Effects of Low- Versus High-Load Resistance Training on Muscle Strength and Hypertrophy in Well-Trained Men

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Effects of Low- Versus High-Load Resistance Training on Muscle Strength and Hypertrophy in Well-Trained Men

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Abstract

The purpose of this study was to compare the effect of low- versus high-load resistance training (RT) on muscular adaptations in well-trained subjects. Eighteen young men experienced in RT were matched according to baseline strength, and then randomly assigned to 1 of 2 experimental groups: a low-load RT routine (LL) where 25-35 repetitions were performed per set per exercise (n = 9), or a high-load RT routine (HL) where 8-12 repetitions were performed per set per exercise (n = 9). During each session, subjects in both groups performed 3 sets of 7 different exercises representing all major muscles. Training was carried out 3 times per week on non-consecutive days, for 8 total weeks. Both HL and LL conditions produced significant increases in thickness of the elbow flexors (5.3 vs. 8.6%, respectively), elbow extensors (6.0 vs. 5.2%, respectively), and quadriceps femoris (9.3 vs. 9.5%, respectively), with no significant differences noted between groups. Improvements in back squat strength were significantly greater for HL compared to LL (19.6 vs. 8.8%, respectively) and there was a trend for greater increases in 1RM bench press (6.5 vs. 2.0%, respectively). Upper body muscle endurance (assessed by the bench press at 50% 1RM to failure) improved to a greater extent in LL compared to HL (16.6% vs. -1.2%, respectively). These findings indicate that both HL and LL training to failure can elicit significant increases in muscle hypertrophy among well-trained young men; however, HL training is superior for maximizing strength adaptations.

Keywords: Light weights, strength-endurance continuum, muscle growth, low intensity strength training, high-intensity strength training
Maintaining high levels of muscle strength and hypertrophy is important to a variety of populations. For the general public, these attributes facilitate the performance of activities of daily living (47) and have wide-ranging implications for health and wellness, including evidence of a clear inverse relationship between muscular fitness and mortality (16). The need to maximize strength is also of particular importance for many athletes, as the capacity to produce near maximal forces is often required in sport. Given the direct correlation between muscle cross-sectional area (CSA) and force production (29), training-induced hypertrophy is essential for optimal strength adaptation assuming growth is specific to contractile elements.

Resistance training (RT) is the primary mode of exercise for enhancing muscular adaptations. Studies show that regimented resistive exercise can promote marked increases in muscle strength and hypertrophy, with improvements seen irrespective of age and gender (23, 24). Current guidelines state that loads of ≥65% 1RM are necessary to elicit favorable increases in hypertrophy, with even higher loads needed to maximize strength (25, 26, 31). It has been postulated that heavy loading is required to fully recruit higher threshold motor units (25). Based on this claim, it stands to reason that optimal improvements in strength and hypertrophy can only be accomplished through complete motor unit activation via the use of heavy loads.

Some investigators have recently challenged this view that heavy loads are required to induce muscular adaptations, and claim that recruitment of the full spectrum of motor units is achievable with low-load training, provided that repetitions are carried out to muscular failure. (10). Indeed, there is evidence to suggest that highly fatiguing resistive exercise may reduce the threshold for recruitment of high-threshold motor units (21, 50, 59). It is thus possible that a greater number of FT motor units are called into play during low-load RT as the point of muscular failure is reached. However, research has yet to demonstrate whether recruitment at
low-loads is comparable to the level of that achieved with heavy loading, with evidence suggesting that recruitment is incomplete during low-load training -- at least at the far right of the strength-endurance continuum (14).

