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# Upper body muscle activation during low- versus high-load resistance exercise in the bench press

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**Abstract.**
**OBJECTIVE:** The purpose of this study was to compare activation of the upper body musculature during the barbell bench press at varying training intensities.
**METHODS:** Twelve young, resistance-trained men performed sets of the bench press to momentary muscular failure with two different loads: a high-load (HIGH) set at 80% of 1RM and a low-load (LOW) set at 50% 1RM. Exercise order was counterbalanced so that half the subjects performed the LOW condition first and the other half performed the HIGH first. Surface electromyography (EMG) was used to assess mean, peak, and iEMG muscle activation of the anterior deltoid, triceps brachii, and sternal and clavicular heads of the pectoralis major.
**RESULTS:** The main effects for trials were significant for mean EMG ($p < 0.001$) and iEMG matched ($p < 0.001$) favoring HIGH and iEMG total favoring LOW ($p = 0.001$) across all muscle groups in both conditions with varying effect sizes. All other main effects and interactions were not statistically significant.
**CONCLUSION:** Despite similarities in peak EMG amplitude, the greater results for mean and iEMG matched in HIGH suggests that heavier loads may produce greater muscle activation.

Keywords: Size principle, low-load, light weights, muscle hypertrophy, training intensity

## 1. Introduction

A prevailing body of research has established that muscle fiber recruitment follows the size principle. First elucidated by Henneman [1], the size principle dictates that the capacity for a motor unit (MU) to produce force is directly related to its size. Accordingly, the smallest MUs are recruited first in a given movement, followed by larger MUs as force production requirements increase. This orderly activation pattern allows for a smooth gradation of force, irrespective of the activity performed.

It has been postulated that heavy loads are required to recruit the full spectrum of MUs in a given motor pool [2]. Since high force output is needed to lift heavy loads, both lower and higher threshold MUs are necessarily recruited during such lifts to meet force de-

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mands. Conversely, force production requirements are low when lifting light loads and thus fewer MUs are needed to carry out these movements. Although this rationale has validity when performing isolated muscle actions, it does not account for the effects of fatigue on MU recruitment during activities requiring repeated muscular efforts. Research has shown a corresponding increase in electromyographic (EMG) amplitude during fatiguing contractions, ostensibly stemming from an increased contribution of higher threshold MUs recruited to maintain force output [3]. Several researchers have therefore posited that training to the point of concentric muscular failure, regardless of the magnitude of load, will ultimately cause the recruitment of the full spectrum of available MUs [4,5]. In spite of this physiological rationale, there is evidence that there may be a minimum loading threshold to achieve maximal EMG activity [6,7].

To date, only a few studies have investigated muscle activation during performance of dynamic resistive exercise using low- versus high-loads when carried out to muscular failure. Cook et al. [8] found that performing knee extensions at 70% of one repetition maximum (1RM) produced significantly greater EMG amplitude of the quadriceps femoris compared to 20% 1RM despite similar decrements in torque. Similarly, Akima et al. [9] reported greater normalized EMG amplitude of the quadriceps femoris during knee extensions performed at 70% 1RM versus 50% 1RM. Both of these studies employed single-joint exercise and participants were untrained, which may limit the ability to maximally exert force. Recently, our lab investigated quadriceps and hamstrings activation in well-trained men while performing the leg press during high- versus low-load conditions [7]. Employing a within-subject design, subjects carried out repetitions to failure at 75% 1RM and 30% 1RM separated by a 15-minute rest period in counterbalanced fashion. Results showed significantly greater mean and peak muscle activation during the heavy load condition (by 57% and 29%, respectively). Taken together, these findings suggest that loads greater than 50% 1RM are required to maximize muscle activation when performing either single- or multi-joint lower body resistive exercise regardless of training experience.

Relatively few studies have investigated muscle activation when performing dynamic upper body resistance training at different loading intensities. Keogh et al. [10] recruited 12 young experienced lifters to perform the bench press using a variety of training methods including conditions with intensities of 55% and 85% 1RM to failure. Results showed that mean concentric EMG activity of the pectoralis major was significantly higher during the heavy load condition by $\sim$18%, 19%, and 12%, for the first, middle, and last repetition, respectively. The disparity was even greater for heavy loading during eccentric actions, with significantly greater mean EMG activity of 32%, 36%, and 36% reported in the first, middle and last repetition, respectively. However, the generalizability of results are limited by the fact that the light lifting condition employed a volitionally slow velocity (5 seconds for both concentric and eccentric actions) while the heavy loading condition performed repetitions with the intent to lift the weight as fast as possible. Findings therefore cannot necessarily be extrapolated to traditional resistance training tempos as the contribution of differing tempo or intensity to the observed results cannot be ascertained. The purpose of this study was to compare mean and peak EMG amplitude of the upper body musculature at high- and low-load conditions during performance of the barbell bench press while strictly controlling for other variables. We hypothesized that the heavier load condition would result in greater muscle activation compared to the lighter load condition.

