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The Effects of 4 and 10 Repetition Maximum Weight-Training Protocols on Neuromuscular Adaptations in Untrained Men

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ABSTRACT

The purpose of this study was to identify and compare the strength, cross-sectional area, specific tension, and anthropometric changes elicited by 4 repetition maximum (RM) and 10RM weight-training protocols in untrained subjects. Twenty-four men (24.17 ± 1.76 years) volunteered to participate and were randomly assigned to either the 4RM group or the 10RM group. Training was performed 3 times per week for 10 weeks; free weights were used to exercise the forearm extensors and flexors. The 4RM group performed 6 sets of 4 repetitions to failure and the 10RM group performed 3 sets of 10 repetitions to failure. Strength (1RM) was measured at 0, 6, and 10 weeks, and muscle cross-sectional area (determined through magnetic resonance imagery), specific tension (kilograms per square centimeter), and relaxed- and flexed-arm girth (corrected for skinfolds) were measured at 0 and 10 weeks. Significant ($p < 0.05$) increases in both forearm extensor and flexor 1RM strength, muscle cross-sectional area, specific tension, and flexed-arm girth occurred in both groups. The 4RM and 10RM loading intensities elicited significant and equal increases in strength, cross-sectional area, specific tension, and flexed girth. These results suggest that 4RM and 10RM weight-training protocols equated for volume produce similar neuromuscular adaptations over 10 weeks in previously untrained subjects.

Key words: strength training, hypertrophy, neural adaptation

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Introduction

The neuromuscular adaptations to resistance training include muscle hypertrophy and increased neural activation, both of which are associated with increases in muscular strength (9, 13, 14, 18, 25). Muscle hypertrophy is the result of an increase in the cross-sectional area (CSA) of individual muscle fibers and a concomitant increase in whole-muscle CSA (4, 10). It has been proposed that increased neural activation is the result of greater recruitment of motor units, quicker firing frequency of the motor units, and improved synchronization of motor unit firing (18). It has also been suggested that there is a decrease in inhibitory or protective neural mechanisms (18, 26).

Increases in strength have been found without a corresponding increase in muscle CSA and have been attributed to neural adaptations (8, 14, 15). Neural adaptations occur in the form of increased integrated electromyographic (iEMG) activity or increased force generated per unit of muscle (specific tension) (7). The greater specific tension of power lifters (compared with that of endurance athletes) has also been proposed in support of neural adaptation (7). Häkkinen (8) found that elite power lifters using loading intensities of 1–3 repetition maximums (RM) demonstrated increases in strength and iEMG activity without significant changes in CSA. A loading intensity of approximately 10RM did not increase strength or iEMG activity. Consequently, it has been recommended that resistance-training programs consisting of relatively high loads (85–90% of 1RM) and few repetitions (that is, 1–4 repetitions) are effective in increasing strength without concomitant increases in CSA (21).

Significant improvements in strength have resulted from significant increases in muscle fiber or whole-muscle CSA (5, 11, 15). The greater CSA of muscle found in strength-trained individuals (compared with CSA of muscle in untrained individuals) has also been proposed as evidence of a hypertrophic response to resistance training (10). As a result of these and other studies, training programs consisting of moderate loads (70–75% of 1RM) and a moderate number of repetitions (that is, 10–12 repetitions) have been recommended to maximize muscle CSA or hypertrophy (20, 24).

However, there has not been any direct attempt to compare the recommended training protocols with regard to the specific hypertrophic and neural adaptations. In addition, studies that have compared different loading intensities have generally not equated for differences in training volume. Consequently, the purpose of this study was to compare the effects of 2 training protocols designed to elicit either a hypertrophic response (10RM) or neural adaptation (4RM) and equated for relative training volume, on muscular strength, CSA, specific tension, and muscle circumference.

Methods

Subjects

Twenty-four men aged 24.2 ± 1.76 years and weighing 80.4 ± 13.9 kg completed the study. Five subjects served as controls, and the remaining 19 subjects were randomly assigned to a high-intensity strength-training group (4RM; $n = 10$) or a medium-intensity hypertrophy-training group (10RM; $n = 9$). All subjects were informed of the testing and training protocols, which were approved by the University of Victoria Ethics Committee, and signed the consent form for participation. Subjects were familiar with strength training but had not followed a regimented weight-training program or participated in weight training for at least 1 year. They were required to refrain from any other form of training during the study.

