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The Acute and Chronic Effects of "NO LOAD" Resistance Training

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Abstract

The purpose of the study was to remove the influence of an external load and determine if muscle growth can be elicited by maximally contracting through a full range of motion. In addition, the acute physiologic and perceptual responses to each stimulus were also investigated. Thirteen participants completed 18 sessions of unilateral elbow flexion exercise. Each arm was designated to either NO LOAD or HIGH LOAD condition (70% one repetition maximum). For the NO LOAD condition, participants repeatedly contracted as hard as they could through a full range of motion without the use of an external load. Our results show that anterior muscle thickness increased similarly from Pre to Post, with no differences between conditions for the 50% [Pre: 2.7 (0.8) vs. Post: 2.9 (0.7)], 60% [Pre: 2.9 (0.7) vs. Post: 3.1 (0.7)] or 70% [Pre: 3.2 (0.7) vs. Post: 3.5 (0.7)] sites. There was a significant condition x time interaction for one repetition maximum (p=0.017), with HIGH LOAD (+2.3 kg) increasing more than the NO LOAD condition (+1 kg). These results extend previous studies that have observed muscle growth across a range of external loads and muscle actions and suggest that muscle growth can occur independent of an external load provided there are enough muscle fibers undergoing mechanotransduction.

Key Words: mechanotransduction; hypertrophy; muscle adaptation; muscle strength

Introduction

Skeletal muscle is required for everyday movement and is the largest storage site of ingested glucose within the body (Ivy et al. 1988), thus methods to increase or maintain muscle size are of great interest. Currently, the American College of Sports Medicine (ACSM) recommends that an external load of at least 70% of one's one repetition maximum (1RM) be lifted repeatedly in order for substantial increases in muscle size to occur (ACSM 2009). This recommendation is not completely supported, given that muscle growth has been repeatedly shown with external loads of less than 70% 1RM (Mitchell et al. 2012; Morton et al. 2016). Thus, evidence exists to question the importance of the absolute load required for muscle growth.

Muscle growth following resistance training has been hypothesized to occur through local mechanisms initiated by muscle contraction (mechanotranduction) (Rennie et al. 2004). Mechanotransduction is the process in which tension placed on a muscle is transmitted into a chemical signal that initiates a cascade responsible for inducing muscle growth, and is only likely to occur in those muscle fibers that are activated during resistance exercise. Therefore, a wide range of protocols may be capable of inducing muscle growth provided they require a large portion of muscle fibers to be activated within the exercised muscles. For example, low loads (20-30% 1RM) with blood flow restriction (Dankel et al. 2016; Loenneke et al. 2012) increases muscle size similar to that of high load (>70%1RM) training. Further, low load (30% 1RM) resistance training without blood flow restriction also increases muscle size and strength when sets were taken to volitional fatigue (Mitchell, Churchward-Venne 2012). Muscle growth was also observed following both isokinetic (Esposito et al. 2005) and isometric training (Ikae & Fukunanaga 1970), illustrating that if a training stimulus produces marked increases in muscle activation, muscle growth will likely occur independent of the external load lifted.

Thus, the purpose of our study was to remove the influence of an external load to determine if muscle growth can still be elicited. We also sought to compare the perceptual responses to each distinct stimulus. To test this, participants repeatedly contracted as hard as they could through a full range of motion without the use of a meaningful load from body mass (e.g. push-ups) or the use of an external load (e.g. dumbbell), here termed “NO LOAD” training. It is acknowledged that a previous study has shown that a contraction held at 90 degree elbow flexion without an external load could increase muscle size, however, this study was compared to a non-exercise control group. We expand on this model by having participants contract through a full range of motion which is more specific to traditional resistance exercise. In addition, we used a within subject design to compare this method to a traditional “HIGH LOAD” training condition (here defined as 70% 1RM) which is known to produce robust growth. Additionally, we tested the acute responses (muscle swelling, fatigue and amplitude) of both conditions after training weeks two and three to better understand the acute response of this exercise. We hypothesized that the increases in muscle size would be similar between NO LOAD and HIGH LOAD training. We further hypothesized that HIGH LOAD training would result in a greater increase in 1RM strength compared to NO LOAD due to the principle of specificity. For the acute response to exercise, we hypothesized that there would be no difference between conditions.

Methods

Participants

Fifteen untrained (6 men, 9 women) participants volunteered to participate in this study. The sample size was chosen based on an estimated effect size of 0.79, which was averaged from three similar studies [0.53 (Hubal et al. 2005), 0.63 (Farup et al. 2015) and 1.2 (Yasuda et al. 2012)]. Using G*Power software (GPower 3.1), an estimated sample size of 12 people was recommended to appropriately observe statistical significance at the 0.05 alpha level with a power level of 0.8. Participants were excluded from participation if they smoked, had a BMI > 30 kg/m^2, were resistance trained in the upper body, or had any orthopedic injuries preventing them from completing biceps curls. Untrained was defined as not participating in a structured upper body exercise program within the last six months. One individual dropped out prior to the start of the study and a second after week two for reasons unrelated to the study. Therefore, data is reported on the thirteen participants (5 men, 8 women) who completed the study. All participants gave written informed consent and the University's Institutional Review Board approved this study.

