The Effects of Moderate- Versus High-Load Resistance Training on Muscle Growth, Body Composition, and Performance in Collegiate Women

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Abstract

Cholewa, JM, Rossi, FE, MacDonald, C, Hewins, A, Gallo, S, Micenski, A, Norton, L, and Campbell, BI. The effects of moderate- versus high-load resistance training on muscle growth, body composition, and performance in collegiate women. *J Strength Cond Res* 32(6): 1511–1524, 2018—Twenty young women (20.3 + 1.5 years, 164 + 6 cm, 68.7 + 13.8 kg) without prior structured resistance training experience were recruited for this study. Body composition (BodPod), compartmental water (Bioelectrical Impedance), 7-site skinfold, and arm and thigh cross-sectional area (CSA) were assessed before and after 8-week training. Performance testing consisted of vertical jump, 3-kg chest pass initial velocity, squat 1RM, and overhead press 1RM. After 2 weeks of familiarization training, subjects were matched for body composition and relative squat strength and randomly assigned to either a high-load (HL: $n = 10$; 4 sets of 5–7 repetitions) or moderate-load (ML: $n = 10$; 2 sets of 10–14 repetitions) group that completed 6–7 exercises per day performed to momentary muscular failure. Training was divided into 2 lower and one upper body training sessions per week performed on nonconsecutive days for 8 weeks. There were no statistically significant main effects for group or group × time interactions for any variable assessed. Both HL and ML resulted in similar significant increases in lean body mass (1.5 ± 0.83 kg), lean dry mass (1.32 ± 0.62 kg), thigh CSA (6.6 ± 5.6 cm^2), vertical jump (2.9 ± 3.2 cm), chest pass velocity (0.334 ± 1.67 $m\cdot s^{-1}$), back squat one repetition maximum (1RM) (22.5 ± 8.1 kg), and overhead press (3.0 ± 0.8 kg). High-load group and ML group also both resulted in significant decreases in percent body fat (1.3 ± 1.3%), total body water (0.73 ± 0.70 L), and intracellular water (0.43 ± 0.38 L). The results of this study indicate that both moderate-load and high-load training are effective at improving muscle growth, body composition, strength and power in untrained young women.

Key Words aesthetics, periodization, hypertrophy, heavy weight training, fat loss

Introduction

Increasing muscular strength and hypertrophy are important to a variety of populations. Because muscle cross-sectional area (CSA) is directly correlated to force output (23), increasing muscle hypertrophy may lead to enhanced performance in strength and power athletes (43). In the general population, increasing strength may benefit the accomplishments of activities of daily living as reduced muscular strength is a predictor of mortality in older adults (42). Resistance training has been well accepted as the primary mode of exercise to enhance muscular strength and hypertrophy. The American College of Sports Medicine (ACSM) recommends performing 8–12 repetitions to muscular fatigue for general health (2), whereas the National Strength and Conditioning Association (NSCA) recommends performing repetitions of 10–12 with 65–85% of the one repetition maximum (1RM) to maximize hypertrophy and repetitions of 1–5 with greater than 85% of the 1RM to maximize strength development (5).

Although strength training among young women has increased since 1998 (18), Patterson et al. (31) reported that among a sample of 421 traditional undergraduate college women not engaged in varsity sports, only 33% of young women meet national strength training recommendations (>2 $d\cdot wk^{-1}$). The association between resistance training and appearing masculine has been identified as a potential barrier to adopting a resistance training program (30). Ratamess et al. (33) reported that 70% of young women

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engaged in resistance training at health clubs described "increased muscle tone" as motivation for resistance training; however, 38% of women who trained at health clubs expressed an adversity to resistance training because of the misconception that resistance training would lead to excessive muscular hypertrophy.

A fear of becoming masculine or developing "large, bulky muscles" (33) may explain why many young women often train with subthreshold intensities or abstain from resistance training altogether. Cotter et al. (8) investigated the difference in rate of perceived exertion (RPE) response to imposed loads (40 and 70% 1RM) and a self-selected load to be used for 3 sets of 10 repetitions that "would be comfortable, yet still provide a challenging workout" in recreationally trained females. Women self-selected an intensity equal to approximately 57% 1RM that corresponded with an RPE of 13–14 ("somewhat hard"). In contrast, 70% 1RM resulted in an RPE of 15–16 ("hard"). Ratamess et al. (33) reported recreationally trained women who trained with a personal trainer self-selected greater loads and worked at a higher RPE than women who trained alone; however, neither group self-selected loads for any of the exercises that exceeded 60% 1RM. In a recent meta-analysis, Schoenfeld et al. (39) demonstrated that low intensity loading (<50% 1RM) may promote hypertrophic adaptation similar to higher intensities (>70% 1RM) provided that sets in the lower intensity protocols are carried out with a high level of effort (i.e.: sets should reach or approach momentary muscular failure). However, the results of the aforementioned studies, and similar findings in untrained women (12), suggest that women with shorter training histories (lower training status) often do not use a load of a high enough relative intensity and/or train with sufficient effort to maximize strength and hypertrophy adaptations during resistance training.

Volume and intensity are 2 variables that are commonly manipulated during a strength training program to induce a desired outcome. Based on the analysis of 15 studies, Fry (14) reported that higher loads account for 18–35% of the variance in hypertrophic responses as a result of resistance training. In contrast, several emerging studies suggest that training with lighter loads to failure will result in similar hypertrophy to using heavier loads when either total sets performed (18,25) or load volume (7,38) are matched between groups. A recent study by Schoenfeld et al. (37) demonstrated no significant differences in muscle growth between low-loading and high-loading conditions with greater strength gains in the high-load condition. A follow-up study by Schoenfeld et al. (36) compared 3 sets of 7 exercises using either a 2–4RM or a 8–12RM in trained young men. Greater strength gains were observed in the heavy group, whereas greater increases in elbow extensor and quadriceps muscle thickness were observed in the moderate group. The larger volume accomplished by the moderate group likely explains the difference in results between these 2 studies. Although a number of studies conducted in male subjects have evaluated the effects of different loading schemes on muscle hypertrophy (39), there are very few studies that have evaluated these outcomes in young, healthy female subjects.