Resistance Training

Training was performed 3 times per week for 10 weeks, with at least 48 hours between sessions. Core exercises consisted of triceps bench press, triceps pulley press-downs, standing biceps barbell curls, and standing simultaneous dumbbell curls. Supplemental exercises were added for other major upper-body muscle groups and included bench press, bench pulls, and shoulder press. The 4RM group performed 6 sets of 4 repetitions (~85% of 1RM) to failure for the core exercises and 2 sets to failure for the supplemental exercises (also ~85% of 1RM). The 10RM group performed 3 sets of 10 repetitions (~ 70% of 1RM) to failure for the core exercises and 1 set for the supplemental exercises (~70% of 1RM). The initial loads were established as a percentage of 1RM and subsequently adjusted to produce either 4RM or 10RM, according to the training group. Both training groups were therefore approximately equated for relative training volume (repetitions × sets × percentage of 1RM, as calculated by O'Hagan et al. [16]). There were 3-minute and 2-minute rest periods between sets for the 4RM and 10RM groups, respectively. The training loads were monitored and increased when necessary to produce failure at the desired number of repetitions. The control group refrained from training during the study.

Strength Testing

Strength was measured as 1RM for the tricep bench press and the standing bicep curl. Prior to testing, subjects warmed up by completing 1 set of 15 repetitions at approximately 25RM, 1 set of 10 repetitions at approximately 15RM, and 1 set of 5 repetitions at approximately 10RM. There were 4-minute rest periods between the warm-up and testing sets. 1RM values were determined by having subjects attempt successive lifts of single repetitions with increasing load. When the maximum value had been reached, the load was taken to a beam scale and weighed. The tricep bench press was performed with the subject lying on the bench, keeping head, shoulders, and buttocks in contact with the bench and feet flat on the floor. Initially, the curling bar was held apart the distance between the nipples, resting on the subject's chest at nipple level. The bar was then pressed to a position in which the elbows were locked. The barbell curl testing was performed with the subject standing with shoulders and buttocks against a wall, knees slightly flexed, and feet shoulder-width apart. With the bar resting on the thighs, the arms fully extended, and hands held shoulder-width apart, the bar was lifted to full flexion of the elbows. Strength was measured at the beginning of the first week, the end of week 6, and the end of week 10. The loads at training repetitions, either 4RM or 10RM, were also recorded at the pre-, mid-, and posttraining periods. At the end of a training session, the loads used for the tricep bench press and the barbell curl test were weighed on a beam scale. Subsequently, the increases in the load from pre- to midtraining and mid- to posttraining were calculated as percentage of change and used as additional dependent measures.

Muscle CSA

Muscle CSA was measured by magnetic resonance imaging (MRI; Siemens Magnetom 1.5 T). Repetition time and echo time were set at 200 and 20 ms, respectively, and slice thickness was set at 10 mm. All scans and measurements were of the right arm. Coronal scans were used to establish humeral length and midpoint. After the midpoint of the humerus was measured, 3 axial scans were taken: 1 at midpoint, 1 at 15% of the total humeral length proximal to the midpoint, and 1 at 15% of the total humeral length distal to the midpoint. The proximal midpoint scan was subsequently not used because of the difficulty in differentiating between the shoulder and arm musculature. Two measures of CSA were included to determine if the training regimen produced any selective hypertrophy along the muscle length. CSA consisted of the combined forearm flexor and extensor muscle groups and included the triceps brachii, biceps brachii, and the brachialis. CSA was measured by using the area function of the MRI computer program. Each image was displayed on the computer screen, and the outlines of the forearm extensor and flexor muscles were traced (Figure 1). The area of the bone was calculated and subtracted from the total area to provide the CSA for