## 2. Materials and methods

### 2.1. Subjects

Twelve young men (height: 175.6 ± 6.6 cm; mass: 77.0 ± 7.1 kg; age: 22.2 ± 2.0 years) with 3.4 ± 2.8 years resistance training experience were recruited from a university population to participate in this study. All subjects were experienced with resistance training, defined as lifting weights for a minimum of two days per week for one year or more, and all stated they regularly performed the bench press. Inclusion criteria required that subjects could read and speak English and pass a physical activity readiness questionnaire (PAR-Q). Those receiving care for any upper body musculoskeletal disorder at the time of the study or those with an amputation of an upper extremity limb were excluded from participation. Each subject provided written informed consent prior to participation. The research protocol was approved by the institutional review board at Lehman College, Bronx, NY. The study conforms to the Code of Ethics of the World Medical Association (Declaration of Helsinki).

### 2.2. 1RM testing

Prior to EMG analysis, 1RM testing was carried out using a free weight barbell bench press. Subjects reported to the lab having refrained from any upper body exercise other than activities of daily living for at least 48 hours prior to testing. Repetition maximum testing was consistent with recognized guidelines as established by the National Strength and Conditioning Association. 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 five repetitions was performed at $\sim$50% 1RM followed by one to two sets of two to three repetitions at a load corresponding to $\sim$60–80% 1RM. Subjects then performed sets of one repetition of increasing weight for 1RM determination. Three to five minutes of rest was provided between each successive attempt. All 1RM determinations were made within five attempts. Successful 1RM bench press 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. All testing sessions were supervised by two fitness professionals to achieve a consensus for success on each attempt. The test-retest ICC from our lab for the 1RMBP was 0.91. The average 1RM for the bench press for all subjects was 101.4 ± 18.3 kg.

### 2.3. Procedure

At least 48 hours after 1RM testing, EMG analysis was conducted on each participant. Subjects were prepared by lightly shaving and then wiping the skin with an alcohol swab in the desired areas of electrode attachment to ensure stable electrode contact and low skin impedance. After preparation, self-adhesive disposable silver/silver chloride pre-gelled dual snap surface bipolar electrodes (Noraxon Product #272, Noraxon USA Inc, Scottsdale, AZ) with a diameter of 1 cm. and an inter-electrode distance of 2 cm. was attached parallel to the fiber direction of the following muscles: pectoralis major sternal head, pectoralis major clavicular head, anterior deltoid, and triceps brachii. Electrode placement was made on the right side of each subject. A neutral reference electrode was placed over the cervical spine. These methods are consistent with the recommendations of SENIAM (Surface EMG for Non Invasive Assessment of Muscles) [11]. After all electrodes were secured, a quality check was performed to ensure EMG signal validity.

### 2.4. Instrumentation

Raw EMG signals were collected at 2000 Hz by a Myotrace 400 EMG unit (Noraxon USA Inc, Scottsdale, AZ), and filtered by an eighth order Butterworth bandpass filter with cutoffs of 20–500 Hz. Data was sent in real time to a computer via Bluetooth and recorded and analyzed by MyoResearch XP Clinical Applications and MyoResearch 3 software (Noraxon USA, Inc., Scottsdale, AZ). Signals were rectified and smoothed (by root mean square [RMS] algorithm with a 100 ms window) in real time.