Schuenke et al. (40) compared 6 weeks of lower-body training with 3 exercises (leg press, squat, leg extension) and 3 sets per exercise using either a high intensity (80–85% 1RM, 6–10 repetitions) or a low intensity (40–60% 1RM, 20–30 repetitions) loading scheme in untrained young women. Although fiber CSA increased in both groups, a greater increase was observed in the high intensity group. In contrast, Alegre et al. (3) used a within subjects design in which subjects trained each leg with a different volume × intensity protocol to reduce interindividual differences in trainability in untrained young women. Subjects trained for 10 weeks with one leg performing high (80% 1RM) and the other leg moderate (50% 1RM) intensity unilateral lower-body resistance exercise (leg press and knee extensions). Quadriceps muscle thickness, CSA, and static and dynamic torque increased similarly for both the high-load and moderate-load legs. The discrepancy in the results between these 2 studies may be the result of how muscular hypertrophy was measured (single-fiber CSA via muscle biopsy vs. ultrasound muscle thickness); however, more research to elucidate the effects of varying the training load with more commonly employed intensities and sets × repetition training schematics on muscular hypertrophy outcomes in young (18–35 years old) women is warranted.

In addition to a lack of research in young women, most of the current studies investigating the effects of different loading schemes in men have compared very low loads (i.e.,: 30–50% 1RM) with more moderately heavy loads (70–80% 1RM). These intensities do not reflect the loads often used in heavy strength training (85–90% 1RM) nor the more moderate loading approach (60–70% 1RM) used by many novice trainers. Therefore, the purpose of this study was to compare changes in strength, body composition, and muscle hypertrophy between repetition-volume matched moderate-load and high-load training in healthy young females over a 9-week period. We hypothesized that strength outcomes would be greater in the heavy loading group, but that there would be no differences between groups for changes in arm and thigh CSA or lean body mass.

Methods

Experimental Approach to the Problem

Subjects were pair-matched based on initial strength levels and body fat percentage and then randomly assigned to 1 of 2 groups: A heavy-load group that performed training within a 5–7 repetition maximum zone and a moderate-loading group that performed training within a 10–14 repetition maximum zone. Training occurred over 9 weeks with the subjects performing 2 lower-body and one upper-body training sessions each week comprised of 4–6 exercises per session. Total repetition volume was equated between groups. Testing was carried out before and after the study for

strength, power, body composition, and arm and thigh cross-sectional area.

Subjects

Subjects were a convenience sample recruited from a university population of female volunteers between the ages of 18–35, without any existing musculoskeletal disorders, free from consumption of anabolic steroids or any other illegal agents known to increase muscle size within the past year, and not engaged in a structured resistance training program for the 6 months leading up to participation. Subjects were instructed to avoid taking any performance-enhancing supplements and to maintain their current diet during the study period. Subjects were instructed to continue their routine physical activities and not to begin any new physical training programs. A minimal adherence of 88% (completion 21 of 24 total training sessions) was set a priori. Subjects that missed a total of 4 training sessions or that missed 3 training sessions in a row were disqualified from the study.

A total of 24 subjects qualified for the study and were pair-matched according to baseline squat strength and body fat percentage. To pair, match subjects were assigned a number and then placed into a groups that corresponded to "strong lean," "weak lean," "strong normal," "weak normal," "strong fat" and "weak fat," whereby strong corresponded to a squat 1RM >60 kg and weak <60 kg, and body fat percentages of 25% lean, 25–35% normal, and >35%. A colleague outside of the research study then randomly assigned subjects based upon their pairing to either a high-load (HL) group that performed bilateral multi joint movements with a 5–6 rep range and assistance movements with a 6–7 rep range or a low-load (LL) group that performed bilateral multi joint movements with a 10–12 rep range and assistance movements with a 12–14 rep range. Twenty subjects (Table 1) completed the study and were included in the final analysis as one dropped out because of an injury that occurred outside of training, one was disqualified for missing 4 training sessions and two more were disqualified for missing 3 training sessions in a row. Approval for the study was obtained from the Coastal Carolina University Institutional Review Board (IRB) and informed written consent was obtained from all subjects before data collection.

Procedures

Testing was conducted in the following order: anthropometrics, power, and strength testing. Anthropometrics were measured before any training and physical performance testing took place 2 weeks after anthropometric testing. All training was completed on a Friday, posttraining performance testing took place the following Monday allowing for 96 hours rest, and final anthropometric testing took place 48–72 hours after posttraining performance testing. Subjects performed 5 familiarization sessions over the course of 2 weeks separated by 48–96 hours of rest before power and strength testing. Subjects were asked to replicate their pretreatment nutritional intakes the days of posttreatment strength and performance testing to reduce the influence of nutritional status affecting the results.

Table 1. Subject baseline characteristics.* Characteristics expressed mean ± *SD*

High load ($n = 10$)	Moderate load ($n = 10$)
Age (y)	
HL	20.8 ± 1.5
ML	20.0 ± 1.7
Height (cm)	
165.5 ± 6.1	162.0 ± 6.4
Body Mass (kg)	
73.3 ± 17.3	65.8 ± 10.7
Body Fat Percentage	
31.8 ± 9.4	31.0 ± 7.4
1RM Squat (kg)	
63.0 ± 10.4	58.5 ± 11.1
Relative Squat (1RM per kg body mass)	
0.88 ± 0.13	0.91 ± 0.22

*HL = high load; ML = moderate load. HL $n = 10$; ML $n = 10$. No significant differences between groups for any variables ($p > 0.05$).

Body Composition. Height was measured using standard anthropometry and body mass was measured using a calibrated scale (Cosmed, Concord, CA, USA). Body composition was measured pretreatment and posttreatment and was determined by whole body densitometry using air displacement plethysmography (Bod Pod; Cosmed). All testing was performed in accordance with the manufacturer's instructions and subjects were tested while wearing only tight fitting compression shorts and a Lycra swim cap (24). The subjects were instructed to wear the same clothing for all testing procedures, to not consume food or drink 3 hours before testing, and to consume a similar quantity of food on both sessions. All testing was carried out at approximately the same time of day (±1 hour) to account for circadian changes in fluid and fecal matter. Thoracic gas volume was estimated for all subjects using a predictive equation integral to the Bod Pod software. The calculated value for body density was the Siri equation to estimate body composition. Data from the Bod Pod included body mass, percent body fat, fat free mass, and fat mass. After Bod Pod testing skin fold, measurements were taken with Lange skin fold calipers (Cambridge Scientific Industries Inc., Cambridge, MD, USA) on the right side of the subject 3 times at 7 sites: triceps, pectoral, midaxilla, subscapula, abdomen, suprailiac, and quadriceps. The sum of the skin folds was used to analyze changes in subcutaneous adipose tissue. Based upon a small pilot study ($n = 6$), the ICC and *SEM* from our lab are 0.998 and 0.56%, respectively.

