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COMPARISON OF RESPONSES TO STRENUOUS ECCENTRIC EXERCISE OF THE ELBOW FLEXORS BETWEEN RESISTANCE-TRAINED AND UNTRAINED MEN

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ABSTRACT

This study compared resistance-trained and untrained men for changes in commonly used indirect markers of muscle damage after maximal voluntary eccentric exercise of the elbow flexors. Fifteen trained men (28.2 ± 1.9 years, 175.0 ± 1.6 cm, and 77.6 ± 1.9 kg) who had resistance trained for at least 3 sessions per week incorporating exercises involving the elbow flexor musculature for an average of 7.7 ± 1.4 years, and 15 untrained men (30.0 ± 1.5 years, 169.8 ± 7.4 cm, and 79.9 ± 4.4 kg) who had not performed any resistance training for at least 1 year, were recruited for this study. All subjects performed 10 sets of 6 maximal voluntary eccentric actions of the elbow flexors of one arm against the lever arm of an isokinetic dynamometer moving at a constant velocity of $90^\circ \cdot s^{-1}$. Changes in maximal voluntary isometric and isokinetic torque, range of motion, upper arm circumference, plasma creatine kinase activity, and muscle soreness before, immediately after, and for 5 days after exercise were compared between groups. The trained group showed significantly ($P < 0.05$) smaller changes in all of the measures except for muscle soreness and faster recovery of muscle function compared with the untrained group. For example, muscle strength of the trained group recovered to the baseline by 3 days after exercise, where the untrained group showed approximately 40% lower strength than baseline. These results suggest that resistance-trained men are less susceptible to muscle damage induced by maximal eccentric exercise than untrained subjects.

KEY WORDS muscle damage, muscle soreness, isometric strength, isokinetic strength, range of motion, plasma creatine kinase activity

INTRODUCTION

Resistance training provides a unique stimulus to the neuromuscular system culminating in neural, muscular, and connective tissue adaptations (3,11,32). Resistance training typically incorporates a mixture of concentric, eccentric, and isometric muscle actions, and individuals who train to increase maximum strength spend significant time exercising at high intensity with resistances in the vicinity of their concentric one repetition maximum (e.g., 1 to 6 RM) (14). Although these resistances usually correspond to 80% or greater of the weight that could be lifted only once through the concentric phase of the movement (1RM), they may represent appreciably less of an individual's capability to generate force eccentrically, which suggests that during traditional resistance training, the majority of the eccentric work may be performed at a submaximal level.

It is well established that unaccustomed eccentric exercise induces muscle damage (6); however, the majority of this research has used either untrained individuals or those who have not been involved in chronic resistance training (7). There is a paucity of literature describing how chronically resistance trained individuals respond to "unaccustomed" maximal eccentric exercise. It is important to understand how these individuals respond to exercise consisting of maximal eccentric muscle actions and their recovery from such exercise. However, no previous study has investigated this systematically, and it is not known whether people with a significant resistance training history respond differently to untrained subjects in terms of changes in markers of muscle damage following maximal eccentric exercise of the elbow flexors. Falvo and Bloomer (7) documented in their recent review that the inclusion of physically trained individuals in muscle damage studies is necessary to better understand the extent of muscle damage from high force resistance exercise in this population.

Four studies had previously untrained subjects exercise for periods of time ranging from 1 session to 9 weeks using only

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concentric actions, after which they were exercised eccentrically and changes in various criterion measures examined (24, 26, 28, 37). Two of the studies (29) reported that previous concentric training caused greater changes in some of the criterion measures and suggested an increased vulnerability to eccentric exercise-induced responses and muscle injury. Ploutz-Snyder et al. (28) suggested that the increased susceptibility might result from a training-induced elevation of the concentric 1RM, allowing the subjects to handle greater eccentric loading. In contrast, Nosaka and Newton (26) found that previous concentric training did not exacerbate eccentric exercise-induced muscle damage, and Nosaka and Clarkson (24) showed that muscle dysfunction was actually attenuated if eccentric exercise was preceded immediately by a bout of concentric work. Differences in protocols used between studies, as well as the training status of the individuals, make it difficult to predict how chronically resistance trained subjects would respond to the same eccentric interventions.

