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Research article

Differential Effects of Heavy versus Moderate Loads on Measures of Strength and Hypertrophy in Resistance-Trained Men

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Abstract
The purpose of the present study was to evaluate muscular adaptations between heavy- and moderate-load resistance training (RT) with all other variables controlled between conditions. Nineteen resistance-trained men were randomly assigned to either a strength-type RT routine (HEAVY) that trained in a loading range of 2-4 repetitions per set (n = 10) or a hypertrophy-type RT routine (MODERATE) that trained in a loading range of 8-12 repetitions per set (n = 9). Training was carried out 3 days a week for 8 weeks. Both groups performed 3 sets of 7 exercises for the major muscle groups of the upper and lower body. Subjects were tested pre- and post-study for: 1 repetition maximum (RM) strength in the bench press and squat, upper body muscle endurance, and muscle thickness of the elbow flexors, elbow extensors, and lateral thigh. Results showed statistically greater increases in 1RM squat strength favoring HEAVY compared to MODERATE. Alternatively, statistically greater increases in lateral thigh muscle thickness were noted for MODERATE versus HEAVY. These findings indicate that heavy load training is superior for maximal strength goals while moderate load training is more suited to hypertrophy-related goals when an equal number of sets are performed between conditions.

Key words: Loading strategies, heavy loads, repetition range, skeletal muscle hypertrophy, muscular adaptations.

Introduction

A generally accepted tenet in the field of exercise science postulates that manipulation of resistance training (RT) program variables is necessary to maximize muscular adaptations (American College of Sports Medicine, 2009; Baechle and Earle, 2008; Kraemer and Ratamess, 2004). The intensity of load used, often delineated by repetition ranges within various loading zones, is widely considered amongst the most important of these variables. Training with heavy loads at or near an individual's 1 repetition maximum (RM) necessarily results in fewer repetitions completed when compared to training with lighter loads at lower intensities. Consistent with the concept of a strength-endurance continuum, the following loading strategies have been proposed to maximize muscular adaptations: a low-repetition loading zone (1-5RM) maximizes muscular strength; a moderate repetition loading zone (8-12RM) maximizes muscular hypertrophy; and a high-repetition loading zone (15+RM) maximizes muscular endurance (Baechle and Earle, 2008).

The volume of RT also has been shown to play a role in muscular adaptations. There is evidence of a dose-response relationship, whereby greater RT volumes are associated with greater increases in strength (Krieger, 2009) and hypertrophy (Schoenfeld et al., 2016). Volume load (VL), defined as the product of the total number of repetitions performed for an exercise and the corresponding amount of load, is affected by the loading zone employed; progressively higher VLs are seen as loading proceeds to the right of the strength-endurance continuum (Schoenfeld et al., 2014; 2015). Thus, a substantially greater number of sets are required to equate volume load between lower and higher loading zones. This can be problematic when training at the far left of the strength-endurance continuum, as high RT volumes combined with heavy loads may chronically overstress the involved joints and soft tissue structures as well as the central nervous system (CNS), thereby increasing the potential for overtraining and injury (Fry and Kraemer, 1997).

A number of studies have endeavored to investigate the effects of low- versus moderate-loading zones on muscular adaptations. The preponderance of research in untrained individuals shows that strength gains are maximized with heavy load (1-5RM) training; these findings are seen both when VL is equated (Campos et al., 2002), as well as when an equal number of sets are performed between conditions thus resulting in a lower VL for low repetition training (Choi et al., 1998; Masuda et al., 1999). Conversely, increases in hypertrophy have been shown to be volume-dependent, with studies employing an equal number of sets showing greater muscular growth for moderate loading (Choi et al., 1998; Masuda et al., 1999) and those equating VL showing no difference between conditions (Campos et al., 2002).