### 2.5. Maximal voluntary isometric contraction

Maximal voluntary isometric contraction (MVIC) data was obtained for the desired muscles by performing a resisted isometric contraction as outlined by Hislop and Montgomery [12]. After an initial warm up consisting of five minutes of light cardiovascular exercise and slow dynamic stretching in all three cardinal planes, testing was carried out as follows: For the horizontal adductors, subjects lied supine on a floor mat with the shoulder abducted to 90 degrees and the arm flexed to 90°. Resistance was applied at the forearm just proximal to the wrist. Subjects were instructed to horizontally adduct the shoulder by slowly increasing the force of the contraction so as to reach a maximum effort after approximately three seconds. Subjects then held the maximal contraction against resistance for three seconds before slowly reducing force over a final period of three seconds. The same process was repeated for seated elbow extension. Subjects sat upright with the arm elevated to 90° of frontal plane abduction and the elbow flexed to 90-degrees. The highest MVIC EMG value was used as the reference for normalizing the EMG signals. Mean amplitude (the average amplitude across each set) and peak amplitude (the highest value found in each set) were reported as a percentage of MVIC. Integrated EMG (iEMG), the total myoelectrical activity across each set, was expressed in $\mu$V·sec.

### 2.6. Exercise description

Five minutes after MVIC testing, subjects performed the bench press with two different loads: a high-load (HIGH) set at 80% of 1RM and a low-load (LOW) set at 50% 1RM. The order of performance of the exercises was counterbalanced between participants so that half the subjects performed the LOW condition first and the other half performed the HIGH con-

Table 1
Main effects

| Dependent variables | 80% 1RM | | | 50% 1RM | | |
|---|---|---|---|---|---|---|
| | M | SD | n | M | SD | n |
| Mean EMG* | 113.74 | 38.02 | 47 | 97.86 | 43.11 | 47 |
| Peak EMG | 284.51 | 114.16 | 47 | 275.91 | 148.15 | 47 |
| iEMG matched ($\mu$V·sec)* | 13,471.27 | 8,588.37 | 48 | 8,867.56 | 5,372.27 | 48 |
| iEMG total ($\mu$V·sec)* | 13,471.27 | 8,588.37 | 48 | 17,178.69 | 10,441.45 | 48 |
| Repetitions* | 10.08 | 2.19 | 12 | 26.83 | 4.24 | 12 |

*$p < 0.01$.

dition first. Fifteen minutes of rest was provided between exercise bouts to ensure that fatigue did not confound results. A metronome was used to maintain a cadence of one second on both concentric and eccentric repetitions in the early phase of each condition. As fatigue began to set in, the velocity of repetitions naturally began to slow on the concentric actions. Sets were carried out to the point of momentary muscular failure (the inability to perform another concentric action with proper form regardless of the ability to maintain the set tempo). Technique instruction and verbal encouragement were provided to each subject before and during performance by the primary investigator who is a certified strength and conditioning specialist to ensure that exercise was carried out in the prescribed manner.

### 2.7. Statistical analysis

Statistical analysis was carried out using SPSS statistical software (version 22.0; IBM Corporation, New York, NY). Given that the onset of fatigue causes an increase in EMG amplitude, we matched analysis of the number of repetitions achieved in HIGH with an equal number of repetitions achieved at the end of the LOW tracing. Thus, if 8 repetitions were performed in HIGH for a given subject, the final 8 repetitions of the LOW condition were analyzed. This provides more of an "apples-to-apples" comparison and helps to avoid negatively biasing the LOW condition. The mean, peak, and iEMG matched values were assessed from this matched data. In addition, the iEMG total values were determined from the entire set of repetitions performed in each respective condition.

Four separate two-way ANOVAs (4 muscles × 2 trials) with repeated measures on the latter factor were used to compare peak EMG, mean EMG, iEMG matched, and iEMG total on the selected muscles. The two trials referred to the HIGH (80% 1RM) and LOW (50% 1RM) conditions. The sternal pectoral head, clavicular pectoral head, anterior deltoid, and triceps muscles were assessed. A dependent t-test was used to compare the number of repetitions performed in the high-load and low-load exercise sets. Cohen's d effect size ($d'$) and observed power statistics were computed for significant main effects. Statistical analyses were performed using IBM SPSS statistics software 22 (IBM Corp., Armonk, NY). Results were considered significant at $\alpha \leqslant 0.05$.

Table 2
Mean EMG amplitude across muscles between conditions

| Muscle | 80% | 50% | ES |
|---|---|---|---|
| Sternal head | 121 ± 33 | 103 ± 39 | +0.50 |
| Clavicular head | 127 ± 45 | 117 ± 53 | +0.20 |
| Anterior deltoid | 115 ± 39 | 105 ± 44 | +0.24 |
| Triceps brachii | 94 ± 30 | 69 ± 23 | +0.94 |

Mean and peak values expressed as percent MVIC; iEMG values expressed in $\mu$V·sec. For ES, a + indicates magnitude favors HIGH while a – indicates magnitude favors LOW.