It is also well established that previously untrained individuals who are exposed to a single bout of either maximal or submaximal eccentric exercise exhibit less muscle damage when exposed to a subsequent bout of maximal eccentric exercise 1 to 10 weeks after the initial bout (2,22,25). This prophylactic effect of an initial bout of eccentric exercise on a subsequent bout is a phenomenon often referred to as the "repeated bout effect" and is characterized by faster recovery of muscle function, reduced muscle soreness and swelling, and attenuated increases of muscle specific proteins in the blood (5,25). It would be reasonable to assume that resistance trained individuals show similar adaptations to those observed with the repeated bout effect as a result of regular training. Therefore, the purpose of the present study was to compare resistance-trained and untrained men for changes in the commonly used indirect markers of muscle damage after maximal voluntary eccentric exercise of the elbow flexors.

METHODS

Experimental Approach to the Problem

The study was an experimental design that incorporated 2 groups of subjects performing an eccentric exercise intervention using one arm. A 2×8 factorial design was used to investigate the effect of the manipulation of the independent variable (training status) on the dependent variables (criterion measures described below). Testing for each subject was conducted over the course of 6 consecutive days preceded by 2 familiarization sessions.

Subjects

Based on a power of 0.8, the minimum calculated sample size for the study was 12 subjects per group. Thirty men, 15 resistance-trained and 15 untrained, volunteered to take part in the study. The mean ($\pm SEM$) age, height, and weight were 28.2 ± 1.9 years, 175.0 ± 1.6 cm, and 77.6 ± 1.9 kg, respectively for the resistance-trained group, and 30.0 ± 1.5 years,

169.8 ± 7.4 cm, and 79.9 ± 4.4 kg, for the untrained group, with no significant differences between groups. All subjects were free of any disease or injuries that would contraindicate their inclusion in the study. Ethical approval was granted by the Institutional Human Ethics Committee, and subjects completed written informed consent consistent with principles set out in the Declaration of Helsinki prior to participation.

The inclusion criteria for the trained subjects required a minimum of 1 year of resistance training with a frequency of at least 3 sessions per week including exercises involving the elbow flexor musculature. Subjects reported performing multiple sets per body part of a combination of free weight and selected machine exercises at an intensity that varied between 2 to 12 repetition maximum. None of the trained subjects performed any eccentric accentuated exercise as part of their resistance-training program. Their experience in resistance training ranged between 2 and 15 years, with an average ($\pm SEM$) of 7.7 ± 1.4 years. The untrained subjects were not currently undertaking any form of vigorous exercise and had not performed any resistance training for at least 1 year. Subjects were requested not to alter their usual eating patterns during the course of the studies and not to perform any exercise, other than that prescribed by the investigator, for one week prior to and during the course of each study.

Pre-exercise Familiarization

In the week preceding commencement of the study, subjects visited the laboratory on 2 occasions, separated by at least 48 hours, during which they were familiarized with the testing protocols. Static and dynamic maximum voluntary strength of the elbow flexors, range of motion (ROM), upper arm circumference, plasma creatine kinase activity (CK), and muscle soreness were measured. The data collected during the 2 familiarization sessions was used to determine reliability of the criterion measures. During the first of the familiarization sessions, subjects were provided with a demonstration by the investigator of the eccentric exercise intervention to be performed.