Measurement of Compartmental Water. Total body water (TBW), intracellular water (ICW), extracellular water

(ECW), and lean dry mass (LDM) were assessed using the Quantum IV bioelectrical impedance analyzer and accompanying software (BIA; RJL Systems, Clinton Township, MI, USA). The BIA was calibrated as per the manufacturer's recommendations on the morning of each measurement session. Bioelectrical impedance spectroscopy has been shown to be a valid tool for assessment of TBW and its various compartments in young women (4,17,21,22,27). Before measurement, participants were instructed to remove all objects containing metal. A urine sample was collected and urine specific gravity was assessed. Subjects with a urine specific gravity greater than 1.025 were asked to sip water and return an hour later. Measurements were performed on a table free from electrical conductors, with subjects lying supine along the table's longitudinal centerline axis, legs abducted at an angle of 45°, and hands pronated. After cleaning the skin with alcohol, two electrodes were placed on surface of the right hand and two on the right foot in accordance with procedures described elsewhere (16). A small pilot study ($n = 7$) with college-aged females was conducted and *Chronbach's alpha* test–retest reliability and the standard error of measurement were $\alpha = 0.97$ and 3.0 L, respectively, for total body water.

Cross-sectional Area. Girth and skin fold measurements were performed on the right limbs to determine lean CSA via the method described by Moritani and DeVries (28). Cross-sectional area of the arm was determined at the midpoint between the humeral greater tuberosity and lateral epicondyle, whereas CSA of the thigh was determined at the midpoint of the distance between the greater trochanter and lateral epicondyle of the femur. Skin-fold measurements were performed 3 times at the 4 quadrants of the limb at the location where the circumference was measured. Cross-sectional area was calculated via the following equation (28): $\mathrm{CSA} = \pi\left[\frac{C}{2\pi} - \frac{\sum_{i=1}^{4}\mathrm{fi}}{4}\right]$. All measurements were performed by the primary investigator to eliminate interrater variability. Distances from the proximal boney land mark (humeral greater tuberosity and greater trochanter) where measurements were performed were recorded and used again for posttreatment measuring. DeFreitas et al. (10) demonstrated that the Moritani and DeVries method is both sensitive (SEE = 3.25 cm^2) and highly correlated ($r = 0.98$) to computed tomography (9). A pilot study ($n = 7$) with college-aged females was conducted and *Chronbach's alpha* test–retest reliability and the standard error of measurement were $\alpha = 0.97$ and $SEM = 3.70$ cm^2, respectively.

Lower-body Power. Vertical jump was assessed using the Just Jump! Mat (Probotics Inc., Huntsville, AL, USA). Leard et al. (19) demonstrated that the Just Jump! Mat is highly correlated ($r = 0.97$) with the 3-camera video analysis "gold standard" method of assessing vertical jump performance. The ICC, *SEM*, and CV of the Jump Jump! Mat have been reported as $\alpha = 0.93$, 1.6 cm, and 4.4%, respectively (29). Subjects were instructed to stand on the mat with feet hip-width apart and perform a rapid lower body eccentric movement followed immediately by a maximal intensity concentric movement. Subjects were instructed to jump straight up and minimize any in-air hip flexion. The best of the 3 trials separated by 1 minute of rest was recorded as vertical jump height (cm). Based upon a small pilot study ($n = 6$), the ICC and *SEM* from our lab are 0.991 and 1.50 cm, respectively.

Upper-body Power. The initial velocity achieved during a seated 3 kg medicine ball chest pass was used to measure upper body power. The Ballistic Ball (Assess2Perform, Steamboat Springs, CO, USA) is a medicine ball with an accelerometer built in that links to a digital device via Bluetooth technology. Initial velocity was calculated via iOS technology provided by the manufacturer. Subjects sat with their backs against a 90° upright adjustable bench and held the medicine ball against their chests. When ready, subjects performed a chest pass and threw the ball forward with maximal exertion. Subjects were instructed to minimize throwing the ball such that it took the trajectory of an arch. The best of 3 trials separated by 1 minute of rest recorded pass velocity ($m \cdot s^{-1}$). Hasegawa (15) reported that initial velocity was significantly related to rotational medicine ball throw distance with a correlation coefficient of $r = 0.64$ with the 3 kg ball. Currently, no data are available on the relationship between chest pass distance and initial velocity; however, we chose the seated chest pass because it is more specific to the incline press and requires less skill than a standing rotational throw. Based upon a small pilot study ($n = 6$), the ICC and *SEM* from our lab are 0.996 and 0.051 $m \cdot s^{-1}$, respectively.

Muscle Strength. Strength was assessed by 1RM testing the parallel back squat (BS) and seated barbell overhead press (OHP) exercises. Subjects reported to the lab having refrained from any exercise other than activities of daily living for at least 48 hours before baseline testing and at least 48 hours before testing at the conclusion of the study. Prestudy and post-study testing was scheduled for the same time of day as the subjects trained during the study to account for diurnal variation in performance. Repetition maximum testing was consistent with recognized guidelines as established by the National Strength and Conditioning Association (1). Subjects performed a general warm-up before testing that consisted of light cardiovascular exercise lasting approximately 5–10 minutes. A specific warm-up set of the given exercise of 5 repetitions was performed at ~50% 1RM followed by one to 2 sets of 2–3 repetitions at a load corresponding to ~60–80% 1RM. Subjects then performed sets of 1 repetition of increasing weight for 1RM determination. Three-minute to 5-minute rest was provided between each successive attempt. All 1RM determinations were made within 5 attempts. Subjects were required to

TABLE 2. Resistance training program.