Study Design

The participants visited the lab 23 times; paperwork, two pre-testing visits, 18 training sessions and two post-testing visits (Figure 1). During the initial testing visit, anthropometric measurements (height and body mass), muscle thickness, 1RM testing, a test of muscular endurance and familiarization of isokinetic and isometric testing were completed. Forty-eight to 72 hours later, participants completed isokinetic and isometric testing, and then were familiarized with training conditions for each arm. The following week, participants started six consecutive weeks of unilateral bicep curls, performed three times per week for each condition. Using a counterbalance design each arm was designated to either the NO LOAD or HIGH LOAD training conditions. The NO LOAD training condition is defined as voluntarily maximally contracting the muscle through the full range of motion without the use of an external load. During each NO LOAD training session, surface electromyography (EMG) electrodes were applied to the biceps to provide feedback to the participant and to help encourage greater activation during each repetition. The participants completed 4 sets of 20 repetitions with 30 seconds of rest between sets. This protocol was based off of pilot work performed in our laboratory which suggested that 4 sets of 20 repetitions should result in increases in both fatigue and muscle activation. In the contralateral arm, the HIGH LOAD condition completed 4 sets of 8-12 repetitions with 90 seconds of rest between sets at 70% of their 1RM. If the participants did not achieve 8 repetitions or could exceed 12 repetitions, we altered the load for the next set to ensure that the participants achieved volitional fatigue (i.e. could not keep to the metronome or maintain proper form) within 8-12 repetitions. Both conditions exercised to a metronome at a cadence of 1.5 seconds for the concentric and eccentric portion of the lift, totaling a 3 second contraction. After the initial training session, a counterbalanced design was used to determine which condition trained first. Within the training study we also measured the acute responses (muscle swelling, fatigue, and muscle activation) to each condition.

Muscle Thickness

Muscle thickness measurements were taken using B-mode ultrasonography (Aloka, SSD-550 with a 5MHz probe). The measurements were taken while the participants stood quietly. A 5-MHz scanning head was placed on the skin surface of the skin using the minimum pressure required, and cross-sections of each muscle were imaged. Muscle thickness was measured as the perpendicular distance between the subcutaneous adipose tissue-muscle interface and muscle-bone interface. Measurements were taken on the anterior and posterior upper arms at 50%, 60% and 70% of the distance between the acromion process of the scapula and to the lateral epicondyle to the humerus, totaling 6 sites on each arm (Abe et al. 1994). An additional measure of muscle thickness on the anterior right thigh 50% of the distance between the greater trochanter and lateral condyle of the femur was made as an internal time control. This internal time control served as a method to demonstrate that our measurement was stable across time by measuring a muscle that was not expected to change. Muscle thickness measurements were taken up to one week before training and 48-72 hours after the last training session. Two images were printed at each site and were analyzed following completion of the study in a blinded manner by the same investigator. To measure the acute muscle swelling response, upper body muscle thickness measurements 10 cm above the lateral epicondyle of the humorous on the anterior portion of the upper arm were measured at pre, immediately following and 15 minutes post-exercise for both conditions during their 7th training session. The minimal difference was calculated at 0.2 cm.

Determination of 1RM

One repetition maximum was defined as the maximum load the participant could lift through the concentric portion of elbow flexion with proper form. The load was handed to the participant at the bottom of the lift to make sure their arm was fully extended. Participants were then instructed to contract when ready and the lift was considered satisfactory only if they were able to lift the load successfully through their complete concentric range of motion. To ensure strict form during the 1RM test, participants stood with their back and heels against the wall, with their heels shoulder width apart. Participants completed a 3-5 repetition warm-up using roughly 30% of their 1RM and then progressed to heavier loads of an estimated 60-75% 1RM. One repetition maximum determination was completed within five attempts, with three to five minutes of rest between attempts and arms were alternated between attempts.

Muscle Endurance

Participants completed as many repetitions of elbow flexion as possible using 35% of their 1RM tested that day to a cadence of 1.5 seconds for the concentric portion and 1.5 seconds for the eccentric portion of the lift. Thirty-five percent was chosen to represent the average of the two conditions (i.e. halfway between 0% and 70% of the external load). The test was terminated when participants were unable to maintain this cadence or could not lift the load through the full range of motion. During testing, the participants kept their heels and back against the wall with their heels shoulder width apart.

Isokinetic/Isometric Strength

Isokinetic and isometric torque were tested on a dynamometer (Biodex Quickset System 4). After the appropriate chair position and arm length were determined and recorded, the limb was weighed to correct for gravity. Participants then completed two sets of three repetitions of isokinetic testing at $180°\cdot sec^{-1}$ followed by two sets of three repetitions at $60\ °\cdot sec^{-1}$ allowing 60 seconds of rest between sets. Following isokinetic testing, participants completed two isometric maximal voluntary contractions (MVC) at 90^o of elbow flexion. Each participant pulled against the fixed lever arm as hard as possible for three seconds with a 60 second rest between each MVC. Finally, the participants completed the same protocol on the contralateral arm. The minimal difference was calculated at 5 Nm for $180°\cdot sec^{-1}$ and 3 Nm for 60. $°\cdot sec^{-1}$. To measure muscle fatigue induced by each condition, isometric torque at 90^o was tested pre, immediately following and 15 minutes post-exercise during their 10th training session.

Surface Electromyography

During the acute testing, electromyography (EMG) activity was recorded from the biceps brachii on the anterior upper arm, 2/3rd of the distance between the acromion process of the scapula and the antecubital fosse, distal to the shoulder, while the elbow was flexed at 90^o (Hermens et al. 2000). Two additional electrodes were applied to the posterior upper arm over the triceps brachii, two finger widths medial to 50% of the distance between the posterior crista of the acromion and olecranon, while the palm was faced downward and the arm was at 90° elbow flexion (Hermens, Freriks 2000). The skin was shaved, abraded and wiped with an alcohol wipe. Bipolar surface electrodes were placed at an inter-electrode distance of 20 mm and the ground electrode was placed on the 7th cervical vertebrae at the neck. The surface electrodes were connected to an amplifier and digitized (iWorkx, Dover, New Hampshire). Using a bandpass filter, the signal was filtered (low-pass filter 500 kHz; high-pass filter 10 kHz), amplified (1000x) and sampled at a rate of 1 kHz. Each participant performed two MVCs for the biceps brachii at a joint angle of 90° with 60 seconds rest between MVCs. Then, participants performed two MVC's for the triceps brachii, using an isometric triceps pushdown exercise at a joint angle of 90° with 60 seconds of rest between MVC's. EMG was recorded continuously from the biceps brachii and triceps brachii during each acute exercise bout. Computer software (Lab Scribe 2) was used to analyze the data. EMG amplitude (root mean square, RMS) was analyzed from the average of the first three repetitions and an average of the last three repetitions for each set and were normalized to the highest pre-exercise MVC for both biceps and triceps (%MVC). During each training session, surface electrodes were applied to the biceps, placed in a similar manner as testing, during the NO LOAD condition in order to give the participant visual feedback.

