF) (Table 1).

For 1RM strength, there was no group × time × exercise interaction ($F(2.483, 52.142) = 1.097$, $p = 0.351$, $p\eta^2 = 0.050$). There was a significant two-way interaction for time × exercise ($F(2.483, 52.142) = 17.003$, $p < 0.001$, $p\eta^2 = 0.447$), but no two-way interactions for group × time ($F(1.265, 26.571) = 0.659$, $p = 0.459$, $p\eta^2 = 0.030$) or group × exercise ($F(1.744, 36.616) = 0.309$, $p = 0.707$, $p\eta^2 = 0.014$). The follow-up one-way repeated-measures ANOVAs to examine changes in 1RM strength (collapsed across group) indicated there were significant differences among timepoints for all 4 exercises (LE, SMP, LC, and LPD; $p < 0.001$ for all exercises). Paired-samples *t*-tests indicated increases in 1RM strength (collapsed across group) in all exercises from pre- to mid-testing (LE: 18 ± 16%, $d = 0.81$; SMP: 9 ± 11%, $d = 0.4$; LC: 12 ± 22%, $d = 0.6$; LPD: 13 ± 9%, $d = 0.57$; $p < 0.005$ for all exercises); from pre- to post-testing (LE: 32 ± 24%, $d = 1.3$; SMP: 17 ± 14%, $d = 0.88$; LC: 23 ± 26%, $d = 1.1$; LPD: 25 ± 13%, $d = 0.93$; $p < 0.001$ for all exercises); and from mid- to post-testing (LE: 11 ± 9%, $d = 0.57$; SMP: 7 ± 9%, $d = 0.44$; LC: 10 ± 7%, $d = 0.57$; LPD: 11 ± 11%, $d = 0.46$; $p < 0.001$ for all exercises) (Figure 1). Figure 2A–D includes the mean absolute values for the pre-, mid-, and post-testing 1RM strength for both groups for LE, SMP, LC, and LPD, respectively.

There were no significant group × time interactions for BFFM ($F(2, 40) = 1.472$, $p = 0.241$, $p\eta^2 = 0.069$) or %BF ($F(1.554, 31.076) = 0.230$, $p = 0.740$, $p\eta^2 = 0.011$). There were no significant main effects for time for BFFM ($F(2, 40) = 2.713$, $p = 0.079$, $p\eta^2 = 0.119$) or %BF ($F(1.554, 31.076) = 0.800$, $p = 0.430$, $p\eta^2 = 0.038$). In addition, there were no significant main effects for group for BFFM ($F(1, 20) = 2.238$, $p = 0.150$, $p\eta^2 = 0.101$) or for %BF ($F(1, 20) = 0.568$, $p = 0.460$, $p\eta^2 = 0.028$). Table 2 includes the BFFM and %BF measurements between groups at each timepoint.

For total volume, there was a significant group × time × exercise interaction ($F(1.358, 28.513) = 8.067$, $p = 0.004$, $p\eta^2 = 0.278$). Follow-up analyses revealed significant 2-way interactions for group × time for LC ($F(1, 21) = 8.508$, $p = 0.008$, $p\eta^2 = 0.288$) and LPD ($F(1, 21) = 7.915$, $p = 0.010$, $p\eta^2 = 0.274$), but there were no significant group × time interactions for LE ($F(1, 21) = 3.696$, $p = 0.068$, $p\eta^2 = 0.150$) or SMP ($F(1, 21) = 2.662$, $p = 0.118$, $p\eta^2 = 0.112$) (Figure 3). For LE, there were significant main effects for group ($F(1, 21) = 4.592$, $p = 0.044$, $p\eta^2 = 0.179$) and time ($F(1, 21) = 222.533$, $p < 0.001$, $p\eta^2 = 0.914$), but only a significant main effect for time ($F(1, 21) = 253.588$, $p < 0.001$, $p\eta^2 = 0.924$) for the SMP. The follow-up paired-samples *t*-tests indicated pre-to-mid total volume accumulation was significantly greater than mid-to-post total volume accumulation for both 30% ($p < 0.001$) and 80% ($p < 0.001$)

Table 1
Mean ± *SD* of the baseline measurements.