## 3. Results

### 3.1. Main effects and interactions

The main effects for trials were significant for mean EMG ($F_{1,43} = 24.33$; $p < 0.001$; $d' = 0.39$; $1 - \beta = 0.998$; Table 1), iEMG matched ($F_{1,43} = 30.74$; $p < 0.001$; $d' = 0.67$; $1 - \beta = 1.00$), and iEMG total ($F_{1,43} = 13.64$; $p = 0.001$; $d' = 0.34$; $1 - \beta = 0.951$) between HIGH and LOW conditions. All other main effects and interactions were not statistically significant. Table 1 displays summary data.

### 3.2. Mean amplitude across muscles between conditions

With respect to mean amplitude, a strong effect was seen in HIGH compared to LOW for the pectoralis major sternal head (121 ± 33 vs. 103 ± 39%, respectively; $d' = 0.50$) and triceps brachii (94 ± 30 vs. 69 ± 23%, respectively; $p < 0.001$; $d' = 0.94$). Weak effects were noted in the clavicular head of the pectoralis major and anterior deltoid favoring the HIGH condition (Table 2).

Table 3
Peak EMG amplitude across muscles between conditions

| Muscle | 80% | 50% | ES |
|---|---|---|---|
| Sternal head | 308 ± 121 | 305 ± 179 | +0.02 |
| Clavicular head | 321 ± 121 | 329 ± 167 | −0.05 |
| Anterior deltoid | 275 ± 102 | 272 ± 128 | +0.03 |
| Triceps brachii | 237 ± 109 | 202 ± 91 | +0.35 |

Mean and peak values expressed as percent MVIC; iEMG values expressed in $\mu$V·sec. For ES, a + indicates magnitude favors HIGH while a – indicates magnitude favors LOW.

Table 4
iEMG Matched across muscles between conditions

| Muscle | 80% | 50% | ES |
|---|---|---|---|
| Sternal head | 9465 ± 5577 | 6388 ± 3323 | +0.67 |
| Clavicular head | 15845 ± 11133 | 9534 ± 6877 | +0.68 |
| Anterior deltoid | 15141 ± 8082 | 11346 ± 5406 | +0.55 |
| Triceps brachii | 13434 ± 8252 | 8202 ± 4624 | +0.78 |

Mean and peak values expressed as percent MVIC; iEMG values expressed in $\mu$V·sec. For ES, a + indicates magnitude favors HIGH while a – indicates magnitude favors LOW.

### *3.3. Peak amplitude across muscles between conditions*

With respect to peak amplitude, a moderate effect was noted for HIGH versus LOW for the triceps brachii (237 ± 109 vs. 202 ± 91%, respectively; $d' = 0.35$). All other muscles displayed a trivial effect for this outcome measure (Table 3).

### *3.4. iEMG matched across muscles between conditions*

With respect to the iEMG matched, a strong effect was seen for all muscles in HIGH compared to LOW conditions (Table 4). The triceps brachii displayed the largest effect (13434 ± 8252 vs. 8202 ± 4624 $\mu$V·sec, respectively; $d' = 0.78$), followed by the pectoralis major clavicular head (15845 ± 11133 vs. 9534 ± 6877 $\mu$V·sec, respectively; $p < 0.05$; $d' = 0.68$), pectoralis major sternal head ((9465 ± 5577 vs. 6388 ± 3323 $\mu$V·sec, respectively; $p < 0.01$; $d' = 0.67$), and anterior deltoid (15141 ± 8082 vs. 1346 ± 5406 $\mu$V·sec, respectively; $d'$: 0.55). (Table 4)

### *3.5. iEMG total across muscles between conditions*

With respect to iEMG total, a strong effect was noted for LOW versus HIGH in the sternal head of the pectoralis major (9465 ± 5577 vs. 6388 ± 3323 $\mu$V·sec, respectively; $p < 0.01$; $d' = 0.67$) and anterior deltoid (21714 ± 10430 vs. 15141 ± 8082 $\mu$V·sec, respectively; $p < 0.001$; $d' = 0.70$). Weak effects favoring LOW were seen in the pectoralis major clavicular head and triceps brachii in this outcome measure (Table 5).