Perceptual Responses

Ratings of Perceived Exertion using the standard Borg RPE (6-20) scale, and ratings of discomfort using the Borg Discomfort scale (CR+10) were recorded before the start of each training session and following each set. RPE scale was described as 6 representing no effort and 20 representing maximal effort. Borg Discomfort scale was described to each participant as 0 representing no discomfort at all and 10 representing their previously worst felt discomfort. If discomfort exceeded their previously worst felt discomfort, they could exceed 10.

Statistical Analysis

All data analysis was completed on SPSS 22.0 statistical software package (SPSS Inc. Chicago, IL). A 2 (condition) x 2 (time) repeated measures ANOVA was used to determine differences in muscle thickness, 1RM, muscle endurance, isokinetic strength, and isometric strength. If there was an interaction, a paired samples t-tests were used to find differences across time points within each condition, and between conditions within each time point. If no interaction was found, main effects were examined. Additionally, between condition effect sizes were calculated for chronic measures of muscle thickness, muscle endurance and muscle strength using Cohen's *d* with the equation [(NO LOAD change score – HIGH LOAD change score) / pooled standard deviation of the change scores]. Effect sizes were calculated such that a positive value favors the NO LOAD condition and negative value favors the HIGH LOAD condition (Supplementary Table 1). A non-parametric Wilcoxon test was used to determine differences in RPE and discomfort between conditions within each set.

For acute measures, a 2 (condition) x 3 (time) repeated measures ANOVA was used to determine differences in muscle swelling and isometric torque. Analysis of muscle activation of the biceps brachii and triceps brachii utilized a 2 (conditions) x 4 (time) repeated measures ANOVA to determine differences in muscle activation of the first three repetitions and the last three repetitions within each set. If interactions were found, a one way repeated measures ANOVA was used to determine differences across time within each condition and a paired sample t-test was used to determine differences between conditions at each time point. Significance was set at $p \leq .05$ for all tests.

Results

Demographics

Participants had an average age of 22 (2) years, a height of 170 (7) cm, a body mass of 72 (14) kg, and a BMI of 24 (3) kg/m^2.

Muscle Thickness

There was no condition x time interaction for anterior muscle thickness at the 50% ($p=0.549$), 60% ($p=0.550$), or 70% ($p=0.203$) site of the arm but there were main effects of time at each site ($p<0.05$, Figure 2A and 2B). Individual responses for the anterior portion of the upper arm are illustrated in Figure 3. The mean (95% CI) change from pre to post for NO LOAD was 0.20 (0.03, 0.36) cm for the 50% site, 0.13 (0.03, 0.24) cm for the 60% site, and 0.13 (0.01, 0.27) cm for the 70% site. The mean (95% CI) change from pre to post for HIGH LOAD was 0.14 (0.04, 0.24) cm for the 50% site, 0.17 (0.10, 0.24) cm for the 60% site, and 0.23 (0.15, 0.30) cm for the 70% site. For posterior muscle thickness of the arm (Figure 2C and 2D), there was a significant condition x time interaction at the 50% ($p=0.003$), 60% ($p=0.014$), and 70% site ($p=0.018$). Follow up tests found that muscle thickness was maintained in the NO LOAD condition at the 50% and 60% sites of the posterior upper arm, however, muscle thickness was decreased at these sites in the HIGH LOAD condition ($p<0.05$). There were no post-hoc differences at the 70% site between conditions ($p\geq0.095$). Individual responses for the posterior portion of the upper arm are found in Figure 4. The mean (95% CI) change from pre to post for NO LOAD was 0.08 (-0.03, 0.20) cm for the 50% site, 0.03 (-0.10, 0.16) cm for the 60% site, and 0.06 (-0.05, 0.19) cm for the 70% site. The mean (95% CI) change from pre to post for HIGH LOAD was -0.26 (-0.40, 0.13) cm for the 50% site, -0.24 (-0.36, -0.12) cm for the 60% site, and -0.08 (-0.19, 0.03) cm for the 70% site. Muscle thickness of the right upper leg (internal control) remained unchanged from pre to post [4.8 (1.0) vs. 4.7 (0.9), $p=0.106$].

One Repetition Maximum

There was a significant condition x time interaction for elbow flexor 1RM (p=0.017). Follow up tests determined that 1RM increased from pre to post in both the NO LOAD [13.8 (5.5) kg vs. 14.8 (5.1) kg, p=0.015) and HIGH LOAD [13.9 (5.8) kg vs. 16.2 (5.1) kg, p<0.001) conditions. The HIGH LOAD 1RM post training was greater than that observed with NO LOAD training (p=0.032). The mean (95% CI) change from pre to post was 1.04 (0.24, 1.85) kg for NO LOAD and 2.32 (1.55, 3.09) kg for HIGH LOAD.