	30% group (*n* = 11)	80% group (*n* = 12)	*p*
Age (y)	21.1 ± 2.6	21.3 ± 1.8	0.865
Height (cm)	166.2 ± 7.0	167.9 ± 4.2	0.499
Body mass (kg)	63.8 ± 6.9	66.5 ± 10.8	0.494
Leg extension (kg)	62 ± 10	66 ± 16	0.498
Seated military press (kg)	22 ± 5	24 ± 5	0.332
Leg curl (kg)	45 ± 9	51 ± 9	0.150
Lat pull down (kg)	35 ± 7	39 ± 7	0.139
Lean body mass (kg)	38.3 ± 4.2	41.3 ± 4.2	0.109
Percent body fat (%)	34.5 ± 6.3	32.1 ± 6.8	0.402

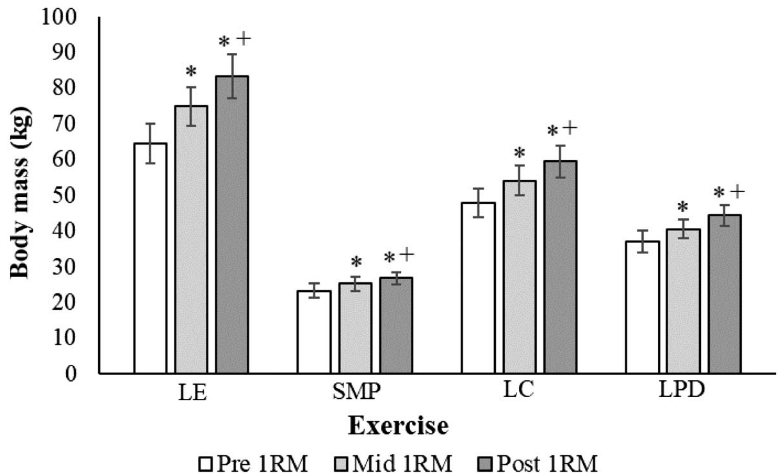

Figure 1. Collapsed mean change in one repetition maximum (1RM) strength on leg extension (LE), seated military press (SMP), leg curl (LC), and lat pull down (LPD) throughout a 9-week resistance training intervention. *Significant increase in 1RM strength from the pre-testing value for the corresponding exercise (Bonferroni-corrected $p \leq 0.017$). +Significant increase in 1RM strength from the mid-testing value for the corresponding exercise (Bonferroni-corrected $p \leq 0.017$). (See Results section for ANOVA analysis). ANOVA = analysis of variance.

1RM groups for LC and LPD. Independent-samples *t*-tests indicated the 30% 1RM group accumulated more volume from pre- to mid-testing than the 80% 1RM group in LC ($p = 0.002$) and LPD ($p = 0.001$) and during mid- to post-testing in LC ($p = 0.001$) and LPD ($p = 0.003$). When collapsed across group, both LE (pre-mid: 3,915 ± 1,069 kg; mid-post: 9,320 ± 2,649 kg; $p < 0.001$) and SMP (pre-mid: 1,136 ± 302 kg; mid-post: 2,944 ± 729 kg; $p < 0.001$) accumulated significantly more total volume during the mid- to post-testing timepoint compared with the pre- to mid-testing timepoint. When collapsed across time, LE average total volume accumulation was greater in the 80% 1RM group (7,332 ± 1779 kg) compared with the 30% 1RM group (5,838 ± 1,541 kg) ($p = 0.044$).