A number of long-term training studies have been carried out to compare muscular adaptations in low- versus high-load training programs. Results of those studies are conflicting with some studies finding superiority for heavier load training (11, 20, 55) and others showing no significant differences (28, 32, 37, 44, 57, 58). One fundamental issue with the current state of the literature is that most studies have reported results from untrained subjects. It is well established that trained individuals respond differently than those who lack training experience (42). Early phase RT strength adaptations are predominantly related to improvements in the ability of the nervous system to efficiently activate and coordinate muscles, whereas the role of hypertrophy for strength becomes increasingly more relevant as one gains experience (53, 54). In addition, a "ceiling effect" makes it progressively difficult for trained individuals to increase muscular gains over time, thereby necessitating progressive RT protocols to elicit continual hypertrophic and strength responses (3). Moreover, there is emerging evidence that consistent training alters the acute response to resistance exercise. Trained muscle differs not only from a structural (30, 52) and functional (2, 22, 51, 52) perspective but alterations in anabolic intracellular signaling in rodents (39) and humans (13) along with altered acute protein synthetic (43, 56, 64), mitochondrial protein synthetic (64) and transcriptional responses (19) may indicate an attenuated hypertrophic response. As such, current findings from untrained subjects cannot necessarily be generalized to the response that might be expected among from a well-trained population. The purpose of this study therefore was to compare the effect of low- versus high-load training on muscular adaptations in resistance-trained subjects. We hypothesized that the
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High-load condition would have greater effects on strength and hypertrophy and that the low-load condition would have a superior impact on local muscle endurance.

Methods

Experimental Approach to the Problem

Subjects were pair-matched based on initial strength capacity and then randomly assigned to a group that either performed training at a loading range of 8-12 repetitions or a group that performed 25-35 repetitions to muscle failure. All other RT variables (e.g., exercises performed, rest, repetition tempo, etc.) were held constant. The training interventions lasted 8 weeks with subjects performing 3 total body workouts per week. Testing was carried out pre- and post-study for muscle strength, muscle endurance, and muscle hypertrophy of the elbow flexors (biceps brachii and brachialis), elbow extensors (triceps brachii), and quadriceps femoris.

Subjects

Subjects were a convenience sample of 24 male volunteers (age = 23.3 yrs; body mass = 82.5 kg; height = 175 cm; resistance training experience = 3.4 yrs), recruited from a university population. Subjects were between the ages of 18-35, did not have any existing musculoskeletal disorders, were free from consumption of anabolic steroids or any other illegal agents known to increase muscle size for the previous year, and were experienced lifters (i.e., defined as consistently lifting weights at least 3 times per week for a minimum of 1 year, and regularly performing the bench press and squat). The range of lifting experience for all subjects was between 1.5 and 9 years of consistent training.

Participants were pair-matched according to baseline strength, and then randomly assigned to 1 of 2 experimental groups: (1) a low-load RT routine (LL) in which 25-35 repetitions (approximately 30-50% 1RM) were performed to failure, per exercise (n = 12) or a
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high-load RT routine (HL) where 8-12 repetitions (approximately 70-80% 1RM) were performed per exercise (n = 12). Approval for the study was obtained from the Institutional Review Board (IRB) at Lehman College, Bronx, NY. Informed consent was obtained from all participants.

Resistance Training Procedures

The RT protocol consisted of 3 sets of 7 exercises per session targeting all major muscle groups of the body. The exercises performed were: flat barbell press, barbell military press, wide grip lat pulldown, seated cable row, barbell back squat, machine leg press, and machine leg extension. The exercises were chosen based on their common inclusion in bodybuilding- and strength-type RT programs (5, 12). 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 three weekly sessions performed on non-consecutive days for 8 weeks. Sets were carried out to the point of momentary concentric muscular failure, i.e., 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 90 seconds 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 training, the LL group underwent 30-repetition maximum (RM) testing and the HL group underwent 10 RM testing to determine individual initial training loads for each
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exercise. Repetition maximum testing was consistent with recognized guidelines as established by the National Strength and Conditioning Association (5).

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. Self-reported food records were collected twice during the study: one week before the first training session (i.e. baseline) and during the final week of the training protocol. A 3-day dietary recall booklet was provided to subjects to assess potential differences in total energy and macronutrient intakes between groups. Subjects were shown how to properly fill out the booklet, and were instructed to record all food items and their respective portion sizes consumed for the designated period of interest. The Interactive Healthy Eating Index (Center for Nutrition Policy and Promotion, United States Department of Agriculture; http://www.usda.gov/cnpp) was used to analyze food records. 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 over the three reference days. To facilitate recovery, subjects were provided with a supplement on training days containing 24g protein and 1g carbohydrate (Iso100 Hydrolyzed Whey Protein Isolate, Dymatize Nutrition, Farmers Branch, TX). The supplement was consumed within one hour post-exercise, as this time frame has been purported to help potentiate increases in muscle protein synthesis following a bout of RT (4).