Muscle Endurance

One participant was unable to successfully complete the pre-test of muscle endurance, so analysis for this test was performed on the remaining 12 participants. For muscle endurance, there was a condition x time interaction (p=0.049). Follow up tests found that muscle endurance increased from pre to post in the HIGH LOAD condition [Pre: 37 (14) vs. Post: 51 (20) repetitions, p=0.006]. This did not reach significance with the NO LOAD condition [Pre: 39 (20) vs. 47 (21), p=0.052]. In addition, there were no significant differences between conditions at Pre (p=0.391) or Post (p=0.053). The mean (95% CI) change from pre to post was 7.5 (0.06, 15.06) repetitions for NO LOAD and 14.6 (5.28, 24.04) repetitions for HIGH LOAD.

Isokinetic and Isometric Strength

There was no interaction (p=0.521) or main effects (p≥0.303) for isokinetic torque at 180°·sec^{-1} [NO LOAD Pre: 34.3 (12.8) Nm vs. NO LOAD Post: 34.4 (13.8) Nm; HIGH LOAD Pre: 32.7 (13.1) Nm vs. HIGH LOAD Post: 33.4 (13.3) Nm]. The mean (95% CI) change from pre to post was 0.14 (-1.69, 1.98) Nm for NO LOAD and 0.77 (-0.95, 2.50) Nm for HIGH LOAD. There was a significant condition x time interaction for isokinetic torque at 60°·sec^{-1} (p=0.024). Follow up tests found that torque increased from pre to post with HIGH LOAD training [Pre: 38.9 (17.7) Nm vs. Post: 41.8 (17.1) Nm, p=0.001] but did not change with NO LOAD Training [Pre: 40.0 (17.3) Nm vs. Post: 40.8 (16.1) Nm, p=0.365]. In addition, there were no significant differences between conditions at Pre (p=0.415) or Post (p=0.583). The mean (95% CI) change from pre to post was 0.86 (-1.1, 2.8) Nm for NO LOAD and 2.87 (1.53, 4.21) Nm for HIGH LOAD. For isometric torque at 90 degrees, there was no condition x time interaction (p=0.376) but there was a main effect of time (Pre: 40.5 (12.2) Nm vs. Post: 44.1 (15.4) Nm, p=0.022). The mean (95% CI) change from pre to post was 2.77 (0.15, 5.39) Nm for NO LOAD and 4.46 (0.07, 8.84) Nm for HIGH LOAD.

Perceptual Responses

Ratings of perceived exertion and discomfort were compared between the first half (Sessions 1-9) and second half (Sessions 10-18) of training. The median value at each time point (e.g. Pre, Set 1, Set 2, etc.) across the first half and second half of sessions was used for this analysis. For sessions 1-9, RPE was higher with NO LOAD training (Table 1, p=0.033). There were no other differences between conditions for sets 2-4. For sessions 10-18, RPE was higher with NO LOAD Training (Table 1, p=0.026). There were no other differences between conditions for sets 2-4. For sessions 1-9, ratings of discomfort were higher with NO LOAD training (Table 1, p=0.024). There were no other differences between conditions for sets 2-4. For sessions 10-18, there were no differences in the rating of discomfort between NO LOAD and HIGH LOAD training.

Exercise Volume

All participants were able to complete all repetitions in the NO LOAD condition. Exercise volume (repetitions x load) cannot be calculated for NO LOAD training due to the lack of an external load. For HIGH LOAD training, there was a significant increase in exercise volume from sessions 1-9 [786.6 (308.7) kg] to sessions 10-18 [927.5 (341.0) kg, $p<0.001$].

Acute Measurements

There was no significant condition x time interaction for acute changes in anterior muscle thickness ($p=0.130$) of the upper arm, but there was a main effect of time ($p<0.001$). Muscle thickness increased from pre to post [3.5 (0.36) cm vs. 3.9 (0.36) cm, $p<0.001$] exercise. In addition, although muscle thickness decreased from Post to 15 minutes post-exercise, it was still significantly elevated over baseline [3.8 (0.36) cm, $p<0.001$].

There was no significant condition x time interaction for acute changes in isometric torque ($p=0.124$), but there was a main effect of time ($p=0.002$). Isometric torque decreased from pre to post [42.2 (14.0) Nm vs. 37.0 (9.3) Nm, $p=0.018$] exercise and remained decreased 15 minutes post exercise [36.6 (11.5) Nm, $p<0.001$].

For biceps EMG amplitude, for the first three repetitions, there was no interaction ($p=0.387$) or main effects for condition or time (Table 2, $p\geq0.207$). For biceps muscle activation of the last three repetitions (Table 2), there was no significant condition x time interaction ($p=0.423$), but there was a main effect of condition with HIGH LOAD training [87 (28) %MVC] having greater amplitude than NO LOAD training [52 (25.2) % MVC, $p=0.019$]. For triceps muscle activation, for the first three repetitions, there was no interaction ($p=0.336$), but there was a main effect of condition with NO LOAD training [34 (10) %MVC] having greater amplitude than HIGH LOAD training [10 (2) %MVC, $p<0.001$]. In addition, for triceps EMG amplitude of the last three repetitions, there was no interaction ($p=0.191$) but there was a main effect of condition with

NO LOAD training [31 (14) %MVC] having greater amplitude than HIGH LOAD training [12 (3) %MVC, p=0.001].

Discussion

This study revealed that muscle growth can occur without the use of an external load and at the group level, occurs similarly to that of HIGH LOAD training. A surprising finding was that posterior arm muscle size decreased with HIGH LOAD training from pre to post, but remained unchanged in the NO LOAD condition. Muscle strength and endurance increased more following HIGH LOAD training which may be explained by the specificity of the tests we employed in this study. With respect to the acute findings, a similar response occurred between NO LOAD and HIGH LOAD training, however HIGH LOAD EMG amplitude of the biceps was higher during the later repetitions.