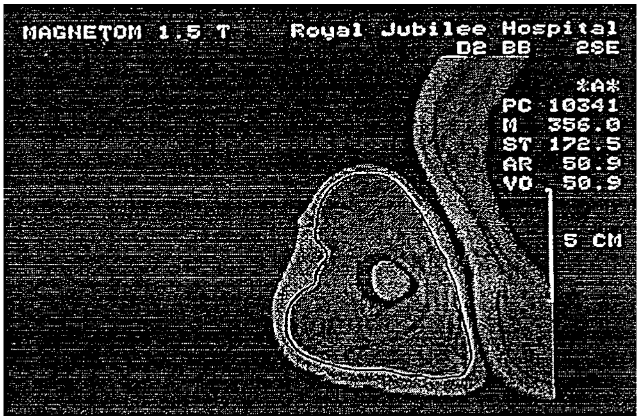

Figure 1. Magnetic resonance image showing the forearm extensor and flexor muscles.

the combined muscle groups. The test reliability for repeated measures of muscle CSA was 0.998. CSA was only obtained at the beginning of the first week and at the end of week 10. CSA was not recorded at mid-training because of the cost and availability of the MRI.

Specific Tension

Specific tension was measured by dividing the combined 1RM tricep press and barbell curl scores (kilograms) by the CSA (square centimeters) at both midpoint and distal axial scans.

Muscle Girth

Girth of the right arm was obtained in relaxed and flexed positions. For relaxed-arm girth measurement, the subject stood with arms relaxed at the side of the body. Measurements were taken at a distance midway between the tip of the acromion and olecranon process. Flexed-arm girth was the largest muscle circumference of the arm with the arm flexed at 90° and the wrist also flexed. Both girth measurements were corrected for skinfolds as described in the *Canadian Standardized Test of Fitness Operations Manual* (1).

Statistical Analysis

There were no initial differences among the 3 groups, so a repeated 3 × 2 analysis of variance (ANOVA; group by time) was used to compare the posttraining values for strength (1RM), CSA, and specific tension, and a repeated 2 × 3 ANOVA (group by time) was used to assess the time effect for each training group. Independent *t*-tests and *t*-tests for paired samples were subsequently conducted when significant differences in the 3 × 2 ANOVA were found to identify differences within and between group means. Statistical significance was accepted at $p \leq 0.05$.

Results

There was no initial difference in any of the dependent variables between the 3 groups. The control group did

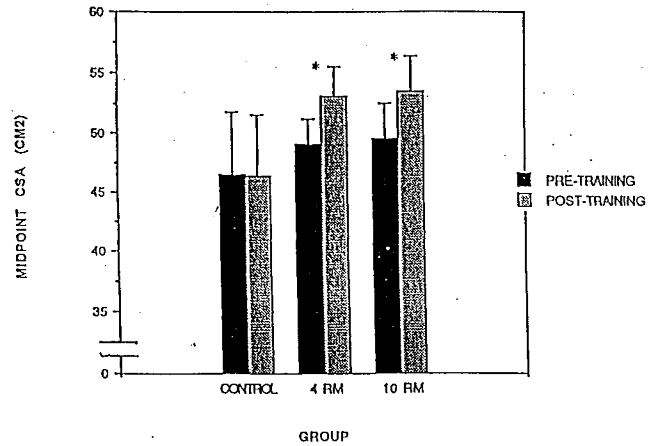

Figure 2. Mean (±*SD*) pretraining and posttraining midpoint cross-sectional area values for control (n = 5), 4 repetition maximum (n = 10), and 10 repetition maximum (n = 9) groups. An asterisk represents significant difference between pretraining and posttraining values.

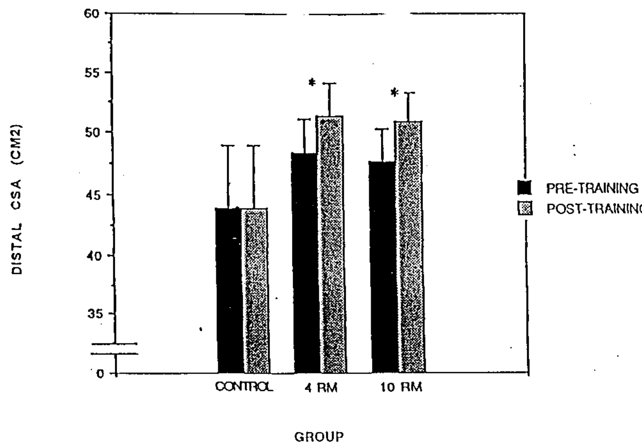

Figure 3. Mean (±*SD*) pretraining and posttraining distal cross-sectional area values for control (n = 5), 4 repetition maximum (n = 10), and 10 repetition maximum (n = 9) groups. An asterisk represents significant difference between pretraining and posttraining values.

not change in any of the dependent variables during the 10-week period of the study.