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 (48). A trained technician performed all testing using a B-mode ultrasound imaging unit (ECO3, Chison Medical Imaging, Ltd, Jiang Su Province, China). The technician, who was not blinded to group assignment, 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 per the protocol by Abe et al. (1). Measurements were taken on the right side of the body at three sites: (1) elbow flexors (combination of biceps brachii and brachialis) (2) elbow extensors (triceps brachii) and (3) quadriceps femoris (combination of rectus femoris and vastus intermedius). For the anterior and posterior arm, measurements were taken 60% distal between the lateral epicondyle of the humerus and the acromion process of the scapula at the midline of the arm (measured from the cubital fossa); for the quadriceps femoris, measurements were taken 50% between the lateral condyle of the femur and greater trochanter for the quadriceps femoris at the midline of the thigh (measured from the distal aspect of the patella). Sites were measured with a vinyl measuring tape and then marked with a felt pen to ensure precision from session to session. During upper extremity measurements, participants remained seated with their arms relaxed in an extended position; measurements for the quadriceps were obtained while standing with legs in a relaxed, extended position. Ultrasound has been validated as a good predictor of gross muscle hypertrophy in these muscles (34, 45), and has been used in numerous studies to evaluate hypertrophic changes (1, 36, 63, 65). In an effort to ensure that swelling in the muscles from training did not obscure results,
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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 muscle thickness return to baseline within 48 hours following a RT session (38). To further ensure accuracy of measurements, at least 2 images were obtained for each site. If measurements were within 10% of one another the figures were averaged to obtain a final value. If measurements were more than 10% of one another, a third image was obtained and the closest of the measures were then averaged. The test-retest intraclass correlation coefficient (ICC) from our lab for thickness measurement of the elbow flexors, elbow extensors, and quadriceps femoris, are 0.976, 0.950, and 0.998, respectively.

**Muscle Strength:** Upper and lower body strength was assessed by 1RM testing in the bench press (1RMBP) followed by the parallel back squat (1RMBS) exercises. Subjects reported to the lab 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 as established by the National Strength and Conditioning Association (5). 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% 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 weight for 1RM determination. Three to 5 minutes rest was provided between each successive attempt. All 1RM determinations were made within 5 attempts. Subjects were required to reach parallel in the 1RMBS for the attempt to be considered successful as determined by the trainer. Successful 1RMBP 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) and executed a full lock-out. 1RMBS testing was conducted prior to 1RMBP with a 5-minute rest period separating tests. Strength testing took place using free weights. Two fitness professionals supervised all testing sessions and an attempt was only deemed successful when a consensus was reached between the two. The test-retest ICC from our lab for the 1RMBP and 1RMBS are 0.91 and 0.87, respectively.

Muscle Endurance: Upper body muscular endurance was assessed by performing bench press using 50% of 1RM (50%BP) 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) and executed a full lock-out. Initial testing used baseline 1RMBP and final testing used the subject’s 1RMBP at the end of the study to determine muscular endurance. The values were expressed in terms of volume load to account for differences between absolute strength from baseline to the study’s end. Muscular endurance testing was carried out after assessment of muscular strength to minimize effects 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 for both groups, with an emphasis on graphical methods such as histograms, scatterplots, and boxplots. Descriptive statistics for strength capacity, and site-specific muscle thickness were reported at baseline, at 8-weeks, and as change from baseline. Paired t-tests were used to examine differences from baseline to post-intervention, within groups. To determine differences in relative changes (i.e., % change) between groups, 2-sample t-tests were used with a class statement for group. Multiple regression analysis with post-intervention
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outcomes as the dependent variable and baseline values as covariates were used to assess the between group differences. The model included a group indicator with two levels and baseline values (centered at the mean values) as predictors. This model 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 primary outcomes. Coefficient of the LL group indicator was employed to estimate the mean post-intervention outcome (e.g. muscle thickness at post-intervention) associated with LL, compared with HL, and the intercept estimated the mean of post-intervention HL. Regression assumptions were checked. Independent t-tests were used to evaluate differences between groups at baseline. Values are reported as mean (±SD). Two-tailed alpha was set a priori at 0.05.