Eccentric Exercise

The exercise consisted of 10 sets of 6 maximal voluntary eccentric actions of the elbow flexors against the lever arm of an isokinetic dynamometer (Cybex 6000, Ronkonkoma, NY) moving at constant velocity of $90^\circ \cdot s^{-1}$. Subjects were seated on an arm curl bench with the exercised upper arm supported at 45° of shoulder abduction and their elbow aligned with the axis of rotation of the dynamometer's lever arm. The forearm remained in a supinated position throughout all sets of exercise. The forearm commenced the movement from an isometric preload at an angle of 90° to the upper arm and moved through a range of movement of 90° , finishing at 180° of elbow extension. Subjects were exhorted to maximally resist the lever arm of the dynamometer throughout the entire lengthening phase of the movement. A 10-second passive recovery period occurred between eccentric actions while the lever arm was returned to the starting position at

$90^{\circ}\cdot\text{s}^{-1}$ by the motor of the isokinetic dynamometer. A 3-minute passive recovery period was undertaken between sets.

Torque and displacement signals were obtained directly from the Cybex 6000 dynamometer output and captured with a data acquisition hardware and software system (AMLAB, Version II, Lewisham, Australia). Peak torque and total work values were determined automatically for each repetition of the eccentric exercise bout and saved for later analysis. A counterbalanced design was used for assigning which arm would be used for the eccentric exercise intervention resulting in both groups having the same number (50%) of dominant and non-dominant arms exercised.

Criterion Measures

The criterion measures consisted of maximal voluntary isometric and isokinetic torque, ROM, upper arm circumference, plasma CK activity, and muscle soreness, which have been used extensively in studies of exercise-induced muscle damage (4,9,29). All of the criterion measures were recorded during the 2 familiarization sessions, before exercise, and 1, 2, 3, 4, and 5 days after exercise. During each testing session the order in which the criterion measurements were taken remained consistent commencing with CK followed by muscle soreness, ROM, upper arm circumference, and concluding with muscle strength (isometric preceding isokinetic). The isometric and isokinetic torques, ROM, and upper arm circumference were also measured immediately and 30 minutes after exercise.

Maximal Voluntary Contraction (MVC) Torque. Subjects were positioned on the arm curl bench as described previously in the exercise protocol. Subjects were encouraged to produce a continuous maximal voluntary contraction of the elbow flexors for three seconds against an immovable lever arm of the Cybex 6000 isokinetic dynamometer at fixed elbow joint angles of 90° and 150° for the isometric measures. Two efforts were allowed at each joint angle, and the highest torque of the 2 efforts was recorded for each angle. A 30-second passive rest period was provided between attempts at a given angle, and 1 minute of passive recovery was used between testing at the 2 joint angles.

Isokinetic torque at concentric velocities of $30^{\circ}\cdot\text{s}^{-1}$, $90^{\circ}\cdot\text{s}^{-1}$, $150^{\circ}\cdot\text{s}^{-1}$, $210^{\circ}\cdot\text{s}^{-1}$, and $300^{\circ}\cdot\text{s}^{-1}$ also were collected during each testing session. Isokinetic assessment followed the isometric measurements with a 2-minute passive recovery provided between the testing modalities. Isokinetic testing velocities were ordered from slowest to fastest for all subjects and testing sessions. Torque was recorded throughout the range of motion, however; only peak torque was used for analytical purposes. Two maximal attempts were made at each concentric velocity, consecutively, and a 1-minute passive recovery was provided between successive velocities. Torque data from the Cybex 6000 dynamometer were collected using AMLAB and the greater of the 2 retained for later analysis.

ROM and Elbow Joint Angles. ROM of the elbow joint was determined by the difference between the flexed (FANG) and extended (EANG) elbow joint angle as measured by goniometry. We determined FANG by the angle formed at the elbow when it is held by the side while the subject attempts to fully flex the elbow joint to touch his or her shoulder with the palm of the supinated hand. We determined EANG as the angle formed at the elbow joint when the subject attempts to extend his or her arm as much as possible with the elbow held by his or her side and the hand in mid-pronation. To obtain consistent measurements, 4 marks were drawn on the skin with a semipermanent ink pen, one laterally approximating the level of the deltoid tuberosity, the second at the level of the lateral epicondyle of the humerus, a third at the midpoint of the wrist, and the fourth laterally at the styloid process of the radius. A plastic Jamar E-Z Read goniometer (Sammons Preston Rolyan, IL) was used to record the FANG and EANG measures. Two measurements were taken for FANG and EANG, with the mean value of the 2 used for the determination of ROM.