	Group		Total reps
Weeks 1–4			
Monday			
A			
Squat	Moderate	2 × 10–12	20–24
	High	4 × 5–6	20–24
B			
Hip Thrust	Moderate	2 × 10–12	20–24
	High	4 × 5–6	20–24
C			
Lunges	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
D			
Leg Extensions	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
Wednesday			
A			
Seated barbell (BB) OHP	Moderate	2 × 10–12	20–24
	High	4 × 5–6	20–24
B1			
Incline Dumbbell (DB) Press	Moderate	2 × 10–12	20–24
	High	4 × 5–6	20–24
B2			
Seated Cable Row	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
C1			
Cable Pressdown	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
C2			
Cable Curls	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
Friday			
A			
Leg Press	Moderate	2 × 10–12	20–24
	High	4 × 5–6	20–24
B			
Romanian Deadlift	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
C			
Goblet Squat	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
D			
Leg Curls	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
Week 5: Active Rest			
Weeks 6–9			
Monday			
A			
Squat	Moderate	2 × 10–12	20–24
	High	4 × 5–6	20–24
B			
Hip Thrust	Moderate	2 × 10–12	20–24
	High	4 × 5–6	20–24
C			
Step-ups	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
D			
Leg Extensions	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28

(continued on next page)

Wednesday			
A			
Seated BB OHP	Moderate	2 × 10–12	20–24
	High	4 × 5–6	20–24
B1			
Incline DB Press	Moderate	2 × 10–12	20–24
	High	4 × 5–6	20–24
B2			
Lat Pull-down	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
C1			
Lying DB Triceps Extension	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
C2			
Dumbbell Curls	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
Friday			
A			
Leg Press	Moderate	2 × 10–12	20–24
	High	4 × 5–6	20–24
B			
Sumo Deadlift	Moderate	2 × 10–12	20–24
	High	4 × 5–6	20–24
C			
Rumanian Deadlift	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28
D			
Leg Curls	Moderate	2 × 12–14	24–28
	High	4 × 6–7	24–28

reach parallel (iliotibial band parallel to the floor) in the BS for the attempt to be considered successful as determined by an NSCA Certified Strength and Conditioning Specialist. A 1RM OHP attempt was deemed successful when subjects lowered the bar to their collar bone and then pressed the bar overhead finishing with the elbows fully extended. BS 1RM and OHP 1RM were divided by the body mass in kg to obtain the relative BS 1RM and relative OHP 1RM, respectively. One-repetition maximum testing has been shown to be a valid ($r = 0.88$) (41) and reliable (ICC = 0.96) (35) measure to assess changes in muscle strength after an exercise intervention. Based on results of a small pilot study

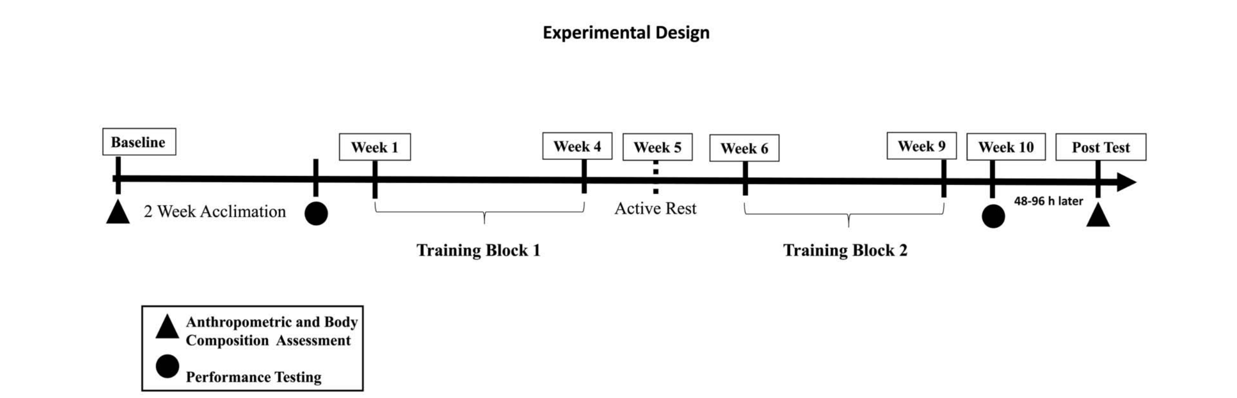

Figure 1. Experimental design timeline.

($n = 5$), the test–retest ICC and SEM from our lab for BS 1RM testing were 0.961 and 2.37 kg, respectively. For OHP 1RM, pilot testing ($n = 6$) revealed an ICC and *SEM* of 0.984 and 1.01 kg, respectively.

Resistance Training Procedures. The resistance training protocol for each group can be found in Table 2. Training consisted of 3 weekly sessions performed on nonconsecutive days for a total of 11 weeks. The first 5 sessions (2 weeks) were an acclimation phase where sets were terminated 2–3 repetitions short of failure and performed for both groups within a repetition range of 8–10. The acclimation phase also served to estimate the starting loads for all exercises with the exception of the squat and overhead press. Physical performance tests occurred on session 6 before group assignment. Thereafter, sets were carried out to the point of momentary concentric muscular failure–the inability to perform another concentric repetition while maintaining proper form–for the final 9 weeks of the study (Figure 1). A 9-week training period was selected since several similar studies have demonstrated changes in muscle growth and body composition after 8 weeks of resistance training (36–38). Since all subjects started the study at the same time, week 5 corresponded with spring break and provided the subjects with a week of active rest between the transitions from mesocycle 1 to mesocycle 2. Cadence of repetitions was carried out in a controlled fashion, with a concentric action of approximately 1 second and an eccentric action of approximately 2 seconds. Subjects were afforded 2 minutes of rest between sets of bilateral multijoint movements and 1 minute of rest between ancillary movement sets. The starting load for the squat and overhead press exercise was 85 and 65% 1RM for the high-load and moderate-load groups, respectively, and the load was adjusted for each exercise as needed on successive sets to ensure that subjects achieved failure in the target repetition range. Attempts were made to progressively increase the loads lifted each week within the confines of maintaining the target repetition range. All routines were directly supervised by the research team to ensure proper performance of the respective routines. Repetitions per set and their corresponding loads were recorded for all exercises and used to compare differences in volume load (sets × repetitions × load) between groups and across time for back squat and