To the authors' knowledge, only 2 studies have investigated muscular adaptations to low- versus moderate-loading schemes in resistance-trained subjects. This is important, as adaptations during the initial stages of RT are primarily related to improvements in the ability of the CNS to efficiently coordinate muscles, whereas increases in muscle mass are theorized to become increasingly more relevant to strength-related improvements as one acquires lifting experience (Sale, 1988; Schoenfeld, 2010). In addition, emerging evidence shows that trained muscle differs not only from a structural (Maughan at al., 1984; Sale et al., 1987) and functional (Always et al., 1988; Huczel and Clarke, 1992; Sale et al., 1983; Sale et al., 1987) standpoint, but also displays altered RT responses in intracellular anabolic signaling (Coffey et al., 2006),

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acute protein synthesis (Phillips et al., 1999; Tang et al., 2008; Wilkinson et al., 2008), mitochondrial protein synthesis (Wilkinson et al., 2008) and transcriptional upregulation (Gordon et al., 2012).

Schoenfeld et al. (2014) carried out an 8-week volume-equated study that randomized resistance-trained men to train with either 7 sets at 3RM or 3 sets of 10RM. Consistent with previous research in untrained subjects, muscle hypertrophy was similar regardless of the load lifted, but maximal strength was statistically greater when training with heavier loads. Recently, Mangine et al. (2015) randomized resistance-trained men to perform 4 sets with either 3-5RM or 10-12RM, so that VL was not equated between conditions. As shown by others, strength increases were greater with low- versus moderate-load training. Interestingly and in opposition to the current body of literature, however, some markers of muscle growth also favored the low repetition condition. A potential confounding issue was that rest intervals were different between conditions (3 min versus 1 min in heavy and moderate loading, respectively), which may have unduly influenced the generalizability of results to loading strategies. The purpose of the present study was to evaluate muscular adaptations between heavy- and moderate-load training in resistance-trained men with all other RT variables controlled between conditions.

Methods

Subjects

Subjects were 26 male volunteers (age = 23.2 ± 4.2 years; height = 1.75 ± 0.06 m; body mass = 84.3 ± 15.2 kg) recruited from a university population. Subjects were between the ages of 18-35, had no existing cardiorespiratory or musculoskeletal disorders, claimed to be free from consumption of anabolic steroids or any other legal or illegal agents known to increase muscle size currently and for the previous year, and were considered experienced lifters, defined as consistently lifting weights at least 3 times per week for at least 1 year. Seven subjects dropped out of the study: 3 sustained minor training related injuries; 1 sustained a non-training injury; and 3 withdrew for personal reasons. Descriptive data for the 19 subjects who completed the study are shown in Table 1.

Table 1. Baseline descriptive statistics. Data are expressed as the mean (±SD).

VARIABLE	HEAVY (n = 10)	MODERATE (n = 9)
Age (yrs)	22.3 (3.9	24.1 (4.5)
Height (m)	1.74 (.08)	1.77 (.04)
Weight (kgs)	84.2 (16.6)	84.4 (14.5)
RT Experience (yrs)	4.3 (4.8)	5.2 (3.4)

Participants were pair-matched according to baseline strength and then randomly assigned to 1 of 2 experimental groups: a strength-type RT routine (HEAVY) that trained in a loading range of 2-4 repetitions per set (n = 10) or a hypertrophy-type RT routine (MODERATE) that trained in a loading range of 8-12 repetitions per set (n = 9). Approval for the study was obtained from the college Institutional Review Board. Informed consent was obtained from all participants prior to beginning the study. A flow chart of the study design is presented in Figure 1.