Cross-sectional Area

CSA data for midpoint and distal MRI scans are shown in Figures 2 and 3, respectively. Significant increases occurred at the midpoint and distal CSA for both the 4RM and 10RM groups. There was no difference in the magnitude of CSA changes between the 4RM and 10RM groups.

Strength

Figures 4 and 5 show the data for forearm extension and flexion strength as measured by 1RM. No significant change occurred for the control group. Significant increases in forearm extensor strength and flexed-

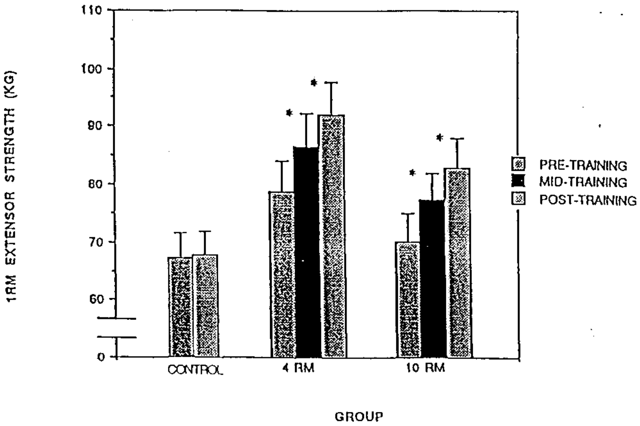

Figure 4. Mean ($\pm SE$) 1 repetition maximum pretraining and posttraining forearm extensor strength values for the control ($n = 5$) group and pretraining, midtraining, and posttraining values for 4 repetition maximum ($n = 10$) and 10 repetition maximum ($n = 9$) groups. An asterisk represents significant differences from previous value.

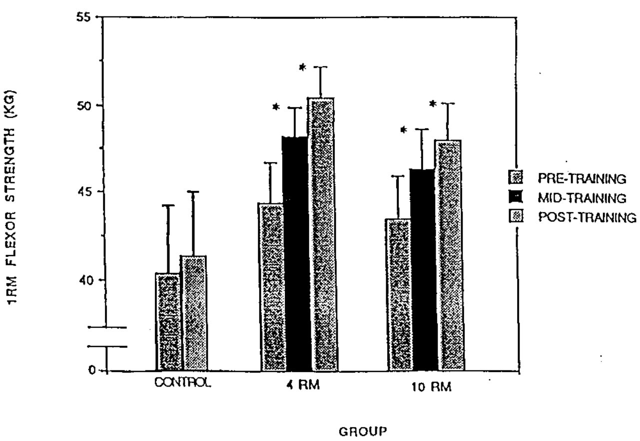

Figure 5. Mean ($\pm SE$) 1 repetition maximum pretraining and posttraining forearm flexor strength values for the control group ($n = 5$) and pretraining, midtraining, and posttraining values for 4 repetition maximum ($n = 10$) and 10 repetition maximum ($n = 9$) groups. An asterisk represents significant difference from previous value.