Table 5
iEMG Total across muscles between conditions

| Muscle | 80% | 50% | ES |
|---|---|---|---|
| Sternal head | 9465 ± 5577 | 13116 ± 7513 | −0.55 |
| Clavicular head | 15845 ± 11133 | 17849 ± 11295 | −0.18 |
| Anterior deltoid | 15141 ± 8082 | 21714 ± 10430 | −0.70 |
| Triceps brachii | 13434 ± 8252 | 16035 ± 11431 | −0.26 |

Mean and peak values expressed as percent MVIC; iEMG values expressed in $\mu$V·sec. For ES, a + indicates magnitude favors HIGH while a – indicates magnitude favors LOW.

### *3.6. Number of repetitions*

Participants performed a significantly greater number of repetitions in LOW compared to HIGH (26.8 ± 4.2 vs. 10.1 ± 2.2, respectively; $p < 0.001$; ES: 4.98).

## 4. Discussion

To the authors' knowledge, this is the first study to directly compare and quantify dynamic upper body muscle activation during low- versus high-load resistance training to concentric failure while controlling for lifting tempo. The primary and novel finding of the study was that peak EMG amplitude was similar during both the LOW and HIGH conditions; however, both mean amplitude and iEMG-matched significantly favored heavier loading. Conversely, the LOW condition produced significantly greater iEMG over the complete set to concentric failure as compared to HIGH. In addition, these effects were not uniformly distributed across the muscle groups utilized to complete the multi-joint bench press exercise.

The lack of significant differences in peak amplitude between conditions indicates that training at 50% of 1RM in the bench press may achieve similar activation of the MU pool for a given instant as training at 80% of 1RM. These results are in contrast with previous work from our lab that showed markedly lower peak activation in 30% vs. 75% 1RM during performance of the leg press [7]. Thus, it can be speculated that 50% 1RM may achieve a threshold of loading sufficient to maximally activate the working muscle during dynamic actions. The possibility that a differential response between upper (bench press) and lower extremity exercises (leg press) between the present and past study cannot be excluded. Similarly, the existing literature base has shown greater peak EMG amplitudes with higher training intensities during the execution of single joint exercises [8,9], and it is possible that exercise type (single versus multi-joint) may also result in differing EMG responses to varying loading intensities.

Despite similarities in peak amplitude, the significantly greater results for mean and iEMG-matched in the HIGH condition suggests that heavier loads may produce higher sustained muscle activation, and therefore greater instantaneous MU recruitment at the cessation of a set to concentric failure. While training at both low and high intensities of load follows the size principle of motor unit recruitment, they elicit different temporal recruitment patterns. It is possible that even if MU recruitment is equivalent with respect to the total number and size of MUs recruited, the temporal activation of specific MUs could vary between the loading conditions based on their recruitment threshold. Low-load training to concentric failure results in a higher number of completed repetitions and greater time-under-load compared with high loads [13–15], and this stimulus may differentially affect MU recruitment of differing thresholds. Conversely, under high-load training, initial MU recruitment is greater due to the elevated force requirements of the task, requiring greater recruitment of high-threshold MUs. Therefore, simultaneous MU recruitment is greater initially under higher load conditions but progressive in nature (low to high) with low-load training [16]. At present, it is unknown whether the differing temporal activation patterns between the various MU sizes results in appreciable differences in the hypertrophic response of differing fiber types.

Alternatively, the significantly greater iEMG total activation favoring LOW could be interpreted to mean that the lighter load condition maintained stimulation of lower threshold MUs over time. It is also possible that with the accumulation of fatigue, the lowered recruitment threshold of higher threshold MU [17], along with the potential derecruitment of fatigued MUs [18] offset each other to a certain degree such that simultaneous MU activation was lower at any given point in time as compared to HIGH. Progressive recruitment of distinct MU populations has been observed with long-duration, submaximal isometric contractions, and such a strategy may also occur during dynamic actions [19]. This strategy allows for greater permutations whereby MU's can be recruited to produce sufficient force to complete the low-load task over extended times-under-load. Regardless, the lower threshold MUs would necessarily include the pool of type I fibers which, given their fatigue-resistant nature, might benefit from the greater time-under-load. Presently it is unknown what specific training parameters result in optimal growth of muscle fibers based on their phenotypic properties, however several lines of evidence indicate that there may be differential responses. It is unknown whether these observed results are related to the temporal relationships observed in the present study.