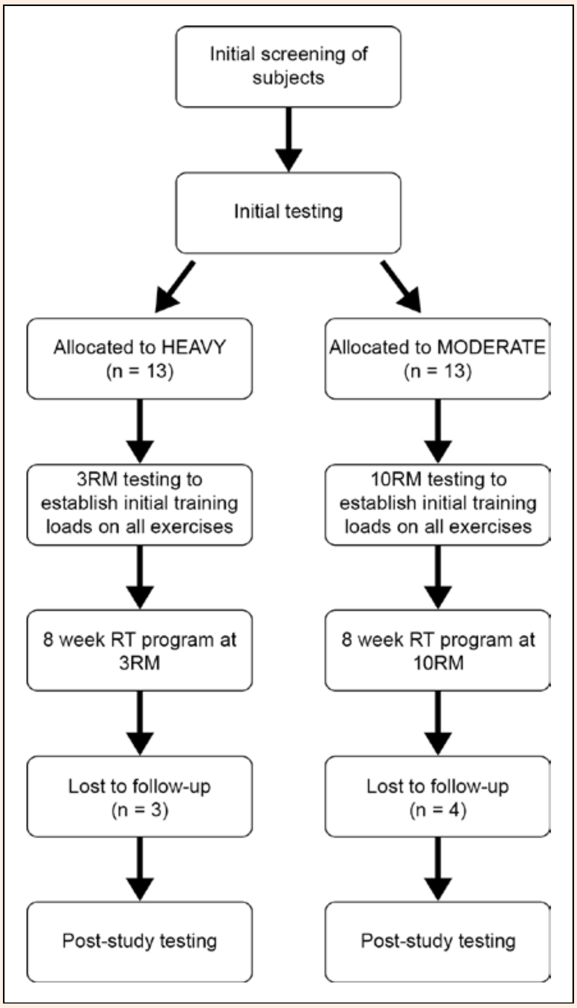

Figure 1. Flow chart of study design.

Resistance training procedures

The RT protocol consisted of the following seven exercises per session targeting major muscle groups of the body: Flat barbell press, barbell military press, wide grip lat pulldown, seated cable row, barbell back squat, machine leg press, and machine leg extension. These exercises were chosen based on their common inclusion in bodybuilding- and strength-type RT programs (Baechle and Earle, 2008; Coburn and Malek, 2011). Subjects were instructed to refrain from performing any additional resistance-type or high-intensity anaerobic training for the duration of the study.

Training for both routines consisted of 3 weekly sessions performed on non-consecutive days for 8 weeks. All sets were carried out to the point of momentary concentric muscular failure, operationally defined as the inability to perform another concentric repetition while maintaining proper form. Cadence of repetitions was carried out in a controlled fashion, with a concentric action of approximately one second and an eccentric action of approximately two seconds. Subjects were afforded 2 minutes rest between sets. The load was adjusted for each exercise as needed on successive sets to ensure that subjects achieved failure in the target repetition range. All routines were directly supervised by the research team, which included a National Strength and Conditioning Association certified strength and conditioning specialist and certified personal trainers, to ensure proper performance of the respective routines. Attempts were made to progressively increase the loads lifted each week within the confines of maintaining the target repetition range. Prior to beginning the training program, subjects in the HEAVY group underwent 3-repetition maximum (RM) testing and subjects in the MODERATE group underwent 10 RM testing to determine individual initial training loads for each exercise. The RM testing was consistent with recognized guidelines as established by the National Strength and Conditioning Association (Baechle & Earle, 2008).

Dietary adherence

To avoid potential dietary confounding of results, subjects were advised to maintain their customary nutritional regimen and to avoid taking any supplements other than that provided in the course of the study. Dietary adherence was assessed by self-reported 5-day food records using MyFitnessPal.com (http://www.myfitnesspal.com), which were collected twice during the study: 1 week before the first training session (i.e. baseline) and during the final week of the training protocol. Subjects were instructed on how to properly record all food items and their respective portion sizes consumed for the designated period of interest. Each item of food was individually entered into the program, and the program provided relevant information as to total energy consumption, as well as amount of energy derived from proteins, fats, and carbohydrates for each time period analyzed. To maximize anabolism, subjects were supplied with a supplement on training days containing 25g protein and 1g carbohydrate (Iso100 Hydrolyzed Whey Protein Isolate, Dymatize Nutrition, Farmers Branch, TX). The supplement was consumed within 1 hour post-exercise, as this time frame has been purported to help potentiate increases in muscle protein synthesis following a bout of RT (Aragon & Schoenfeld, 2013).