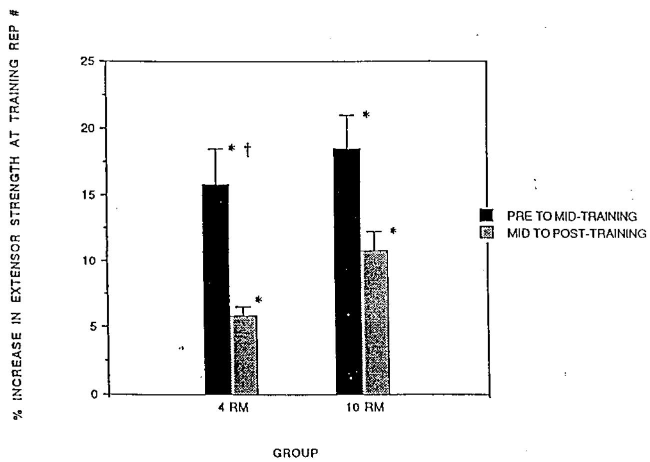

Figure 6. Mean ($\pm SE$) pretraining to midtraining and midtraining to posttraining percentage increases for forearm extensor strength of 4 repetition maximum (4 repetitions; $n = 10$) and 10 repetition maximum (10 repetitions; $n = 9$) groups. An asterisk represents significant within-group difference ($p < 0.05$); a dagger represents a significant difference between pretraining–midtraining and midtraining–posttraining values.

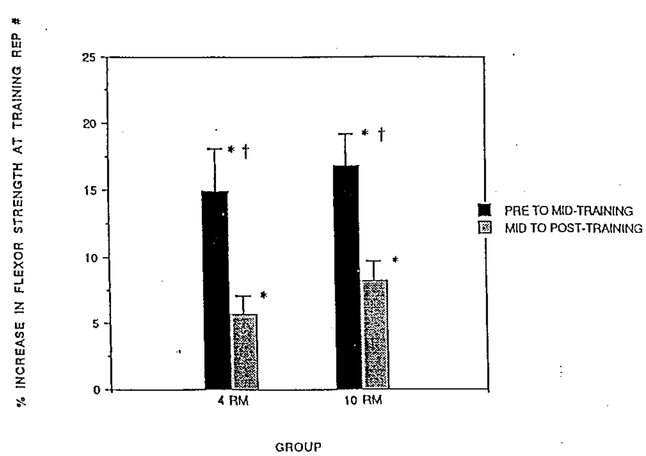

Figure 7. Mean ($\pm SE$) pretraining to midtraining and midtraining to posttraining percentage increases for forearm extensor strength of 4 repetition maximum (4 repetitions; $n = 10$) and 10 repetition maximum (10 repetitions; $n = 9$) groups. An asterisk represents significant within-group difference ($p < 0.05$); † represents a significant difference between pretraining–midtraining and midtraining–posttraining values.

forearm strength occurred between pre- and midtraining and mid- and posttraining for both the 4RM and 10RM groups. There was no significant difference in the magnitude of strength changes between the 2 training periods, and there was no difference between the 4RM and 10RM groups. The percentage of change in forearm extensor and flexor strength (load) related to training repetition number (4RM or 10RM) are shown in Figures 6 and 7. Both training groups (4RM and 10RM) showed significant increases in the percentage of change in forearm extensor and flexor strength at the respective training loads. Significant percentages of change occurred from pretraining; there was no significant difference in the percentage of strength changes between the 2 groups. For the 4RM group, a significantly greater percentage increase in forearm extensor strength related to training repetition number occurred from the pre- to midtraining periods compared with the mid- to posttraining periods. Both groups showed a significantly greater percentage increase in forearm flexor strength at training load during the pre- to midtraining period compared with the mid- to posttraining period.

Specific Tension

Figures 8 and 9 show specific tension data for midpoint and distal measurements, respectively. Signifi-

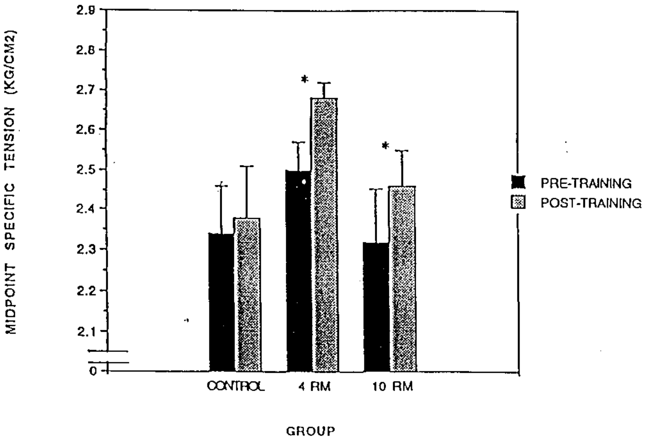

Figure 8. Mean (*SE*) pretraining and posttraining midpoint specific tension values of control ($n = 5$), 4 repetition maximum ($n = 10$), and 10 repetition maximum ($n = 9$) groups. An asterisk represents significant difference between pre- and posttraining values ($p < 0.05$).