TABLE 3. Body composition outcomes.*

	Pretraining	Posttraining	Effect size	95% CI for time difference
Body Mass (kg)				
HL	73.3 ± 17.3	73.8 ± 16.1	0.04	−0.09 to 1.58
ML	65.8 ± 10.7	66.9 ± 10.3	0.08	
Sum of Skinfolds (mm)				
HL	187.6 ± 77.3	181.7 ± 68.7	−0.08	−8.02 to 6.57
ML	166.1 ± 62.6	170.5 ± 58.4	0.07	
Body Fat (%)				
HL	31.8 ± 9.4	30.5 ± 8.7†	−0.15	−2.26 to −0.37
ML	31.0 ± 7.4	29.8 ± 7.4 †	−0.14	
Fat Mass (kg)				
HL	24.4 ± 12.5	23.3 ± 11.1	−0.10	−1.68 to 0.09
ML	21.0 ± 8.7	20.5 ± 8.4	−0.05	
Fat Free Mass (kg)				
HL	48.9 ± 7.4	50.4 ± 7.5†	0.26	0.98 to 2.09
ML	44.8 ± 4.0	46.4 ± 4.3†	0.28	
Total Water (L)				
HL	34.0 ± 5.8	33.1 ± 5.4†	−0.11	−1.19 to −0.27
ML	31.5 ± 4.7	31.0 ± 2.7†	−0.06	
Intracellular Water (L)				
HL	17.5 ± 2.9	17.0 ± 2.4†	−0.22	−0.69 to −0.17
ML	16.4 ± 1.6	16.1 ± 1.3†	−0.13	
Extracellular Water (L)				
HL	16.4 ± 3.1	16.1 ± 3.0	−0.13	−3.35 to 1.42
ML	15.2 ± 1.7	15.4 ± 2.2	−0.08	
Lean Dry Mass (kg)				
HL	14.8 ± 1.4	16.2 ± 1.3†	1.12	0.90 to 1.73
ML	13.6 ± 1.1	14.8 ± 1.5†	0.96	

*HL = high load; ML = moderate load.
†Significantly different from pretraining.

Table 4. Limb cross-sectional area outcomes.*

	Pretraining	Posttraining	Effect size	95% CI for time difference
Thigh CSA (cm^2)				
HL	202.8 ± 32.1	209.2 ± 25.0†	0.24	2.79 to 10.42
ML	192.7 ± 21.8	204.3 ± 23.3†	0.43	
Arm CSA (cm^2)				
HL	100.8 ± 19.5	102.0 ± 17.7	0.07	−0.93 to 6.75
ML	93.6 ± 17.1	98.3 ± 10.5	0.27	

*HL = high load; ML = moderate load.
†Significantly different from pretraining.

overhead press. The average load used per session was used to calculate the relative intensity (% 1RM) used.

Dietary Adherence. Subjects were instructed to maintain their customary nutritional regimen and to avoid taking any supplements. Dietary intake was assessed by self-reported 3-day food records, which were collected 3 times during the study: 1 week before the first training session (i.e., baseline), at week 4, and during the final week of the training protocol. Subjects were instructed on how to properly complete the logs and record all food items and their respective portion sizes consumed for the designated period of interest. All nutrition logs were scrutinized by the research team and clarification was obtained from subjects when there was confusion regarding the food item or portion consumed. Each item of food was individually entered into Diet Analysis Plus version 10 (Cengage, Boston, MA, USA) and total energy consumption, and the amount of energy derived from proteins, fats, and carbohydrates was assessed.

Statistical Analyses

All data are reported as means ± standard deviations. Preintervention differences in body composition and strength were

Table 5. Performance variable outcomes.*

	Pretraining	Posttraining	Effect size	95% CI for time difference
Vertical Jump (cm)				
HL	41.6 ± 6.4	43.8 ± 7.8†	0.34	0.82 to 5.00
ML	39.5 ± 6.4	43.1 ± 8.0†	0.56	
Chest Pass ($m \cdot s^{-1}$)				
HL	4.13 ± 0.50	4.35 ± 0.49†	0.55	0.007 to 0.325
ML	3.95 ± 0.30	4.04 ± 0.42†	0.23	
Squat 1RM (kg)				
HL	63.0 ± 10.4	89.8 ± 18.4†	2.49	17.15 to 27.85
ML	58.5 ± 11.1	76.6 ± 10.1†	1.68	
Relative Squat (1RM per kg body mass)				
HL	0.88 ± 0.13	1.23 ± 0.19†	2.00	0.23 to 0.38
ML	0.91 ± 0.22	1.16 ± 0.15†	1.43	
Overhead Press 1RM (kg)				
HL	29.0 ± 7.3	31.8 ± 4.9†	0.49	1.13 to 4.92
ML	27.5 ± 4.1	30.7 ± 3.4†	0.56	
Relative Overhead Press (1RM per kg body mass)				
HL	0.40 ± 0.09	0.44 ± 0.07†	0.66	0.02 to 0.07
ML	0.42 ± 0.07	0.47 ± 0.08†	0.83	

*HL = high load; ML = moderate load.
†Significantly different from pretraining.

Table 6. Energy and macronutrient intake.

	Baseline	Midtraining	Posttraining
Energy (kcal)			
High Load	1767 ± 496	1904 ± 352	1,674 ± 345
Moderate Load	1816 ± 565	1795 ± 352	1979 ± 523
Protein (g)			
High Load	68 ± 20	71 ± 19	68 ± 27
Moderate Load	72 ± 20	70 ± 18	82 ± 25
Carbohydrate (g)			
High Load	228 ± 71	247 ± 63	216 ± 48
Moderate Load	235 ± 81	237 ± 44	247 ± 72
Fat (g)			
High Load	65 ± 19	72 ± 23	62 ± 19
Moderate Load	68 ± 29	66 ± 18	76 ± 23

assessed using independent samples *t*-tests. A 2 × 3 mixed factorial analysis of variance (ANOVA) with repeated measures (group × time) was used to compare differences in preintervention, midintervention and postintervention dietary intakes between groups. A 2 × 8 mixed factorial ANOVA with repeated measures (group × time) was used to compare squat and overhead press volumes. A series of 2 × 2 mixed factorial ANOVAs with repeated measures (group × time) was used to assess differences in strength, power, body composition, and limb CSA. When a significant main effect of group or interaction was found, relative percent differences were calculated {percent difference = ([post-intervention measure − baseline measure]/baseline measure) × 100} and compared with independent samples *t*-tests with the Bonferroni correction. The normality of the data was checked and subsequently confirmed with the Shapiro–Wilk test. For all measured variables, the estimated sphericity was verified according to Mauchly's W test, and the Greenhouse–Geisser correction was used when necessary. Effect sizes were defined as small, medium, and large and are represented by Cohen's *d* of greater than 0.2, 0.5, and 0.8, respectively. All analyses were completed using SPSS version 22 (IBM, Armonk, NY, USA) and an alpha level of $p \le 0.05$ was set a priori.