Measurements

Muscle Thickness: Ultrasound imaging was used to obtain measurements of muscle thickness (MT). The reliability and validity of ultrasound in determining MT has been reported to be very high when compared to the "gold standard", magnetic resonance imaging (mean intraclass correlation coefficients (ICC) of 0.998 and 0.999 for reliability and validity, respectively) (Reeves et al., 2004). A trained technician performed all testing using a B-mode ultrasound imaging unit (ECO3, Chison Medical Imaging, Ltd, Jiang Su Province, China). The technician applied a water-soluble transmission gel (Aquasonic 100 Ultrasound Transmission gel, Parker Laboratories Inc., Fairfield, NJ) to each measurement site, and a 5 MHz ultrasound probe was placed perpendicular to the tissue interface without depressing the skin. When the quality of the image was deemed to be satisfactory, the technician saved the image to hard drive and obtained MT dimensions by measuring the distance from the subcutaneous adipose tissue-muscle interface to the muscle-bone interface, as described previously (Abe et al., 2000). Measurements were taken on the right side of the body at three sites: 1) elbow flexors; 2) elbow extensors; and 3) lateral thigh. For the anterior and posterior upper arm, measurements were taken 60% distal between the lateral epicondyle of the humerus and the acromion process of the scapula; for the lateral thigh, measurements were taken 50% between the lateral condyle of the femur and greater trochanter for the quadriceps femoris. In an effort to ensure that swelling in the muscles from training did not obscure results, images were obtained 48-72 hours before commencement of the study, as well as after the final training session. This is consistent with research showing that acute increases in MT return to baseline within 48 hours following a RT session (Ogasawara et al., 2012). To further ensure accuracy of measurements, 3 images were obtained for each site and then averaged to obtain a final value. The test-retest intraclass correlation coefficient (ICC) from our lab for thickness measurement of the elbow flexors, elbow extensors, and lateral thigh are 0.986, 0.981, and 0.997, respectively. The standard errors of the measurement (SEM) for these measures are 0.16, 0.50, and 0.25 mm, respectively.

Muscle strength: Upper- and lower-body strength was assessed by 1RM testing in the parallel back squat (1RMSQUAT) and bench press (1RMBENCH) exercises. These exercises were chosen because they are well-established as measures of maximal strength. Subjects reported to the laboratory having refrained from any exercise other than activities of daily living for at least 48 hours prior to baseline testing and at least 48 hours prior to testing at the conclusion of the study. Repetition maximum testing was consistent with recognized guidelines established by the NSCA (Baechle and Earle, 2008). In brief, subjects performed a general warm-up prior to 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% of subjects' perceived 1RM followed by one to two sets of 2-3 repetitions at a load corresponding to ~60-80% 1RM. Subjects then performed sets of 1 repetition of increasing load for 1RM determination. Three to 5 minutes rest was provided between each successive attempt. All 1RM determinations were made within 5 trials. In the 1RMSQUAT, subjects were required to squat down so that the top of the thigh was parallel to the ground for the attempt to be considered successful as determined by a research assistant who was positioned laterally to the subject. Successful 1RMBENCH was achieved if the subject displayed a five-point body contact position (head, upper back, and buttocks firmly on the bench with both feet flat on the floor), lowered the bar to his chest, and executed full elbow extension. 1RMSQUAT testing was conducted prior to 1RMBENCH with at least a 5 minute rest period separating tests. Strength testing took place using barbell free weights. All testing sessions were supervised by the research team to achieve a consensus for success on each trial. The test-retest ICC for the

1RMBENCH and 1RMSQUAT from our lab are 0.995 and 0.998, respectively. The SEM for these measures are 1.03 and 1.04 kgs, respectively.

Muscle endurance: Upper body muscular endurance was assessed by performing bench press using 50% of the subject's initial 1RM in the bench press (50%BENCH) for as many repetitions as possible to muscular failure with proper form. Successful performance was achieved if the subject displayed a five-point body contact position (head, upper back, and buttocks firmly on the bench with both feet flat on the floor), touched the bar to his chest, and executed a full lock-out. Muscular endurance testing was carried out after assessment of muscular strength to minimize the potential of metabolic stress interfering with performance of the latter.