Another interesting aspect of the study was the finding that different loads had differential effects on activation of the individual working muscles. The greatest discrepancies between conditions were seen in triceps brachii, which displayed markedly higher EMG values in HIGH versus LOW with strong effects noted for mean and iEMG matched activation, and a moderate effect for peak amplitude. In fact, the triceps brachii was the only muscle that showed a meaningful effect in peak activation between conditions. In agreement, Sakamoto et al. [13] found greater EMG amplitudes for the triceps brachii when training at higher intensities of load during fatiguing repetitions of the bench press exercise at three different tempos. In addition, a reduced difference in EMG amplitude was noted in the anterior deltoid and pectoralis major with increasing fatigue, consistent with the lack of difference in peak EMG in the present dataset for these muscles. In contrast, Pinto et al. [20] found linear increases in EMG amplitude during isometric bench press performance at 60, 70, 80, and 90% of maximum voluntary isometric contraction for both the pectoralis major and the anterior deltoid. However, these isometric actions were not carried out to muscular failure, limiting generalizability to the current study.

Of the remaining muscle groups, the sternal and clavicular heads of the pectoralis major and anterior deltoid had greater iEMG matched values, whereas only the sternal head of pectoralis major also had greater mean EMG matched, all favoring HIGH. Conversely, the LOW condition demonstrated greater iEMG total for the three muscle segments. Given the progressive increase in EMG with increasing fatigue, that the allowable reduction in force prior to task failure has a much larger margin in low versus high-load training [13], and the greater time component, it is understandable that total iEMG is maximized with low load training.

Although the potential implications of our findings are intriguing, one must be wary when extrapolating results of surface EMG to MU recruitment. While surface EMG amplitude is sensitive to the number of recruited MUs in general, it cannot provide precise determination of the number of active MUs at a given point in time, as EMG is reflective of both neural and peripheral factors [21,22]. Therefore, is not yet possible to discern MU recruitment from increases in EMG amplitude in fatiguing, dynamic conditions [21–24]. During a sustained, fatiguing contraction, the recruitment threshold of high threshold MUs is reduced [17], and the ensuing recruitment of these MUs facilitates continued force production. The concept of MU derecruitment suggests that during prolonged contractions, fatigued MUs may also cease firing, at least momentarily, as a strategy to reduce fatigue [18]. Therefore, it is plausible that at any given point in time, simultaneous MU activation may be lower in low-load training as compared to high-load training; however, a comparable complement, or number, of MUs may be recruited despite reduced peak and mean EMG amplitudes during low-load training, and ultimately greater numbers of MUs are recruited at the completion of the set than at initiation [25]. However, notwithstanding the peripheral constituents of EMG amplitude, as noted by Farina et al. [26], the neural indices of EMG amplitude are largely dependent upon the recruitment of high threshold MUs. Therefore, should the reported increases in EMG have neural origins, it is likely that these increases were due to the sequential recruitment of higher threshold MUs. In other words, it cannot be said for certain that the observed increases in EMG amplitude are strictly due to MU recruitment, but if the increases have neural origins, they are likely due to MU recruitment.

## 5. Conclusions

Based on our findings, it is plausible to conclude that HIGH and LOW loads may confer unique advantages related to the temporal dynamics of MU activation, and therefore that a variety of loading intensities are required to maximize the hypertrophic response to resistance training. Recent research suggests that low-loads can produce comparable hypertrophy to high-loads [27,28], and therefore personal preference, in addition to consideration of orthopedic factors (joint forces) and injuries, may be predominate factors in the determination of appropriate loading strategies. It should be noted that our findings are specific to single set protocols; whether these findings apply to protocols involving multiple sets remains undetermined.

Nevertheless, if peak EMG amplitude is indicative of complete MU activation, low-load training can seemingly achieve comparable levels of activation with reduced force production required, albeit with extended time-under-load. It is possible that the differing activation profiles in the present study may relate to differential effects on muscle fiber-types, such that maximal muscle growth may require the use of multiple intensities of load. Strictly speaking, these data provide mechanistic insight for the existence of differential neuromuscular stimuli, which eventually lead to similar hypertrophy. Because this work is cross-sectional and mechanistic in nature, extrapolating training and clinical applications from these data alone may be considered presumptuous; therefore, these data, in addition to previously published training studies, suggest that differential neuromuscular recruitment strategies are at play in loading schemes that yield similar hypertrophy, but the effects of taking advantage of these differential neuromuscular recruitment strategies are unclear, Therefore, future studies comparing the effects of exclusively high and low-load training against a mixed intensity program are required to address this hypothesis.

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## Conflict of interest

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