Muscle Size

In agreement with our hypothesis, anterior upper arm muscle thickness increased in the NO LOAD condition, despite training with no external load. This increase was similar to that of HIGH LOAD training, which is a stimulus known to increase muscle size (Mitchell, Churchward-Venne 2012; Ogasawara et al. 2013; Pyka et al. 1994). This study supports Rennie and colleague's (2004) hypothesis that high levels of localized muscle activation produced from repeated contractions can provide sufficient stimulation of skeletal muscle hypertrophic pathways. When interpreting the individual response data (Figure 3), NO LOAD training appears to have greater variability than HIGH LOAD training, which may be related to each participant's ability to maximally contract during NO LOAD training. Another possibility may be that we are not able to quantify total exercise volume with NO LOAD training. Nonetheless, this study, along with previous studies which have observed muscle growth despite low external loads (Loenneke, Wilson 2012; Mitchell, Churchward-Venne 2012) and differing muscle actions (Esposito, Ce 2005; Ikae & Fukunanaga 1970; Maeo et al. 2014), suggests that a muscle can significantly increase size as long as a sufficient amount of the targeted muscle is activated and placed under tension.

To our surprise, the HIGH LOAD condition decreased posterior upper arm muscle thickness following 6 weeks of bicep curl training. We are not aware of any studies that investigated HIGH LOAD resistance training that targeted only the biceps and measured muscle size of both the biceps and triceps. In contrast to HIGH LOAD, the NO LOAD condition maintained posterior upper arm muscle size, similar to a previous study at the four week mark which did not use an external load but had participants contract maximally at 90 degrees of elbow flexion (Maeo, Yoshitake 2014). Given that our measurement of muscle thickness was blinded and that decreases were only observed in the HIGH LOAD condition, we suggest, that this may be a real change. This is further supported by our internal time control measurement of muscle size which remained stable across six weeks of training. It was noted that the EMG amplitude of the triceps was lower with HIGH LOAD training, even with that we would not have expected a decrease in muscle size from baseline. Thus, we are presently unable to explain this finding and follow up studies are needed to investigate this further.

Strength and Endurance

Following six weeks of training, the HIGH LOAD condition increased 1RM strength more than the NO LOAD condition. Contrary to our expectations, HIGH LOAD training also performed better in our test of endurance despite NO LOAD training completing more repetitions per training session. These differences may be explained by the principle of specificity. For example, the 1RM and endurance tests were completed using a dumbbell, which the NO LOAD condition was not accustomed to using. For the 1RM tests, previous research has repeatedly shown that conditions closely mimicking a specific test will perform better in that test (Mitchell, Churchward-Venne 2012; Ward & Fisk 1964; Yasuda et al. 2011).

To try and circumvent the subjective nature of the previous strength tests, we employed isokinetic and isometric dynamometry. We found that isokinetic strength at 180°$\cdot$sec^{-1} remained unchanged for both conditions, perhaps due to a slower training cadence used in the present study. Contrary to our hypothesis, isokinetic strength at 60°$\cdot$sec^{-1} increased following HIGH LOAD training but not NO LOAD training. This observation appears to support the findings from isotonic testing which suggests that the HIGH LOAD condition produces superior strength adaptations. Although we hypothesized that isokinetic dynamometry would be less specific to either condition, it may not be given that the NO LOAD condition is never pulling against an external load during the training sessions. In fact, subjective observations suggested that many in the NO LOAD condition did not appear to maximally contract their bicep until the top portion of the movement. This may provide explanation for the similar increase in both conditions for isometric torque measured at 90^{o} seen in both conditions. Taken together, repeated practice of the movement provided better testing results in the trained action (Pipes & Wilmore 1975; Symons et al. 2005) and that strength and performance tests results appear to be subjective and highly dependent on the test used. Despite the test selection, the NO LOAD condition still appeared to increase strength in some of the measures, albeit to a lesser degree overall compared to the HIGH LOAD condition.

Acute Measurements

The acute changes of NO LOAD and HIGH LOAD exercise were of interest given that these indirect markers have been associated with muscle growth in previous studies. For example, Yasuda et al. (Yasuda, Loenneke 2012) suggested that the combination of acute muscle swelling with high levels of muscle activation might be important for muscle growth. We found high levels of EMG amplitude and similar increases in acute muscle swelling for both the NO LOAD and HIGH LOAD conditions. Furthermore, both the acute decrease in torque as a marker of fatigue (Loenneke et al. 2015), and increases in muscle activation (Rudroff et al. 2008) have been used as potential indicators of whether an exercise will produce skeletal muscle growth. Although one should use great caution when extrapolating an acute effect into a chronic change, similar acute changes in torque and EMG amplitude have been shown to produce similar muscular changes (Counts et al. 2016). The current study found similar acute decreases in torque between conditions. The similar acute responses between conditions and the similar muscle growth provides further support that these indirect markers may be associated with long term muscle adaptation.

Limitations

This study is not without limitations. First, this study was completed using an untrained population and these findings do not necessarily reflect what would happen in those who were already resistance trained. Second, we were not able to quantify the volume of work completed in the NO LOAD condition, but both conditions showed similar increases in muscle thickness. Our inability to quantify volume may explain some of the variability in the growth response following NO LOAD training (Figure 3). Third, our strength and endurance tests were more specific to the HIGH LOAD condition and less specific to the NO LOAD condition. Thus, it stands to reason that NO LOAD training's effect on strength may be underestimated. Another potential limitation could be the cross education of strength from one limb to the other. We do not believe this to be the case, as it has been noted previously that the cross education effect is minimal or nonexistent when both limbs are trained with different protocols (Mitchell, Churchward-Venne 2012). Additionally, our estimate of muscle growth was assessed via changes in muscle thickness, not the gold standard estimate from magnetic resonance imaging. However, previous studies indicate a strong relationship between ultrasound estimates and more sophisticated measures (Dupont et al. 2001; Kawakami et al. 1993; Koskelo et al. 1991). Additionally, we used surface EMG and did not directly measure muscle activation produced between the NO LOAD and HIGH Load condition. Lastly, these findings are limited to the elbow flexors and do not necessarily apply to other muscle groups or muscle actions requiring multi joint movements.