Statistical analyses

Descriptive statistics were used to explore the distribution, central tendency, and variation of each measurement. An independent t-test was used to compare baseline values between groups. Descriptive statistics (means ± SE) for each variable were reported at baseline, at 8 weeks, and as percent change from baseline. In order to test differences between groups, the proc reg procedure was used to generate separate multiple linear regression models, with post-intervention outcomes as the dependent variable and baseline values as covariates. The model included a group indicator with two levels and baseline values (centered at the mean values) as predictors. This modeling approach is equivalent to an analysis of covariance, but has the advantage of providing estimates associated with each group, adjusted for baseline characteristics that are potentially associated with the outcomes. This was also important due to the fact that using change scores as the dependent variable are subject to regression to the mean. Each model included a group indicator with two levels (0,1), as well as baseline values (centered at the mean values) as predictors. Specifically, the coefficient for the HEAVY group indicator was used to estimate the mean difference in the outcome (e.g. MT change) associated with HEAVY compared with MODERATE and the intercept estimated the mean change in MODERATE. Regression assumptions were checked. Independent t-tests were used to compare volume-load between groups. To quantify the magnitude of changes in outcome measures, effect sizes were calculated using Hedges g (Cooper et al., 2009). The following scale was used to categorize the magnitude of effect: <0.2 = trivial; 0.2 - 0.5 = small; 0.5 - 0.8 = medium; 0.8 - 1.3 = large, and >1.3= very large. Descriptive statistics and multiple regression was carried out using SAS software version 9.3 (SAS Institute, Cary, NC) with 2-sided 95% confidence intervals to determine significance. Effect size calculations were computed using StataMP 13 (StataCorp LP, College Station, TX).

Results

No significant differences were noted between groups in any baseline measure. Overall attendance for those who completed the study was 89%, with no differences noted between HEAVY and MODERATE conditions (91% vs 88%, respectively). Total aggregate weekly VL over the 8 weeks was significantly greater for MODERATE compared to HEAVY (56049 ± 11101 vs 25867 ± 3731 kg, respectively).

Muscle thickness

Significant increases in MT of the elbow flexors were noted for both HEAVY ($p = 0.02$) and MODERATE ($p < 0.001$) groups from baseline to post-study. No significant between-group differences were noted between conditions ($p = 0.19$). Effect sizes favored MODERATE compared to HEAVY (0.42 versus 0.28, respectfully), with both conditions showing small effects (see Table 2).

A significant increase in MT of the elbow extensors was noted for the MODERATE ($p = 0.02$) but not the HEAVY ($p = 0.25$) group from baseline to post-study. No significant between-group differences were noted between conditions ($p = 0.74$). Effect sizes were similar between MODERATE and HEAVY (0.21 versus 0.17, respectfully), with both conditions showing trivial to small effects (see Table 2).

Significant increases in MT of the lateral thigh were noted for both HEAVY ($p = 0.02$) and MODERATE ($p < 0.001$) groups from baseline to post-study. A significant between-group difference was noted such that MODERATE produced superior results compared to HEAVY ($p = 0.007$). Effect sizes markedly favored MODERATE compared to HEAVY (1.17 versus 0.33, respectfully), with MODERATE showing a large effect and HEAVY showing a small effect (see Table 2).

Maximal strength

Both HEAVY and MODERATE groups showed a significant increase in 1RMBENCH from baseline to post-study (all $p < 0.01$). No significant between-group differences were noted between conditions ($p = 0.07$). Effect sizes favored HEAVY compared to MODERATE (0.67 versus 0.38, respectfully), with HEAVY showing a medium effect and MODERATE showing a small effect (see Table 3).

Both HEAVY and MODERATE groups showed a significant increase in 1RMSQUAT from baseline to post-study (all $p = 0.001$). A significant between-group difference was noted such that HEAVY produced superior results compared to MODERATE ($p = 0.03$). Effect sizes markedly favored HEAVY compared to MODERATE (1.12 versus 0.71, respectfully), with HEAVY showing a large effect and MODERATE

Table 2. Pre- vs. Post-Study muscle thickness. Data are expressed as the mean (±SD) in mm.

OUTCOME MEASURE	HEAVY			MODERATE		
	PRE-STUDY	POST-STUDY	HEDGE'S G	PRE-STUDY	POST-STUDY	HEDGE'S G
Elbow Flexors	46.7 (4.4)	48.1 (4.8) *	.28	46.9 (5.3)	49.2 (5.3) *	.42
Elbow Extensors	47.3 (8.0)	48.6 (7.2)	.17	48.4 (7.2)	49.9 (6.6) *	.21
Lateral Thigh	56.5 (5.8)	58.8 (7.1) *	.33	56.0 (4.7)	61.8 (4.7) *#	1.17

An asterisk (*) indicates a significant effect from baseline values. A number sign (#) indicates a significant difference between groups.