Results

A total of 18 subjects completed the study; 9 subjects in LL and 9 subjects in HL. Six subjects dropped out prior to completion; 2 because of minor injuries sustained during training (one in each group) and 4 for personal reasons. Overall attendance was good for those who completed the study, with a mean participation rate of 93.7% in HL and 95.1% in LL. No significant differences were noted between groups in any baseline measure. There were no differences in any dietary measure either within- or between-subjects over the course of the study. Results of all outcomes are presented in Table 1.

Muscle Thickness

Ultrasound imaging of the elbow flexors showed that both the HL and LL groups increased muscle thickness from baseline to post-study by 2.5 ± 2.9 mm (5.3%) and 3.7 ± 3.2
mm (8.6%), respectively (p < 0.01). No significant between-group differences were noted for absolute or relative change, nor when adjusting for baseline (p=0.22) (see Figure 1).

Ultrasound imaging of the elbow extensors showed that both the HL and LL groups increased muscle thickness from baseline to post-study by 2.7 ± 2.2 mm (6.0%) and 2.3 ± 3.3 mm (5.2%), respectively (p < 0.05). No significant between-group differences were noted for absolute or relative change, nor when adjusting for baseline (see Figure 2).

Ultrasound imaging of the quadriceps femoris showed that both the HL and LL groups increased muscle thickness from baseline to post-study by 5.3 ± 2.2 mm (9.3%) and 5.2 ± 4.8 mm (9.5%), respectively (p < 0.05). No significant between-group differences were noted for absolute or relative change, nor when adjusting for baseline (see Figure 3).

Maximal Strength

The HL group showed a significant increase in 1RMBP from baseline to post-study by 6.5% (p < 0.01); the LL group showed a non-significant increase of 2.0% (see Figure 4). No significant between-group differences were noted for absolute or relative change, nor when adjusting for baseline. However, there was a strong trend for HL producing superior results for absolute (+4.6 kgs ± 5.0) and relative (+4.5%) strength.

Both groups showed a significant increase in 1RMBS from baseline to post-study by 19.6% (p < 0.01) and 8.8% (p < 0.05), respectively for HL and LL (see Figure 5). When
adjusting for baseline strength, a significant difference was noted such that HL produced superior results compared to LL ($\beta=28.11; p<0.05$).

Muscle Endurance

The LL group showed a significant increase in muscular endurance of 16.6% ($p < 0.05$); whereas no differences were noted from baseline in the HL group (see Figure 6). Significant differences were noted between groups, such that LL training produced superior results for absolute ($+230.6 \pm 52.5$ kgs) and relative ($+17.8\%$) gains. After adjustment for baseline values, the difference remained significant, such that LL produced superior results compared to HL ($\beta=330.54$ kgs; $p<0.05$).

Discussion

To the authors’ knowledge, this is the first study to evaluate muscular adaptations in low-versus high-load training in well-trained individuals. The study produced several important findings. With respect to gross measures of muscle hypertrophy, LL significantly increased muscle thickness of the upper and lower extremities. In comparison to a traditional hypertrophy protocol of 8-12 repetitions per set, the LL condition produced similar gains in thickness of the elbow flexors (5.3 vs. 8.6%, respectively), elbow extensors (6.0 vs. 5.2%) and quadriceps femoris (9.3 vs. 9.5%). These results run contrary to generally accepted hypertrophy training guidelines, which profess that loads of at least 65% are necessary to stimulate muscle growth in well-trained individuals (25, 26, 31).