For time under tension, there was a group × time × exercise ($F(1.130, 23.734) = 7.949$, $p = 0.008$, $p\eta^2 = 0.275$) interaction, and follow-up analyses revealed significant 2-way interactions for group × time for each exercise (LE: $p = 0.001$; SMP: $p < 0.001$; LC: $p =< 0.001$; LPD: $p = 0.004$). Paired-samples *t*-tests indicated time under tension for each lift (LE, SMP, LC, and LPD) was significantly greater during the mid- to post-training vs. the pre- to

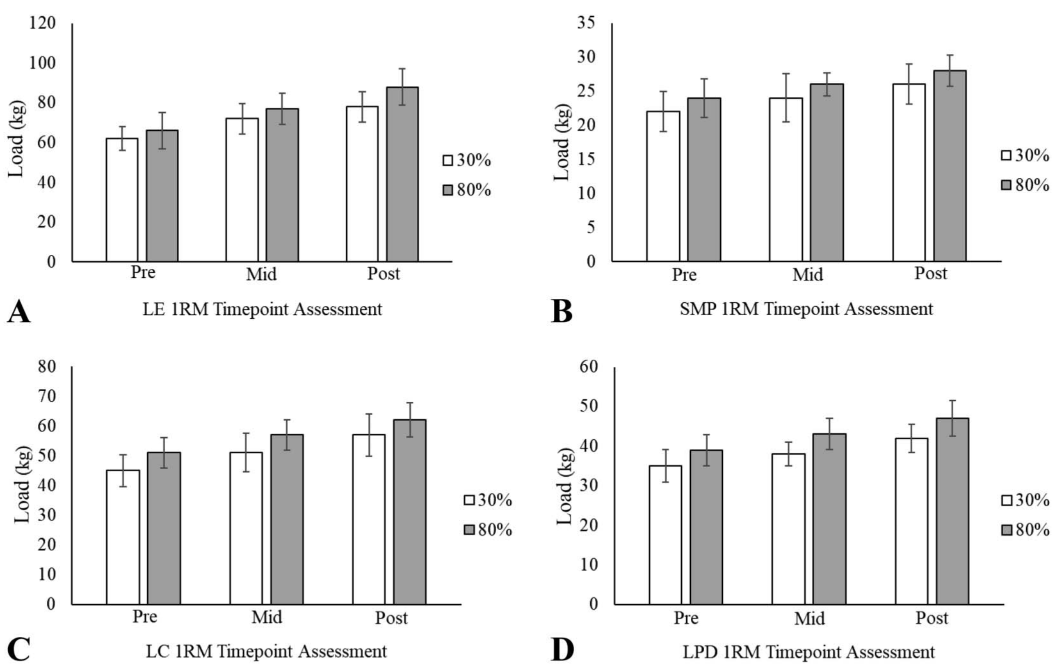

Figure 2. Mean values for one repetition group maximum (1RM) strength increases at each timepoint for leg extension (LE; A), seated military press (SMP; B), leg curl (LC; C), and lat pull down (LPD; D) by group. *There were no significant differences between groups for any exercise. See Results section for ANOVA analysis. ANOVA = analysis of variance.

Table 2
Mean ± *SD* of the body composition measurements.

	Bone- and fat-free mass (kg)		Fat mass (kg)		Percent body fat	
	Pre	Post	Pre	Post	Pre	Post
30% group	38.3 ± 4.2	39.4 ± 3.4	21.9 ± 5.8	22.2 ± 5.9	34.5 ± 6.3	34.2 ± 5.6
80% group	41.3 ± 4.2	41.4 ± 3.9	21.6 ± 8.4	23.6 ± 10.2	32.1 ± 6.8	32.2 ± 7.2

No significant differences existed between groups or timepoints at Bonferroni-corrected $p \leq 0.017$.

mid-training for the 30% 1RM group ($p < 0.05$ for all exercises) and the 80% 1RM group ($p < 0.001$ for all exercises). Independent-samples *t*-tests indicated the 30% 1RM group had significantly greater time under tension than the 80% 1RM group for all exercises (LE, SMP, LC, and LPD) during the pre- to mid-training ($p < 0.001$ for all exercises) and during the mid- to post-training ($p < 0.001$ for all exercises). Figure 4 includes the independent- and paired-samples *t*-test results for time under tension.