Table 3. **Pre- vs. Post-Study Muscle Strength. Data are expressed as the mean (±SD) in kgs.**

OUTCOME MEASURE	HEAVY			MODERATE		
	PRE-STUDY	POST-STUDY	HEDGE'S G	PRE-STUDY	POST-STUDY	HEDGE'S G
$1RM_{BENCH}$	92.7 (19.3	106.1 (18.9) *	.67	95.5 (23.8)	105.5 (26.3) *	.38
$1RM_{SQUAT}$	114.5 (30.8)	148.9 (27.7) *#	1.12	119.5 (26.0)	139.4 (27.2) *	.71

An asterisk (*) indicates a significant effect from baseline values. A number sign (#) indicates a significant difference between groups.

Table 4. **Pre- vs. Post-Study Muscle Endurance. Data are expressed as the mean (±SD) in repetitions.**

OUTCOME MEASURE	HEAVY			MODERATE		
	PRE-STUDY	POST-STUDY	HEDGE'S G	PRE-STUDY	POST-STUDY	HEDGE'S G
$50\%_{BENCH}$	25.2 (3.4)	31.9 (5.9) *	1.32	28.8 (3.5)	34.7 (5.5) *	1.21

An asterisk (*) indicates a significant effect from baseline values. A number sign (#) indicates a significant difference between groups.

showing a medium effect. (see Table 3).

Muscular endurance

Both HEAVY and MODERATE groups showed a significant increase in 50%BENCH from baseline to post-study (all p < 0.01). No significant between-group differences were noted between conditions (p = 0.07). Effect sizes were similar between HEAVY and MODERATE (1.32 versus 1.21, respectfully), with both conditions showing large to very large effects (see Table 4).

Nutrition

Analysis of self-reported dietary records revealed that total protein intake was statistically greater for MODERATE versus HEAVY at baseline (1.4 g/kg versus 1.9 g/kg, respectively; p = 0.005), but these differences abated by study's end (1.7 g/kg versus 1.8 g/kg, respectively; p = 0.63). Subjects in HEAVY statistically increased the amount of calories (p = 0.02) consumed from pre- to post-study, but total intake was not statistically different between groups at either time point. No other statistical differences in nutrition were noted either between or within groups. Results of nutritional data are illustrated in Figure 2.

Discussion

The present study showed that training with heavy versus moderate loads elicits differential effects on muscular strength and hypertrophy. Increases in 1RMSQUAT were significantly greater in HEAVY compared to MODERATE (30.0% versus 16.8%, respectively) with HEAVY showing a large magnitude of effect compared to a medium effect in MODERATE (1.12 versus 0.71, respectively). Increases in 1RMBENCH also favored HEAVY versus MODERATE (14.4% versus 10.5%, respectively), and given the low p-value (p = 0.07) and relatively small sample size, non-significant results may be attributed to a type II error. Indeed, effects sizes suggested a meaningful difference in 1RMBENCH, with HEAVY showing a medium effect compared to a small effect for MODERATE (0.62 versus 0.46, respectfully). Our findings are in line with those of Mangine et al. (2015), who also found greater strength improvements when resistance-trained men trained at 3-5RM versus 10-12RM. Similar results have been reported in untrained individuals as well (Choi et al., 1998; Masuda et al., 1999). The totality of these findings provide compelling evidence that specificity of training at the far left of the