Conclusion

This study showed that contracting a muscle without an external load produced sufficient muscle activation to induce muscle growth to a similar degree as that of HIGH LOAD training. These results extend previous studies that have observed muscle growth across a range of external loads and muscle actions and suggest that robust muscle growth can occur independent of an external load provided a large portion of the muscle is activated and placed under tension. However, overall changes in strength and endurance appeared to be greater in the HIGH LOAD condition, in part due to the subjective and specific nature of the tests we employed. Future studies should further investigate NO LOAD training as well as explore additional methods to augment muscle growth, possibly with the addition of blood flow restriction, or in a different population prone to muscle atrophy.

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The authors declare no conflict of interests.

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Figure Legends

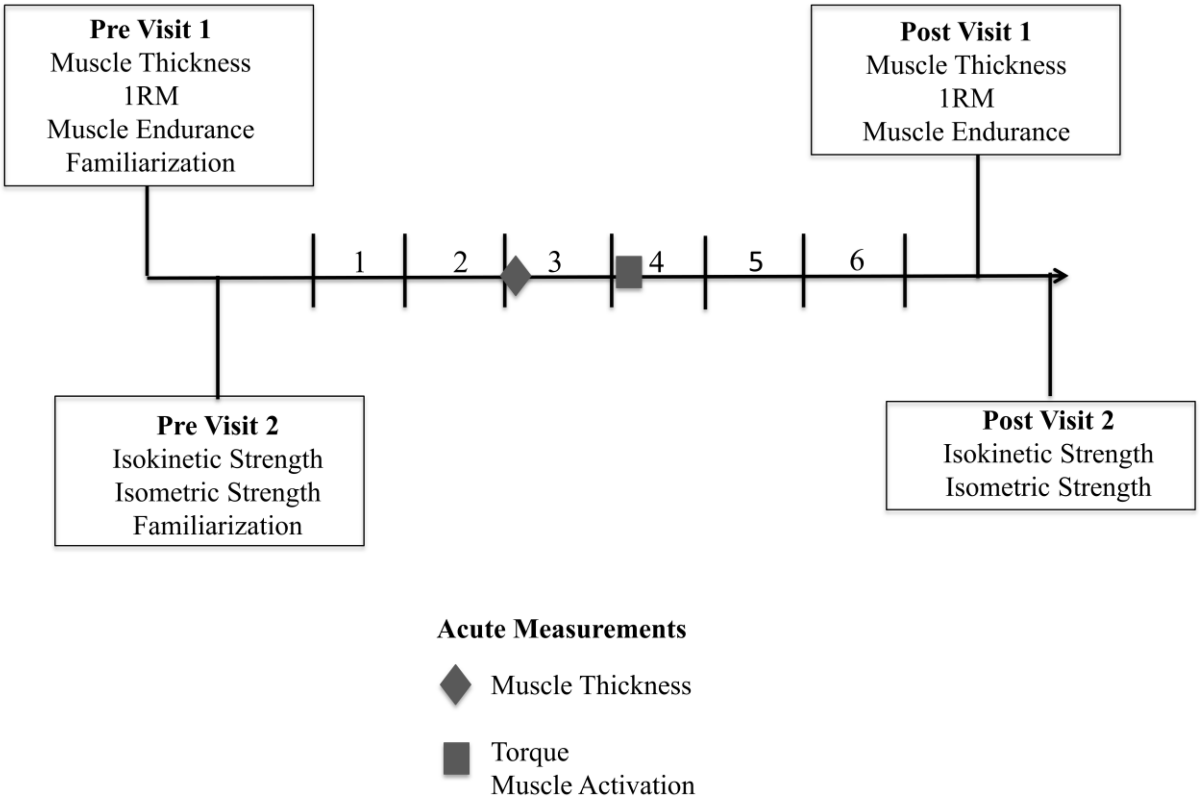
Figure 1. Study design outline. 1RM – one repetition maximum.

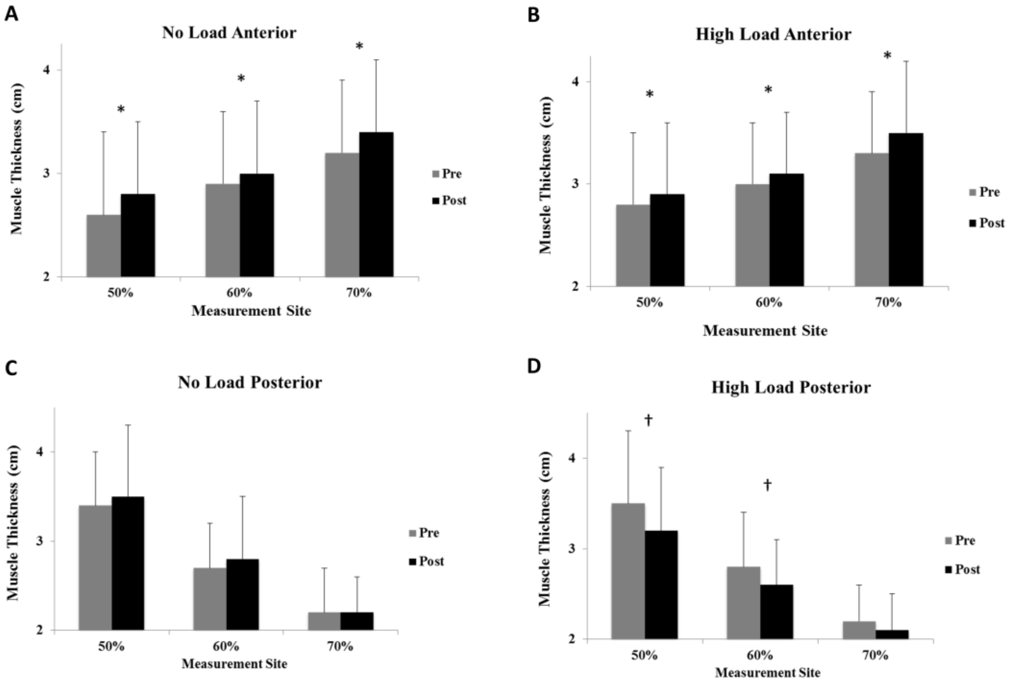
Figure 2. Mean muscle thickness from pre to post training at 50%, 60% 70% sites of the anterior and posterior upper arm. Main effect of time occurred for NO LOAD (A) and HIGH LOAD (B) conditions at all anterior upper arm sites denoted by *. Posterior upper arm muscle thickness remained unchanged with NO LOAD training (C), but decreased in HIGH LOAD (D) at the 50% and 60% sites denoted by †. Variability represented by standard deviations.