Results

There were no significant differences between groups at baseline for any of the dependent variables ($p > 0.05$). Adherence for the high-load group was 99.5 ± 1.80%. One subject in the high-load group missed 2 sessions and one subject in the moderate-load group missed one session. Adherence in the moderate-load group was 99.5 ± 2.55%; one subject missed a total of 3 sessions.

Body Composition

Body composition results are displayed in Table 3. There were no statistically significant ($p = 0.075$, $F = 3.56$) main effects of time, group ($p = 0.261$, $F = 1.35$) nor interactions ($p = 0.435$, $F = 0.64$) for body mass. There were no statistically significant main effects for time ($p = 0.837$, $F = 0.04$), group ($p = 0.591$, $F = 0.30$), or interaction ($p = 0.155$, $F = 0.04$) for sum of skinfold measures. There was a statistically significant ($p = 0.008$, $F = 8.82$) main effect of time for body fat percentage; however, there were no statistically significant main effects for group ($p = 0.854$, $F = 0.04$) or ($p = 0.899$, $F = 0.02$) interactions. There were no statistically significant ($p = 0.075$, $F = 3.57$) main effects of time, group ($p = 0.462$, $F = 0.51$), nor interactions ($p = 0.524$, $F = 0.42$) for fat mass. There was a statistically significant ($p < 0.001$, $F = 33.48$) main effect of time for fat free mass; however, there were no statistically significant ($p = 0.811$, $F = 0.06$) interactions.

Compartmental Water

Compartmental water results are displayed in Table 3. There were no statistically significant main effects for time ($p = 0.902$, $F = 0.02$), group ($p = 0.783$, $F = 0.08$), nor interactions ($p = 0.153$, $F = 2.23$) for urine specific gravity. Mean urine specific gravity was 1.014 ± 0.009 and 1.014 ± 0.008 at pretesting and posttesting, respectively. There was a statistically significant ($p = 0.004$, $F = 11.11$) main effect of time for total body water; however, there were no statistically significant main effects for group ($p = 0.145$, $F = 2.32$) nor interactions ($p = 0.422$, $F = 0.68$). There was a statistically significant ($p = 0.003$, $F = 12.30$) main effect of time for intracellular water; however, there were no statistically significant main effects for group ($p = 0.278$, $F = 1.25$) nor interactions ($p = 0.341$, $F = 0.96$). There were no statistically significant main effects of time ($p = 0.868$, $F = 0.03$), group ($p = 0.406$, $F = 0.72$), nor interactions ($p = 0.240$, $F = 1.48$) for extracellular water. There was a statistically significant main effect of time ($p < 0.001$, $F = 45.00$) and group ($p = 0.031$, $F = 5.48$) for lean dry mass; however, there were no significant ($p = 0.625$, $F = 0.25$) interactions. *Post hoc* analysis for percent change in lean dry mass revealed no statistically significant ($p = 0.751$, $t = 0.323$) differences between groups.

Limb Cross-sectional Area

Changes in limb CSA are displayed in Table 4. There was a statistically significant ($p = 0.002$, $F = 13.26$) main effect of time for thigh CSA; however, there were no statistically significant main effects for group ($p = 0.387$, $F = 0.789$) nor interactions ($p = 0.931$, $F = 0.01$). There were no statistically significant main effects of time ($p = 0.129$, $F = 2.53$),

group ($p = 0.460$, $F = 0.57$), nor interactions ($p = 0.353$, $F = 0.91$) for arm CSA.

Performance

Changes in performance variables are displayed in Table 5. There was a statistically significant ($p = 0.009$, $F = 8.57$) main effect of time for vertical jump; however, the main effect for group ($p = 0.665$, $F = 0.19$) and interaction was not statistically significant ($p = 0.507$, $F = 0.46$). There was a statistically significant ($p = 0.042$, $F = 4.81$) main effect of time for chest pass; however, the main effect for group ($p = 0.585$, $F = 0.31$) and interaction was not statistically significant ($p = 0.469$, $F = 0.55$). There was a statistically significant ($p < 0.001$, $F = 78.13$) main effect of time for squat 1RM; however, the main effect for group ($p = 0.106$, $F = 2.89$) and interaction was not statistically significant ($p = 0.107$, $F = 2.88$). There was a statistically significant ($p < 0.001$, $F = 75.93$) main effect of time for relative squat 1RM; however, the main effect for group ($p = 0.759$, $F = 0.10$) and interaction was not statistically significant ($p = 0.154$, $F = 2.22$). There was a statistically significant ($p = 0.004$, $F = 11.12$) main effect of time for overhead press 1RM; however, the main effect for group ($p = 0.549$, $F = 0.37$) and interaction was not statistically significant ($p = 0.862$, $F = 0.03$). There was a statistically significant ($p = 0.004$, $F = 11.00$) main effect of time for relative overhead press 1RM; however, the main effect for group ($p = 0.460$, $F = 0.57$) and interaction was not statistically significant ($p = 0.899$, $F = 0.02$).