Discussion

In this study, we examined the effects of RT to failure in untrained women at 2 different loads (30% 1RM and 80% 1RM) on 1RM strength and body composition (BFFM and %BF). Currently, RT is most commonly prescribed at a load corresponding to at least 70% of an individual's 1RM to increase maximal strength and BFFM and decrease %BF (8,31). The results of this study, however, indicated significant increases in upper- and lower-body 1RM strength (LE, SMP, LC, and LPD) regardless of the training load (30% 1RM and 80% 1RM) at all 1RM timepoints (pre- to mid-testing, pre- to post-testing, and mid- to post-testing), and no change in body composition (BFFM and %BF) in untrained women when repetitions were taken to failure.

The increases in 1RM strength, regardless of training load (30% 1RM vs. 80% 1RM) for untrained women in this study are consistent with previous findings of increased strength during both low- and high-load machine weight RT in trained men (23). For free weight exercise training (i.e., back squat and bench press) programs in trained men, however, there were greater increases in 1RM strength for the high-load training (75–90% 1RM) groups than the low-load training (30–50% 1RM) groups (23,28). Similarly, for untrained men performing RT to failure at low- (30% 1RM) vs. high- (80% 1RM) loads for forearm flexion and LE exercises, there were greater 1RM strength increases in the high-load groups than the low-load groups, who had smaller or no increases in 1RM strength (15,21). These previous studies (15,21), however, have isolated training programs to 1 exercise, while this study used 4 different exercises to mimic a whole-body training program. Thus, the equivalent gains in 1RM strength for low- and high-load machine weight training of the upper- and lower-body in untrained women were consistent with previous

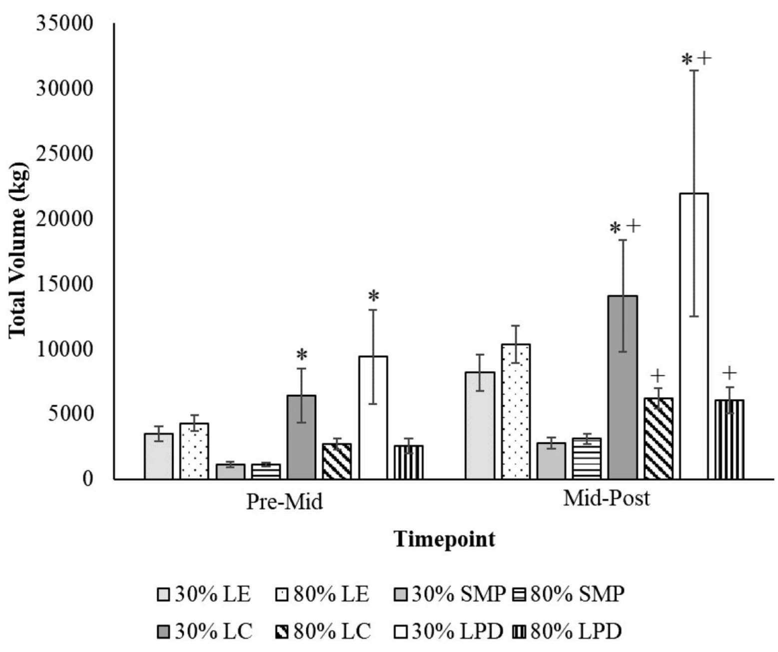

Figure 3. Comparisons for the pre-to-mid vs. mid-to-post total volume accumulation between 30% 1RM and 80% 1RM groups by exercise (leg extension [LE]; Seated military press [SMP]; leg curl [LC]; and lat pull down [LPD]). Based on the ANOVA analyses, simple main effects were examined only for the LC and LPD. For the LE and SMP, comparisons were made on the collapsed values (across group and time). (See Results for description of ANOVA analyses) *30% 1RM group had significantly greater total volume than the 80% 1RM group per exercise at $p < 0.05$. +Mid-to-post training total volume was greater than the pre-to-post training volume to the corresponding exercise at $p < 0.05$. 1RM = one repetition maximum; ANOVA = analysis of variance.