Previous research on the hypertrophic effects of low-load training have shown mixed results, with some studies reporting similar gains to high-load training (28, 32, 37, 44, 57, 58, 63).
and other studies showing an inferior adaptive response (11, 20, 55). Discrepancies between findings may at least in part be attributed to differences in training volume between conditions. The majority of prior studies standardized the number of sets such that the greater number of repetitions performed during low-load training resulted in a higher total amount of work for this condition. With the exception of Schuenke et al. (55), all studies that did not equate volume reported similar increases in muscle growth between high- and low-load training (28, 32, 37, 44, 57, 58). Conversely, the two studies that did equate total intra-session work showed a hypertrophic advantage for high-load exercise (11, 20). The LL group in our study performed approximately three times the total volume (sets x repetitions) compared to the HL group. Given that compelling evidence exists for a dose-response relationship between hypertrophy and RT volume at least up to a certain threshold (27), it can be hypothesized that the differences in total work performed between groups had an effect on results.

Another intriguing possibility is that fiber-type specific responses may have played a role in mediating muscle protein accretion. It is generally accepted that type II fibers display an approximately 50% greater capacity for growth compared to type I fibers. However, the superior hypertrophic capacity type II fibers may be more a consequence of the models in which they have been studied as opposed to an intrinsic property of the fiber itself (40). Specifically, research to date has been biased towards RT intensities >60% 1RM, with a paucity of studies investigating lower intensities. Given the fatigue-resistant nature of type I fibers, it seems logical to conclude that the increased time-under-load associated with low-load training is necessary to fully stimulate these fibers. This hypothesis is supported by Netreba et al (35), who found that training at 80-85% 1RM induced preferential increases in CSA of fast-twitch fibers while training at 50% 1RM produced greater increases in slow-twitch fiber CSA. Consistent with these findings,
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data from Mitchell et al. (32) found type I fiber CSA was greater with low-load training (23% versus 16%), although the difference was not statistically significant due to low statistical power.

It should be noted that none of the subjects in our study reported training with more than 15 repetitions per set as part of their normal resistance-training programs. Thus, it is possible that the type I fibers of subjects were underdeveloped in comparison to the type II fibers as a result of training methodologies. The type I fibers therefore may have had a greater potential for growth compared to the type II fibers, and the extended duration of the LL sets conceivably provided a novel stimulus to promote greater growth in the endurance-oriented type I fibers. This hypothesis requires further study.

It is also plausible that differing inter-muscle activation strategies in multi-joint or multi-muscle movements could account for the comparable hypertrophy under certain circumstances. For the squat exercise specifically, it has been shown that increased training intensity (%1RM) is associated with greater contribution from joints other than the knee (hip, ankle), whereas the knee, and therefore quadriceps, have a constant relative mechanical effort in response to increased training loads (7, 17). Given these findings, it is conceivable that varying training intensities in the squat may represent equivalent stress to the quadriceps muscle group, thereby providing a comparable training stimulus for muscle growth. Conversely, others have demonstrated that EMG activity is greater in the quadriceps with higher than lower training loads during single joint exercises (14). Consequently it is not possible to reconcile these findings, as differences in experimental methodology confound the issue. Further research is required to clarify the role of inter-muscle differences in activation with single- and multi-joint exercises across varying training intensities to determine whether such a mechanism influences the findings of the present and previous studies ((32, 37).
Strength gains between groups were consistent with the concept of a strength-endurance continuum (11, 62). Although LL did increase maximal muscle strength, HL resulted in greater increases in both 1RMBP (6.5 vs. 2.0%, respectively) and 1RMBS (19.6 vs. 8.8%, respectively). The observation of increased improvement in strength with HL despite equivalent hypertrophy is consistent with other comparisons of high- versus low-load training (32, 46). Multiple meta-analyses have identified that peak gains in strength occur with training above 60%-1RM in both trained and untrained individuals, although the optimal intensity is higher in the trained (41, 42, 49). The disparate strength adaptations despite equivalent hypertrophic changes between HL and LL are not unexpected given that muscle hypertrophy accounts for approximately 19% of the change in muscle strength with chronic resistance exercise in untrained individuals (15). Even in the untrained state, muscle size is estimated to explain at most 50% of the variability in maximum muscle strength (6), suggesting that other mechanisms contribute to alterations in strength with training. Neural adaptations can contribute to increased strength with RT, including but not limited to increased muscle activation, increased motor unit firing rates, increased frequency of doublet firing, enhanced motor unit synchronization, and/or alterations in agonist-antagonist co-activation ratios (18), however, the contribution of these mechanisms to the present dataset is not known. Regardless of potential mechanisms, it can be inferred that muscle strength is increased with both low- and high-load training but high-load training is superior for maximal strength development.