Figure 3. Individual plots of anterior upper arm muscle thickness at all sites for pre to post training.

Figure 4. Individual plots of posterior upper arm muscle thickness at all sites for pre to post training.

Figure 1 Displays the Study Design.




A
No Load Anterior
Muscle Thickness (cm)
2
3
4
*
*
*
50%
60%
70%
Measurement Site
■ Pre
■ Post
B
High Load Anterior
Muscle Thickness (cm)
2
3
4
*
*
*
50%
60%
70%
Measurement Site
■ Pre
■ Post
C
No Load Posterior
Muscle Thickness (cm)
2
3
4
50%
60%
70%
Measurement Site
■ Pre
■ Post
D
High Load Posterior
Muscle Thickness (cm)
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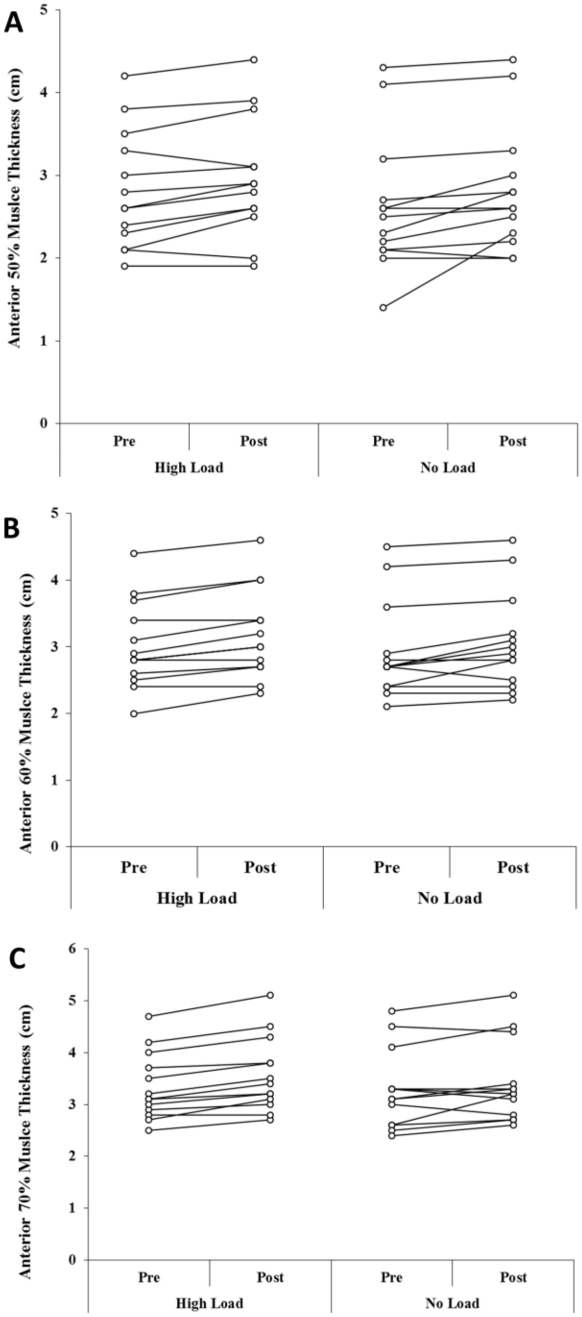
60%
70%
Measurement Site
■ Pre
■ Post