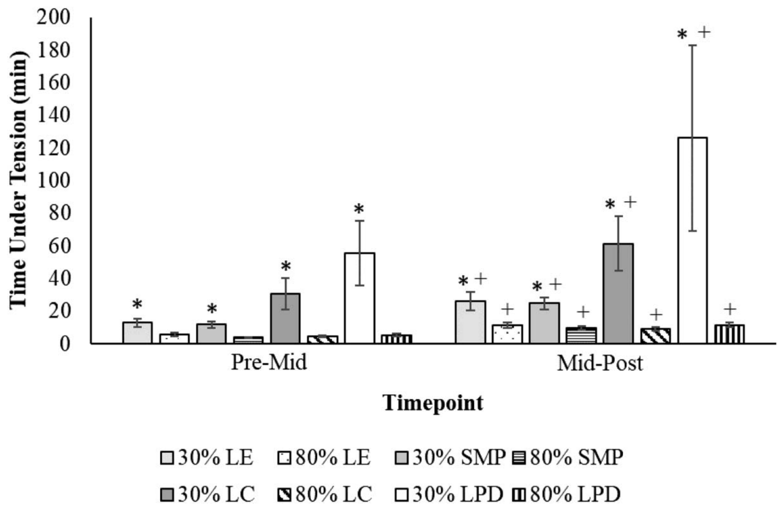

Figure 4. Comparisons for the pre-to-mid vs. mid-to-post training time under tension between 30% 1RM and 80% 1RM groups by exercise (leg extension [LE]; Seated military press [SMP]; leg curl [LC]; lat pull down [LPD]). *30% 1RM had significantly greater time under tension than the 80% 1RM group at $p < 0.05$. +Mid-to-post training time under tension was greater than the pre-to-post training time under tension to the corresponding exercise at $p < 0.05$. 1RM = one repetition maximum.

findings from low- and high-load machine weight training programs in trained men. The current findings, however, were not consistent with free weight exercises or single-muscle group exercises in trained and untrained men. Therefore, the results of this study, in conjunction with those of others (15,21,23,28), indicated the 1RM strength response to low- or high-load training may be dependent on sex, the training status of the subjects, and the modality of exercise.

The increased strength for each exercise at each testing timepoint in this study was likely primarily related to neuromuscular adaptations (4,19,25), with little contribution from hypertrophy. Specifically, there were no significant changes in BFFM after the 9-week training period when measured by DXA. This is inconsistent with previous research on trained and untrained men, who demonstrated increases in muscle thickness, muscle cross-sectional area, and BFFM of the upper and lower body after 2–12 weeks of low- and high-load training to failure (15,21,23,28). Previous studies, however, used ultrasound (15,28) or magnetic resonance imaging (21) to measure changes in muscle thickness or volume. The current study used DXA, which has been shown to have large measurement error, and, therefore, may not be a valid testing measure to examine small changes in muscle mass during an RT study (7). It is possible that small changes in contractile protein size and number occurred in this study, which the BFFM measurement from DXA was not sensitive enough to detect. Because of the relatively short duration (9 weeks) of the training protocol, however, it is likely the strength adaptations were primarily related to neuromuscular adaptations including increased muscle activation of the agonist and/or decreased coactivation of antagonist muscle groups (17,18,20,22).