Dietary Adherence

Total energy and macronutrient intakes are displayed in Table 6. There were no statistically significant main effects of time ($p = 0.761$, $F = 0.28$) or group ($p = 0.651$, $F = 0.21$) for total energy intake. A statistically significant ($p = 0.044$, $F = 3.40$) interaction for total energy intake was found. However, *post hoc* analysis revealed no statistically significant differences between groups at baseline ($p = 0.834$, $t = 0.21$), mid-training ($p = 0.500$, $t = 0.69$), or posttraining ($p = 0.146$, $t = 1.51$), nor did a 1-way repeated measures ANOVA reveal any statistically significant differences between time points for high-load ($p = 0.117$, $F = 2.43$) or moderate-load ($p = 0.274$, $F = 1.39$) energy intake. There were no statistically significant main effects of time ($p = 0.428$, $F = 0.78$), group ($p = 0.499$, $F = 0.48$), nor interactions ($p = 0.266$, $F = 1.37$) for protein intake. There were no statistically significant main effects for time ($p = 0.594$, $F = 0.53$), group ($p = 0.709$, $F = 0.14$), nor interactions ($p = 0.218$, $F = 1.59$) for carbohydrate intake. There were no statistically significant main effects for

Table 7. Weekly squat load volume.

	Squat volume (kg)	% Baseline 1RM
Week 1		
High Load	1,234 ± 224	83.3 ± 3.3
Moderate Load	947 ± 191	68.9 ± 2.6
Week 2		
High Load	1,269 ± 185	86.9 ± 4.8
Moderate Load	1,000 ± 211	73.4 ± 4.2
Week 3*		
High Load	1,349 ± 250	91.5 ± 6.7
Moderate Load	1,082 ± 208	78.4 ± 5.2
Week 4*		
High Load	1,399 ± 229	95.0 ± 7.7
Moderate Load	1,146 ± 209	83.2 ± 5.4
Week 5†		
High Load	1,444 ± 235	97.7 ± 10.4
Moderate Load	1,178 ± 201	85.6 ± 6.8
Week 6‡		
High Load	1,518 ± 253	102.5 ± 13.6
Moderate Load	1,215 ± 199	88.7 ± 8.3
Week 7†		
High Load	1,559 ± 244	103.9 ± 13.0
Moderate Load	1,197 ± 246	88.5 ± 15.5
Week 8§		
High Load	1,600 ± 243	106.6 ± 12.9
Moderate Load	1,262 ± 251	93.0 ± 9.3

*Significantly different than week 2.
†Significantly different than week 2 and 3.
‡Significantly different than week 1, 2, 3, and 4.
§Significantly different than week 1, 2, 3, 4 and 5.

Table 8. Weekly overhead press load volume.

	Total volume (kg)	% Baseline 1RM
Week 1		
High Load	479 ± 97	80.3 ± 6.2
Moderate Load	395 ± 75	66.2 ± 4.7
Week 2		
High Load	487 ± 86	78.4 ± 10.5
Moderate Load	410 ± 91	66.0 ± 3.9
Week 3		
High Load	480 ± 78	82.5 ± 21.1
Moderate Load	407 ± 65	64.8 ± 7.6
Week 4		
High Load	502 ± 84	83.6 ± 22.0
Moderate Load	406 ± 51	63.2 ± 7.5
Week 5		
High Load	532 ± 99	87.2 ± 19.6
Moderate Load	400 ± 68	68.2 ± 7.3
Week 6		
High Load	547 ± 85	86.8 ± 14.7
Moderate Load	416 ± 65	70.8 ± 10.9
Week 7*		
High Load	550 ± 81	88.0 ± 16.4
Moderate Load	431 ± 80	70.6 ± 9.1
Week 8*		
High Load	550 ± 51	89.1 ± 18.6
Moderate Load	444 ± 77	72.4 ± 8.6

*Significantly different than week 1, 2, and 3.

time ($p = 0.851$, $F = 0.16$), group ($p = 0.657$, $F = 0.20$), nor interactions ($p = 0.101$, $F = 2.45$) for fat intake.

Training Volume

The volume load and corresponding relative intensity for the squat exercise can be found in Table 7. A statistically significant ($p = 0.008$, $F = 9.13$) main effect of group was found for squat volume. The high-load group completed more weekly volume compared with the moderate-load group (1,421 ± 212 vs. 1,129 ± 210 kg, respectively). A statistically significant ($p < 0.001$, $F = 38.62$) main effect of time was also found for squat volume; however, the interaction was not statistically significant ($p = 0.713$, $F = 0.65$). The volume load and corresponding relative intensity for the overhead press exercise can be found in Table 8. A statistically significant ($p = 0.007$, $F = 9.74$) main effect of group was found for overhead press volume. The high-load group completed more weekly volume than the moderate-load group (516 ± 68 vs. 414 ± 70 kg, respectively). A statistically significant ($p < 0.001$, $F = 6.13$) main effect of time was also found; however, the interaction was not statistically significant ($p = 0.141$, $F = 1.60$).

Discussion

To the authors' knowledge, this was the first study to investigate the differences in body composition and performance outcomes between full body repetition-equated high-load and moderate-load resistance training in recreationally active females. The primary findings of the study elucidated both high-load and moderate-load training programs increased measures of muscular strength and power, lean body mass, and thigh CSA, with no spastically significant differences between groups.

Our results demonstrate that both high-load and moderate-load resistance training equally increases lean body mass and lean thigh CSA as evidenced by a 3.0 ± 2.3% and 3.3 ± 2.7% increase in LBM, respectively, and a 3.2 and 6.0% increase in thigh CSA, respectively. Despite a slightly greater hypertrophic response in the moderate-load training group (high load vs. moderate load thigh CSA ES: 0.24 vs. 0.43 and arm CSA ES: 0.07 vs. 0.27, respectively), no statistical between-group differences were found. These results agree with other studies investigating the effects of high loading vs. moderate loading. Alegre et al. (3) reported a 4.6 and 3.1% increase in thigh lean mass for high and moderate loading, respectively, after 12 weeks of unilateral leg press and knee extension exercise in untrained female subjects, and Chestnut and Docherty (7) also reported no significant difference between groups in thigh CSA after 10 weeks of high-load (4RM) and moderate-load (10RM) resistance training in untrained men.