Adaptations in muscular endurance favored the LL condition, with a mean volume load increase in 50%BP to failure of 16.6% compared to a small non-significant decrease of -1.2% for HL. The superiority of higher repetition, low-load training on muscle endurance is consistently observed in the literature (11, 32, 46). Training with LL may result in favorable phenotypic
alterations that would support increased muscular endurance, namely increased size and/or proportion of type I and IIa fibers, however the increase in IIa fibers is a generalized consequence of strength training regardless of loading intensity. In addition, the longer time-under-load that occurs with high-repetition, low-load training (8) differentially and favorably affects mitochondrial protein synthesis that may enhance cellular energetics, culminating in improved fatigue resistance (9). It should be noted that the greater increase in bench press strength for the HL group resulted in their lifting slightly higher mean loads (~2 kg) compared to LL. However, given the large magnitude of difference in this outcome favoring LL, the additional load lifted by HL likely had minimal effect on measures of muscle endurance.

The present study had several limitations that must be considered when extrapolating conclusions based on the results. First, the study period lasted only 8 weeks. While this duration was sufficient to produce significant increases in muscular strength and hypertrophy, it is not clear whether results between groups would have diverged over a longer term.

Second, muscle thickness was measured only at the middle portion of the muscle. Although this region is generally considered to be indicative of overall growth of a given muscle, there is evidence that hypertrophy manifests in a regional-specific manner, with greater gains sometimes seen at the proximal and/or distal aspects (60, 61). This may be related to exercise-specific intramuscular activation and/or tissue oxygenation saturation (33, 60, 61). Thus, we cannot rule out the possibility that greater changes in proximal or distal muscle thickness occurred in one protocol versus the other.

Third, subjects were provided with post-workout whey protein supplementation. The protein supplement was provided to ensure that all subjects consumed adequate protein to promote a maximal anabolic response to the resistance training protocol. It is conceivable that
some participants might have responded differently to an increase in protein intake. However, dietary analysis revealed no differences in total daily protein intake between groups. Moreover, there is no research suggesting that the provision of protein differentially affects a given loading range. Thus, it is highly unlikely that such provision confounded results.

Finally, our subject population consisted exclusively of young resistance-trained men. Findings therefore cannot necessarily be generalized to other populations including adolescents, women and the elderly. It is possible that differences in hormonal influences, anabolic sensitivity of muscle, recuperative abilities, and other factors could alter muscular adaptations to low- and/or high-load protocols in these individuals.

**Practical Applications**

In conclusion, our results provide compelling evidence that low-load training can be an effective method to increase muscle hypertrophy of the extremities in well-trained men. The gains in muscle size from low-load training were equal to that achieved with training in a repetition range normally recommended for maximizing muscle hypertrophy. Provided that maximal hypertrophy is the primary outcome goal irrespective of strength increases, these findings suggest that a new paradigm should be considered for hypertrophy training recommendations, with low-load training promoted as a viable option. On the other hand, if maximizing strength gains is of primary importance, then heavier loading should be employed at the exclusion of lower load training. Given the preservation of the strength-endurance continuum regarding muscle strength and endurance adaptations alongside equivalent muscle hypertrophy, it is possible that HL and LL preferentially affect CSA of different fiber types. Considering the inconclusive nature of existing data regarding the fiber-type specific effects of HL and LL (11, 20, 32, 55), further research is required to clarify whether HL and LL result in similar whole
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muscle hypertrophy brought about through growth of specific populations of fibers of a given phenotype. It therefore can be hypothesized that combining low- and high-load sets would be optimal for maximizing muscle growth. These findings suggest a potential benefit to incorporating a wide spectrum of loading ranges in a hypertrophy-oriented program.