The specific stimuli responsible for the neuromuscular adaptations and increased 1RM strength observed for low- and high-load training may reflect different underlying mechanisms that were dependent on the training load. For the low-load (30% 1RM) training group, fatigue-induced metabolic byproduct accumulation was likely the primary stimuli, whereas mechanical stress and specificity of training may have been more important in the high-load (80% 1RM) training group. Specifically, within the 30% 1RM group, greater metabolic stress, compared with the 80% 1RM group, likely resulted in the accumulation of metabolic byproducts and the fatigue-induced recruitment of higher threshold motor units as the set progressed, thereby subjecting more motor units to the training stimulus (20). This fatigue-induced recruitment of higher threshold motor units in the low-load training group likely contributed to the observed increase in 1RM strength (27). When repetitions are performed for longer durations of time without rest, greater volume and time under tension are accumulated. This results in increased accumulation of metabolites and hormones, such as blood lactate (and the associated H^+) and growth hormone, respectively (12,13,28). Although conflicting evidence does exist (30,33), an increase in metabolite and hormone accumulation from greater time under tension has been linked to increases in muscle protein synthesis and significantly greater increases in strength compared with RT with less time under tension (i.e., higher load or rest between sets) (2,3,12,24,29). In this study, the time under tension for the 30% 1RM group was significantly greater in each lift compared with the 80% 1RM group (Figure 4) and thus may have led to increased metabolite accumulation. Interestingly, greater total volume accumulation and muscle activation has been shown to vary by group, depending on the exercise performed. In this study, average total volume accumulation was greater in the 80% 1RM group compared with the 30% 1RM group for LE. Previously, Jenkins et al. (14) reported increases in muscle activation for both low-load (30% 1RM) and high-load (80% 1RM) repetitions to failure in the LE, although the 80% 1RM group had a greater increase compared with the 30% 1RM group. By contrast, for LC and LPD, this study observed greater average total volume accumulation in the 30% 1RM group than the 80% 1RM group (Figure 3). For muscle activation, repetitions performed to failure in the bicep curl resulted in no significant differences in muscle activation between the low-load (30% 1RM) training group and the high-load (80% 1RM) training group (16). In the SMP, there was no difference between groups in average total volume accumulation. These findings suggest a muscle group–specific response in volume accumulation and muscle activation when repetitions are taken to failure and indicated time under tension may be a more important indicator of the metabolic stimulus necessary to elicit strength adaptations during low-load (30% 1RM) exercise. Thus, the strength increases observed in untrained women in the 30% 1RM training group were primarily related to neuromuscular adaptations, such as increased motor unit activation, as a result of a greater time under tension and metabolic stress compared with the 80% 1RM group.

The strength increases in the 80% 1RM training group likely reflected a different underlying mechanism than metabolite accumulation responsible for the stimulus for the 30% 1RM training group strength increase. Specifically, mechanical tension and specificity of training may have aided in the 1RM increases seen in the 80% 1RM group through the increased ability to activate and coordinate all motor units (17,19,27). Higher training loads (≥80% 1RM) of an individual's 1RM have been commonly prescribed to elicit gains in muscular strength (31). Mechanical tension has been suggested to provide a myogenic adaptation, potentially increasing the number of contractile proteins available in the muscle to aid in strength development (20). Although hypertrophy (as measured by changes in BFFM) did not occur in this study, there may have been small increases in contractile proteins in response to heavier tension on the muscle and thus increased 1RM strength in the 80% 1RM group. In addition, mechanical tension leads to increased motor unit recruitment of higher threshold motor units, increasing the ability to activate all motor units and improve force production (19). Furthermore, specificity of training contributes to improved performance in a specific skill when training protocols mimic the desired response to the greatest degree, allowing for coordination of the motor units used for the specific skill (18,19). In this study, women in the 80% 1RM group performed an average of 5–6 repetitions per set for each exercise (range- LE: 1–16 repetitions; SMP: 2–11 repetitions; LC: 2–14 repetitions; LPD: 2–17 repetitions) and lifted repetitions to failure at a weight more closely aligned to that of a 1RM, which is consistent with strength training regimens prescribed by the ACSM and NSCA (8,31). Therefore, it is likely that the specificity of the 80% 1RM group, as well as mechanical tension from the higher training load, led to neuromuscular adaptation and aided in the significant increases in strength at all timepoints.