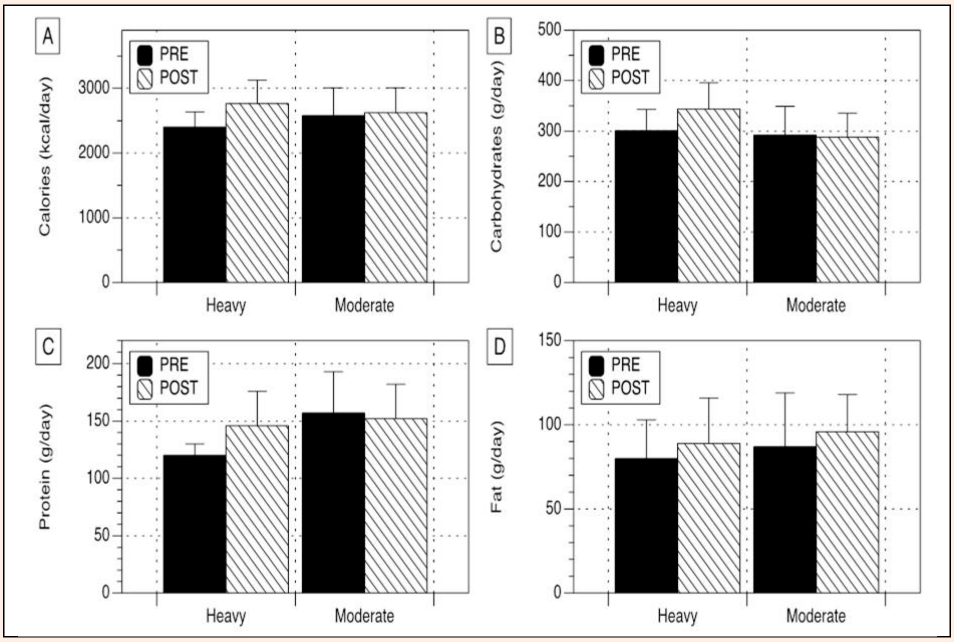

Figure 2. **Graphical representation of nutritional intake pre- and post-intervention for HEAVY and MODERATE, mean (±SD).**

strength-endurance continuum is preserved even when weekly RT volume is markedly lower; while RT volume has been shown to play a role in strength-related outcomes (Krieger, 2009), higher intensities of load appear to be of paramount importance.

Although the underlying mechanisms remain to be determined, it can be speculated that neural adaptations associated with training close to one's 1RM were responsible for the superior strength increases when using heavy loads. There is evidence that the biomechanics of multi-joint exercise performance change with alterations in intensity of load. For example, the ratio of hip-to-knee extensor moments has been found to increase with heavier loads during squats, lunges, deadlifts, and hex-bar deadlifts (Beardsley and Contreras, 2014). Therefore, motor pattern coordination conceivably is optimized by practicing an exercise with the form most specific to that which will be used in the maximal lift.

It is unclear as to whether *in vivo* normalized force production, or its homologous counterpart, specific tension, increases, decreases, or remains the same following training, as research is equivocal on the topic (Erskine et al., 2010; Kawakami et al., 1995; Narici and Kayser, 1995). While no training studies have endeavored to elucidate the role of loading zones in such phenomena, cross-sectional data suggests that bodybuilders, who normally train closer to the hypertrophy loading zone, have larger muscles with lower normalized force and specific tension than power athletes (Ikegawa et al., 2008; Meijer et al., 2015). Therefore, it is conceivable that specific tension changes may have occurred in one or both groups, and that such a response is at least partially responsible for greater strength outcomes in the HEAVY group with greater hypertrophic responses in the MODERATE group. Additional research is needed to delineate such mechanisms.

In contrast to strength-related adaptations, training with moderate loads tended to produce superior increases in MT compared to heavy-load training. This finding was particularly evident in the lateral quadriceps femoris, where statistically greater increases in muscle thickness were observed in MODERATE compared to HEAVY (10.4% versus 4.1%, respectively). Moreover, MODERATE showed a large magnitude of effect while HEAVY showed a small effect (1.17 versus 0.33, respectively), indicating that differences were indeed meaningful. Although no statistical differences were found in MT of the upper arms, ES differences in the elbow flexors showed a modest superiority for the MODERATE condition as well. These results run contrary to those of Mangine et al. (2015), who found similar improvements in MT between moderate versus heavy load training, and in fact noted greater increases in lean arm mass as determined by dual-energy X-ray absorptiometry. The discrepant findings between studies are not clear, but may at least in part be due to differences in the length of rest intervals. While our study equated rest intervals between conditions (2 minutes rest between sets), Mangine et al. (2015) employed a 3-minute rest interval for the heavy load condition and a 1-minute rest interval for the light-load condition. Recent work from our lab found that taking short rest periods (1 minute) attenuated the hypertrophic response to RT (Schoenfeld et al., 2016), and it is possible that the reduced rest periods used by Mangine et al. (2015) compromised muscular gains. This hypothesis warrants further investigation.