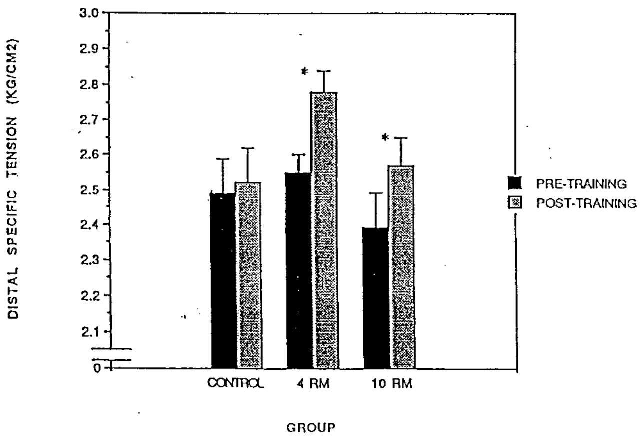

Figure 9. Mean (*SE*) pretraining and posttraining distal specific tension values of control ($n = 5$), 4 repetition maximum ($n = 10$), and 10 repetition maximum ($n = 9$) groups. An asterisk represents significant difference between pre- and posttraining values ($p < 0.05$).

cant increases in specific tension were found for midpoint and distal CSA for both the 4RM and 10RM groups, but there was no difference between the 2 training groups.

Anthropometric Girth Measurement

Data for relaxed-arm girth, flexed-arm girth, and sum of skinfolds are shown in Table 1. Significant increases in flexed-arm girth (corrected) occurred for the 4RM and 10RM groups; there was no difference between the 2 training groups. There were no differences between the pre- and posttraining values for relaxed girth or sum of skinfolds in any group.

Discussion

In the present study, the 4RM and 10RM training protocols elicited similar increases in strength, CSA, specific tension, and muscular circumference. These results are in agreement with Sale et al. (19), who used 3RM and 10RM training protocols. Unfortunately, these results were only reported in abstract form, and it is difficult to compare the studies without detail in regard to design, especially regarding the equating of training volume.

Table 1. Pretraining and posttraining relaxed-arm girth, flexed-arm girth, and sum of skinfolds (SOS) values for control ($n = 5$), 4RM ($n = 10$), and 10RM ($n = 9$) groups (mean ± *SE*).

Group	Relaxed-Arm Girth (cm)	Flexed-Arm Girth (cm)	SOS (cm)
Control			
pretraining	28.5 ± 1.9	30.3 ± 1.6	1.3 ± 0.3
posttraining	28.5 ± 2.1	30.6 ± 1.7	1.3 ± 0.3
4RM			
pretraining	31.2 ± 0.9	33.2 ± 1.0	1.4 ± 0.1
posttraining	31.5 ± 1.0	33.9 ± 1.1*	1.3 ± 0.2
10RM			
pretraining	31.1 ± 1.0	32.8 ± 0.9	1.3 ± 0.2
posttraining	31.8 ± 0.9	33.6 ± 0.9*	1.3 ± 0.2

* Significant difference between pretraining and posttraining values ($p < 0.05$).

Several studies have reported increases in strength and hypertrophy using training loads from 6–8RM to loads of 15–20RM (2, 11, 20, 23). However, none of the studies compared the specificity of different training loads within their designs or equated training volumes. In addition, a variety of training loads have consistently elicited significant increases in CSA.

The magnitude of the increase in strength was the same in the present study for both the 4RM and 10RM training groups. Schmidtbleicher and Haralambie (22) also found a similar increase in strength for groups that trained at either 90–100% or 30% of their maximum voluntary strength. Stone et al. (24) compared 2 high-intensity training programs and reported that increasing intensity from 10RM to 2RM significantly increased strength gains in previously untrained subjects. However, 1 group performed 3 sets at 6RM for the entire study, whereas the other group performed 5 sets at 10RM for the first 3 weeks, 5 sets at 5RM for the fourth week, 3 sets at 3RM for the fifth week, and 3 sets of 2RM for the final week. The volume of training differed between the groups, and the second group had the possible stimulus of varying intensity over the training cycle. It has been proposed that adaptation to a training stimulus can deteriorate within 2 weeks of exposure, and that adding variety can optimize the training response (3, 8, 17).