A limitation of this study was the lack of control for the menstrual cycle, including documentation of the use of oral contraceptives in the subjects. There is conflicting evidence regarding the effects of the phase of the menstrual cycle on maximal strength (9,26). Although the menstrual cycle phase was not controlled for in this study, the groups were randomized and tested every 4 or 5 weeks, so each subject should have been in the same phase of the cycle at 1RM testing, depending on cycle length (9,26). Future studies should monitor the phase of the menstrual cycle and perform maximal testing during the menstrual phase that is least affected by hormone concentrations to determine whether similar changes in strength as those in this study are observed. In addition, while our subjects were required to refrain from eating and from drinking caffeine a minimum of 4 hours before DXA scanning and to maintain normal hydration levels of the day of testing to help increase the likelihood of a euhydrated state, it has been previously suggested that DXA scanning should optimally be performed after an overnight fast (32). We also did not control diet during this study, which presents a limitation as diet does play a role in body composition changes over time. Interestingly, the subjects completed a wide range of repetitions per exercise within each training group and thus may have been training with different energy systems, potentially altering the stimulus each subject received to gain 1RM strength. Future studies should anchor training loads and repetition ranges within a specific energy system to examine the stimulus (i.e., metabolic disturbance or central fatigue) that plays a role in 1RM strength increases during RT to failure in untrained women.

In summary, there were increases in maximal strength in untrained women in this study for both the low- (30% 1RM) and high-load (80% 1RM) training groups. These strength increases were likely primarily related to neuromuscular adaptations such as increased voluntary activation of the agonist muscle groups and/or decreased coactivation of the antagonist muscle groups. There were muscle group–specific responses in total volume accumulation that were dependent on the exercise load (30% 1RM vs. 80% 1RM), but 30% 1RM training resulted in a greater time under tension than 80% 1RM training, for each exercise. The greater time under tension for the 30% 1RM group, than the 80% 1RM group, was the primary stimuli for increased 1RM strength due to the metabolic stress and the fatigue-induced recruitment of higher threshold motor units as the set progressed. These findings indicated time under tension may be a more important indicator of the metabolic stimulus necessary to elicit strength adaptations during low-load (30% 1RM) exercise. By contrast, the 80% 1RM group trained at a load more specific to maximal strength and experienced greater mechanical tension, thereby increasing the voluntary activation of the agonist muscle groups. Thus, the current findings indicated equivalent increases in 1RM strength for untrained women for low- and high-load RT to failure that were likely related to neuromuscular adaptations from stimuli (i.e., time under tension, mechanical tension, and specificity of training) that were dependent on the training load.

Practical Applications

The results of this study demonstrated RT to failure at low (30% 1RM) and high (80% 1RM) loads are effective for increasing 1RM strength in untrained women. Women tend to self-select RT loads that are lower than those recommended by governing bodies (6,10,11). Based on this study, performing repetitions to failure at 30% 1RM resulted in a similar increase in 1RM strength as the 80% 1RM group, indicating lower loads are effective for increasing strength when repetitions are performed to failure. In addition, for the low-load (30% 1RM) training group, time under tension had a greater effect on increased strength than total volume accumulation. Therefore, time under tension may be a more important variable than total volume for practitioners to consider when training clients at lighter (<30% 1RM) loads with the goal to increase strength. Training at 30% 1RM, however, resulted in greater time spent during the training session, compared with the 80% 1RM group. Consequently, performing multiple sets of repetitions to failure at low loads (≤30% 1RM) may increase the time commitment to the training program. Therefore, personal trainers should discuss client preference for lifting load and time commitment before prescribing a RT program. Training at lower loads can improve maximal strength, which may be preferable to untrained women as noted by self-selection of low-load training intensities.

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