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References


Table 1: Pre- vs. Post-Study Outcome Measures

<table>
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<tr>
<th>MEASURE</th>
<th>LL-PRE</th>
<th>LL-POST</th>
<th>ES</th>
<th>HL-PRE</th>
<th>HL-POST</th>
<th>ES</th>
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<tr>
<td>Elbow flexor thickness (mm)</td>
<td>42.4 ± 6.6</td>
<td>46.0 ± 7.1*</td>
<td>0.54</td>
<td>46.6 ± 6.3</td>
<td>49.1 ± 6.2*</td>
<td>0.40</td>
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<td>Elbow extensor thickness (mm)</td>
<td>44.5 ± 6.8</td>
<td>46.9 ± 7.4*</td>
<td>0.33</td>
<td>45.6 ± 5.4</td>
<td>48.3 ± 3.9*</td>
<td>0.57</td>
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<td>Quadriceps thickness (mm)</td>
<td>54.6 ± 10.9</td>
<td>59.8 ± 9.2*</td>
<td>0.51</td>
<td>57.1 ± 4.2</td>
<td>62.3 ± 5.2*</td>
<td>1.10</td>
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<tr>
<td>1RM Bench Press (kg)</td>
<td>101.0 ± 25.6</td>
<td>103.0 ± 23.3</td>
<td>0.08</td>
<td>101.5 ± 20.5</td>
<td>108.1 ± 21.0*</td>
<td>0.32</td>
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<td>1RM Back Squat (kg)</td>
<td>122.1 ± 39.7</td>
<td>132.8 ± 36.5*</td>
<td>0.28</td>
<td>121.0 ± 36.6</td>
<td>144.7 ± 27.4*</td>
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<td>50% Bench Press (kg)</td>
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<td>1.23</td>
<td>1438.4 ± 311.7</td>
<td>1421.0 ± 257.0</td>
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An asterisk* indicates a significant effect from baseline values.
Figure Captions

**Figure 1** Graphical representation of muscle thickness values of the biceps brachii pre- and post-intervention for LL and HL, mean (±SD). Values expressed in mms. *Significantly greater than corresponding pre-training value.

**Figure 2** Graphical representation of muscle thickness values of the triceps brachii pre- and post-intervention for LL and HL, mean (±SD). Values expressed in mms. *Significantly greater than corresponding pre-training value.

**Figure 3** Graphical representation of muscle thickness values of the quadriceps femoris pre- and post-intervention for LL and HL, mean (±SD). Values expressed in mms. *Significantly greater than corresponding pre-training value.

**Figure 4** Graphical representation of 1RM bench press values pre- and post-intervention for LL and HL, mean (±SD). Values expressed in kgs. *Significantly greater than corresponding pre-training value.

**Figure 5** Graphical representation of 1RM back squat values pre- and post-intervention for LL and HL, mean (±SD). Values expressed in kgs. *Significantly greater than corresponding pre-training value. #Significantly greater than corresponding group.

**Figure 6** Graphical representation of 50% bench press to failure values pre- and post-intervention for LL and HL, mean (±SD). Values expressed as total volume-load (total number of repetitions x load) in kgs. *Significantly greater than corresponding pre-training value. #Significantly greater than corresponding group.
Figure 2

Elbow extensor thickness (mm)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Low Load</th>
<th>High Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Statistically significant difference.
Figure 4

1RM bench press (kg)

Condition

Low Load

High Load

Pre

Post

[Graph showing comparison of 1RM bench press between Pre and Post conditions for Low and High Load conditions.]

* Significant difference.
Figure 5

Comparison of 1RM back squat (kg) between Pre and Post conditions for Low Load and High Load conditions.

- Pre condition:
  - Low Load: 120 kg
  - High Load: 140 kg

- Post condition:
  - Low Load: 140 kg
  - High Load: 160 kg

Significant difference indicated by *.

* indicates a significant difference compared to Pre condition.

# indicates a significant difference between Low Load and High Load within Post condition.

Note: The data points are marked with error bars to indicate variability.
Figure 6

- **Condition**
  - Low Load
  - High Load

- **50% bench press (kg)**
  - Pre
  - Post

- **Data Points**
  - 0 kg
  - 200 kg
  - 400 kg
  - 600 kg
  - 800 kg
  - 1000 kg
  - 1200 kg
  - 1400 kg
  - 1600 kg
  - 1800 kg
  - 2000 kg
  - 2200 kg

- **Significant Differences**
  - # P < 0.05
  - * P < 0.01