The proposed advantage in varying the training stimulus could partly account for the differences in the percentage increases in strength from pre- to midtraining compared with mid- to posttraining. A significantly greater increase in percentage change in strength occurred during pre- to midtraining compared with mid- to posttraining for forearm and flexor strength in both the 4RM and 10RM training groups. It has been proposed in the coaching literature that the training stimulus (such as load) should be changed every 2 to 3 weeks to maximize neuromuscular adaptations (17). The present program used a relative constant load, so the optimal training response probably occurred between the pre- and midtraining period.

Specific tension in the present study was used to reflect changes in strength attributable to neural adaptations (2, 8, 15). Both the 4RM and 10RM training protocols produced significant increases in specific tension, suggesting that both intensities evoked increases in neural drive. There was no significant difference between the specific tension of the training groups. Garfinkel and Cafarelli (2) found that a 10RM loading intensity did not significantly increase specific tension in previously untrained subjects. However, they did not do a statistical within-group comparison; if they had, it may have revealed a significant training effect based on their reported findings.

The results related to the measure of specific tension should be interpreted within the limitations of the measurement techniques. Muscle CSA was calculated from the combination of the forearm flexors and extensors, and the force was the combined scores of the 1RM tricep press and barbell curl. In addition, the tricep press may not have been the optimal measure of the strength of the forearm extensors. Specific tension was also calculated from bilateral exercises, but the CSA of the limb was measured from the MRI scan. Separation of the CSA of the forearm flexors and extensors (not possible from the MRI scan), inclusion of unilateral exercises, and use of triceps push-down would have provided more specific information in regard to the neural adaptations that were considered to be reflected by the measure of specific tension. However, because specific tension was compared between the pre- and posttest results using the same method of calculation, changes in the value would reflect some form of neural adaptation. It is also possible that changes in fiber type and protein expression could have contributed to the increases in strength that were found for both training groups.

Significant and equal increases in flexed-arm girth were demonstrated by the 4RM and 10RM training loads in this study. Similar results were reported by Moritani and DeVries (14), who used a 10RM training load for forearm flexors, and MacDougall et al. (12), who reported significant increases in arm girth using a 8–10RM loading intensity for forearm extensors. These results suggest that corrected flexed-arm girth measurement can be used to reflect training-induced changes in muscle hypertrophy.

Discrepancies between the results of this and previous studies and the lack of specificity in the neuromuscular adaptations to the different training loads may be partly attributable to the training age of the subjects. Although the subjects were familiar with weight training, they were regarded as untrained. Untrained subjects may have a more generic response to resistance training than trained subjects. It has been suggested that, with untrained subjects, initial strength gains from resistance training programs are primarily the results of neural adaptations; whereas after 6 weeks, muscle hypertrophy contributes more to the increases in strength (14, 15, 18). Unfortunately, it was not possible to describe the time line of the neural and hypertrophic adaptations within the design of the present study. In addition, it has been suggested that high loads are critical factors in maintaining or eliciting strength and neural adaptations in trained individuals (6, 8). It is possible that trained subjects would have responded differently than the untrained subjects in this study in their response to the 4RM and 10RM training loads.

Practical Applications

For relatively untrained males, a 10-week training regimen of either 4RM or 10RM will produce both an increase in strength and some degree of muscular hypertrophy. Both programs were performed 3 times per week, and each set was done to muscle failure. For untrained individuals, it may be beneficial to use a lighter training load to reduce the risk of injury and to help them acquire good exercise techniques while realizing improvements in strength and size. However, the lack of specificity in the response to training at different loads may not hold for individuals with a resistance-training background. It has been previously proposed that individuals with several years of resistance training may require high loads (4–6RM) to elicit significant neuromuscular adaptations. The relationship between training age and the specificity of neuromuscular response to different training loads and protocols is an area requiring further research.

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