There is evidence of a dose-response relationship between RT volume and muscle hypertrophy, with greater volumes resulting in greater gains in muscle mass (Schoenfeld et al., 2016). Given that weekly VL for MODERATE was more than double that for HEAVY, this could seemingly explain the superior gains in muscle growth seen with moderate load training in the present study. Previous work from our lab showed similar increases in growth of the elbow flexors in resistance-trained men when volume was equated between moderate and heavy load conditions (Schoenfeld et al., 2014), lending support to the hypothesis that RT volume is a primary driver of muscle hypertrophy.

Improvements in upper body muscle endurance were found to be similar between conditions, with large to very large ESs noted for both HEAVY and MODERATE (1.32 versus 1.21, respectively). On the surface, these findings run contrary to the principle of specificity, which dictates that greater increases in muscle endurance are seen when training in higher repetition ranges. However, testing for 50%BENCH was based on the subjects' baseline 1RM bench press. The larger increases in maximal strength for HEAVY compared to MODERATE across the study period therefore resulted in HEAVY performing post-testing at a lower percentage of 1RM. Previous research from our lab found that training in a higher repetition range (25-35 RM) elicited greater increases in upper body muscle endurance compared to training in a moderate repetition range when loads were readjusted based on post-study increases in 1RM (Schoenfeld et al., 2015). Whether very high repetition ranges (> 20 RM) confer greater effects on muscle endurance when loads are not readjusted remains undetermined.

The present study had several limitations that should be taken into account when attempting to draw evidence-based conclusions from results. First, measurements of MT were obtained only at the mid-portion of each muscle. Although this assessment can be considered a proxy of overall growth of a given muscle, there is evidence that hypertrophy often manifests in a non-uniform manner, with greater muscle protein accretion seen in the proximal or distal aspects (Wakahara et al., 2012; 2013). We therefore cannot rule out the possibility that discrepant hypertrophic changes may have taken place to a greater extent proximally or distally in one condition versus the other, which would not have been observed in our protocol. Moreover, it remains possible that changes in MT as assessed by ultrasound may be confounded by edema associated with muscle damage, although this event seems unlikely given that subjects were experienced in resistance training and thus the repeated bout effect would have diminished the potential for damage, particularly over the course of an 8-week training period.

Second, results may have been influenced by the novelty factor of changing programs. Pre-study interviews revealed that 16 of the 19 subjects regularly trained with loads ≥8RM, and only one subject reported regularly using loads <5RM. Given evidence that the muscular response is heightened when RT program variables are altered outside of traditional norms (Kraemer et al., 2003), it is feasible that subjects in HEAVY unduly benefited from the unfamiliar stimulus of training in a low repetition range. This hypothesis merits further study.

Finally, our findings are specific to young resistance-trained men and cannot necessarily be generalized to other populations. It is well-documented that adolescents, women, and the elderly respond differently to RT compared to young adult men. Future research should endeavor to investigate muscular adaptations in low- versus moderate-load RT across populations.

Conclusion

Our findings provide evidence that training in different loading zones elicit differential muscular adaptations in resistance-trained men when an equal number of sets are performed. Although the mechanisms remain undetermined, we can infer that strength related adaptations are maximized by training closer to one's 1RM. Alternatively, increases in muscle size seem to be driven more by higher training volumes, at least up to a certain threshold. It is conceivable that combining loading strategies may have a synergistic effect on strength and hypertrophic improvements. This hypothesis warrants further investigation.

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Key points

- Heavy loads maximize muscular strength when the numbers of sets are equated.
- Moderate loads maximize muscle hypertrophy when the number of sets are equated
- Volume load appears to be more important to increases in muscle hypertrophy compared to absolute strength

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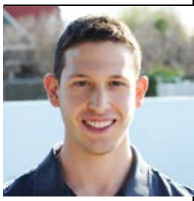

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