A
Anterior 50% Muslce Thickness (cm)
5
4
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1
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Pre
Post
High Load
No Load
B
Anterior 60% Muslce Thickness (cm)
5
4
3
2
1
0
Pre
Post
Pre
Post
High Load
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Anterior 70% Muslce Thickness (cm)
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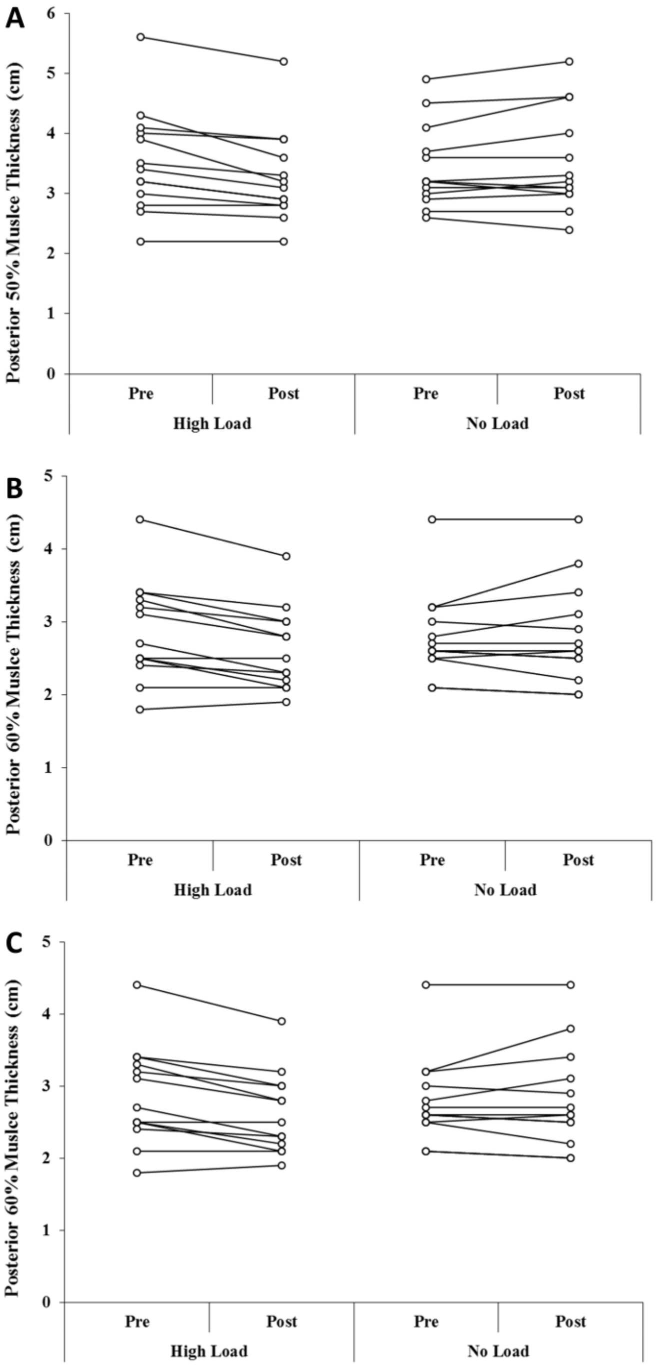
A
Posterior 50% Muslce Thickness (cm)
0
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2
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B
Posterior 60% Muslce Thickness (cm)
0
1
2
3
4
5
Pre
Post
Pre
Post
High Load
No Load
C
Posterior 60% Muslce Thickness (cm)
0
1
2
3
4
5
Pre
Post
Pre
Post
High Load
No Load

Table 1. Ratings of Perceived Exertion (RPE) and discomfort across the 25th, 50th, and 75th percentiles. * denotes a significant difference between conditions at a specific time point.

		Training Sessions 1-9			**Training Sessions 10-18**		
	RPE	**25th**	**50th**	**75th**	**25th**	**50th**	**75th**
Pre	NO LOAD	6	6	6	6	6	6
	HIGH LOAD	6	6	6	6	6	6
Set 1	NO LOAD	9	11*	15.5	8	11*	14.5
	HIGH LOAD	8	10	13.5	8	10	13.5
Set 2	NO LOAD	11.5	13	17	10.5	13	15.5
	HIGH LOAD	12	12	14.5	10.5	12	14
Set 3	NO LOAD	13	14	17.5	12	15	17
	HIGH LOAD	13	14	17	11.5	14	16
Set 4	NO LOAD	14.5	16	18	13	15	17.5
	HIGH LOAD	13.5	15	17.5	14	15	17
	Discomfort	**25th**	**50th**	**75th**	**25th**	**50th**	**75th**
Pre	NO LOAD	0	0	0	0	0	0
	HIGH LOAD	0	0	0	0	0	0
Set 1	NO LOAD	0.3	0.5*	1	0	0.7	1
	HIGH LOAD	0	0.5	0.7	0	0.5	1
Set 2	NO LOAD	0.4	1.5	2	0.1	1	2
	HIGH LOAD	0.4	1	2	0.1	0.7	1.7
Set 3	NO LOAD	0.5	2	3	0.2	2	3
	HIGH LOAD	0.6	1.5	2.5	0.3	1	3
Set 4	NO LOAD	0.6	2.5	3.5	0.5	1.5	3.5
	HIGH LOAD	0.7	2	3	0.5	2	3.2

Table 2: Average EMG amplitude of the Biceps Brachii and Triceps Brachii during the acute testing session. Variability represented by standard deviations (SD). Conditions with different levels represent significant differences between conditions ($p \leq 0.05$)

	EMG Amplitude of First 3 reps (% MVC)			
Biceps Brachii	**Set 1**	**Set 2**	**Set 3**	**Set 4**
NO LOAD	53 (26)	55 (27)	55 (29)	56 (26)
HIGH LOAD	67 (28)	65 (32)	71 (23)	73 (27)
Triceps Brachii				
NO LOAD[a]	34 (11)	35 (17)	31 (12)	34 (12)
HIGH LOAD[b]	10 (3)	9 (3)	10 (3)	10 (2)
	EMG Amplitude of Last 3 reps (%MVC)			
Biceps Brachii	**Set 1**	**Set 2**	**Set 3**	**Set 4**
NO LOAD[a]	55 (32)	53 (26)	52 (25)	49 (20)
HIGH LOAD[b]	85 (37)	89 (38)	85 (23)	88 (25)
Triceps Brachii				
NO LOAD[a]	33 (15)	30 (15)	31 (17)	31 (15)
HIGH LOAD[b]	12 (4)	12 (3)	13 (4)	13 (3)

1. Contracting a muscle through the full range of motion with no external load increases muscle size comparable to that of high load training.

2. High load training produced larger increases in 1RM strength and muscle endurance compared to contracting through the full range of motion with no external load.

3. Muscle growth can occur independent of the external load provided sufficient tension is produced by the muscle; however, strength is proportional to the load being used and the modality of exercise being performed.