Given that greater rates of postexercise protein synthesis have been associated with higher total muscular work (6), it has been proposed that greater volume loads will lead to enhanced hypertrophy (38). Schoenfeld et al. (38) compared 8 weeks of volume-load equated high-load (7 sets of 3 repetitions) and moderate-load (3 sets of 10 repetitions) training in young men and also reported no differences in biceps brachii thickness. In the current study, the high-load group accomplished significantly more total volume load, but no differences in limb CSA or lean body mass were found between groups. Although this may seem to refute prior suggestions that volume load and greater mechanical tension lead to superior hypertrophic adaptations, the repetition volume between groups was matched. By matching the repetition volume and maintaining the same repetition cadence, the time under tensions was similar between groups. Experimental studies in rodents have shown that greater the time under tension, the greater the phosphorylation of jun-N-terminal-kinase, an upstream activator of mTOR that acts as a mechanical stimuli sensor (20). Therefore, a higher possible metabolic stress combined with a similar time under tension may explain why similar improvements, lean body mass and thigh lean mass, occurred between groups despite the high-load group having performed a greater volume of total work.

Abe et al. (1) reported increases in muscle thickness in the upper body are greater and occur earlier in the training process compared with the lower body during the first 12 weeks of a resistance training program. Our results contrast with these reports, as we found significant increases in lean thigh CSA, but not arm CSA. This discrepancy in results is not surprising given that the lower extremities were trained twice as frequently and with approximately twice as much volume as the upper extremities in the present study, whereas Abe et al. employed full body resistance training 3 days per week. Our difference in CSA results between the upper and lower extremity further the training principal of specificity and lend evidence to the hypothesis that volume load, at least up to a certain point, is a major driver of hypertrophy (38). We chose this resistance training protocol because lab space limited training to 3 times per week and to increase subject adherence because preliminary interviews with pilot subjects revealed a strong desire to improve lower-body strength and aesthetics compared with the upper body.

There were no differences between groups for changes in total or compartmental body water. Both groups experienced decreases in total and intracellular, but not extracellular water. These results are in contrast with Ribeiro et al. (34) who reported increases in total body water and intracellular and extracellular water after 16 weeks of resistance training in men and women. The authors noted that the greatest increases in intracellular water occurred during the final 8 weeks of training. It is possible that differences in training length may account for these changes. Additionally, the total energy (26.6 ± 9.0 $kcal \cdot kg^{-1}$) and carbohydrate (3.5 ± 1.3 $g \cdot kg^{-1}$) consumption in this study was low. Inadequate carbohydrate consumption may have led to reduced intramuscular glycogen concentrations over the course of the study, which may have attenuated the osmotic effects

of glycogen, and may explain the discrepancy in results between this study and Ribeiro et al.

Some caution should be taken when interpreting the body composition outcomes of this study. Subjects were instructed not to change their dietary habits and nutrient intakes were analyzed, but we did not standardize or recommend any particular dietary strategies because compliance could not be ensured. Although issues with underreporting dietary intakes exist, the subjects in this study likely did not consume enough energy to support optimal muscular adaptations. In particular, protein consumption was particularly low with an average of 0.94 and 1.13 $g \cdot kg^{-1}$ consumed by the high-load and moderate-load groups, respectively. These values are well below the higher (2.0 $g \cdot kg^{-1}$) protein recommendations of the NSCA (5) and International Society of Sports Nutrition (26) for individuals engaged in a resistance training exercise. As such, it is possible that a more robust hypertrophic response would have occurred with higher protein and energy intakes.

The NSCA (5) recommends higher loads and lower repetitions for the optimization of muscular strength. The results of a recent meta-analysis demonstrate that strength gains can be made training with both high and low loads, but that higher loading appears more favorable toward maximizing muscular strength (39). Schoenfeld et al. (37) reported greater increases in bench press and back squat 1RM after 8 weeks of training with 3 sets of 10 repetitions compared with 3 sets of 20 repetitions in trained young men. Although we found no statistical differences between groups for improvements in overhead press or back squat strength, nor vertical jump height or chest pass velocity, effect sizes for squat 1RM were largely in favor of the high load group and may represent a type II error given the small sample size. Alegre et al. (3) also reported no differences in strength outcomes between high-load and moderate-load training in untrained young women. Differences in training status between this study and Schoenfeld et al. are likely to account for the divergence in results. The results of a meta-analysis exploring the dose–response relationship for strength reveal a linear relationship between the load (as a % of the 1RM) and strength outcomes in highly trained subjects but display an inverted U in untrained subjects whereby strength gains are maximized around 60% 1RM and decline with increasing intensities (32). The results of this study and Alegre et al. suggest that, at least in untrained young women, strength can be gained by training at moderate intensities (50–70% 1RM) at a similar rate to training at higher intensities (>85% 1RM); however, the results of our study with the large differences in effect size suggest that the utilization of higher intensities may optimize strength gains to a greater degree, especially as subjects acquire older training statuses.

Some limitations must be addressed when interpreting or applying these results. The study was short in duration compared with the long-term training process many recreational weightlifters and athletes take part in. Additionally, these protocols were carried out in subjects with minimal resistance training experience. It is well accepted that with advanced training age, more complex and/or demanding training protocols are necessary to induce hypertrophy and strength gains (32). As such, caution should be taken when extrapolating these results to a long-term training plan or subjects/athletes with greater training ages. Finally, comparing these results with a control group performing the same exercises and repetitions, but with self-selected loads, could strengthen the use of training protocols with higher intensities (>70% 1RM) or higher intensities of effort to maximize muscular adaptations.

Practical Applications

The success of an exercise program depends heavily on adherence, and individuals with a low-affinity for training are more likely to drop out or not comply with resistance training prescription. A fear of becoming masculine is an obstacle to adopting a resistance training program in young women (30), and women who resistance trained with self-selected lower loads reported greater self-efficacy and intention to continue training compared with higher imposed loads (13). The results of this study lend support to a growing body of evidence that individuals with lower training status can make improvements in muscular strength and hypertrophy training with more moderate loads and may be used by fitness professionals to further prescribe evidence-based resistance training protocols that also appeal to the individual's training preferences. The data obtained in this study also serve to further debunk some of the myths that may otherwise impede young women from strength training, including a fear of excessive hypertrophy (11,33). The exercises used in this program were selected to replicate training modalities commonly employed by young, healthy women interested in enhancing aesthetics. Given the similar small effect sizes for increases in lean body mass and limb CSA between groups, the results of this study suggest that fitness professionals can prescribe young women with either moderate or heavy loads to promote strength and hypertrophic adaptations without inducing a bulky appearance.

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