Upper Arm Circumference. Upper arm circumference was determined using a Gulick constant tension tape measure (model J00305, Lafayette Instrument, IN) at 5 sites on the upper arm 3, 5, 7, 9, and 11 cm from the elbow crease. Measurements were collected with the subject's arm relaxed and hanging by their side. Two measurements were taken from each site and the mean value was determined. An overall mean for the 5 sites was then calculated and used for later analysis. To obtain consistent measurements over the study period, the 5 sites were marked on the skin with a semi-permanent ink pen.

Plasma CK Activity. Approximately 30 μL of blood was collected in a heparinized capillary tube after the piercing of the subject's precleaned finger with a spring-loaded lancet. The blood was immediately transferred by pipette to a CK test strip and assayed by a Reflotron spectrophotometer (Boehringer-Manheim, Pöde, Czech Republic) for plasma CK activity. According to the information provided with the CK test strips, the "normal" reference range for CK using this method is 24 to 195 $\text{IU}\cdot\text{L}^{-1}$ when assaying at 37°C . When CK activity exceeded the linear accuracy of the spectrophotometer (approximately 1500 $\text{IU}\cdot\text{L}^{-1}$) another blood sample was obtained from the subject and diluted with saline solution before being assayed. The resulting CK activity was then adjusted to account for the dilution.

Muscle Soreness. Muscle soreness was assessed by the investigator palpating the subject's upper arm and forearm, and extending and flexing the elbow joint while the subject attempted to relax the arm. Subjects rested their arms on a table during arm palpation and flexion measures; however, during measurement of extension soreness, the investigator raised the subject's relaxed arm off the table to perform the evaluation. Palpation soreness was assessed by the examiner applying firm pressure to the specific location on the arm or

forearm directing pressure primarily through the index and middle fingers. Two of the 4 sites used for palpation soreness were located using the lines marked for upper arm circumference measurements. The first site was located on the belly of the biceps brachii between the lines marked 3 and 5 cm above the elbow crease. The second site was located between the lines marked 9 and 11 cm above the elbow crease and pressure was once again applied to the belly of the biceps brachii. The third site was located on the lateral side of the upper arm just above the elbow and was targeted at the brachialis musculature. The final site for palpation soreness was located on the forearm and was targeted at the brachioradialis. During flexion and extension soreness measures, the subject was asked to relax his or her arm as much as possible while the investigator passively flexed and extended the elbow joint. A visual analog scale (VAS) was used to provide a quantitative measure of the subject's soreness. The VAS incorporates a 100 mm line marked with 0 at one end, indicating no discomfort at all, and 100 at the other, representing very painful. The subject marked the 100 mm line with a pen, using the hand of the arm not being assessed, at a point along the scale that coincided with their perceived level of soreness. The distance from 0, in millimeters, was measured and the numerical result recorded for later analysis.

Reliability of Criterion Measures

Data collected from the 2 familiarization sessions were used to determine the test-retest reliability of selected criterion measures. The criterion measures assessed for reliability were isometric and isokinetic torque, ROM, upper arm circumference, and plasma CK activity. Muscle soreness was not assessed for test-retest reliability due to all subjects recording VAS scores of zero for each soreness class during both familiarization sessions. Intraclass correlations were used to determine the test-retest reliability of the 2 familiarization sessions for the selected criterion measurements. Statistical Package for the Social Sciences (SPSS) version 13.0 for Windows was used to perform the reliability computations. The reliability for isometric and isokinetic torque, ROM, upper arm circumference, and plasma CK activity were 0.96, 0.91, 0.98, and 0.93, respectively.

Statistical Analyses

Both absolute and "normalized" data were used for analysis of selected criterion measures. In terms of both isometric and isokinetic maximal voluntary contraction torques, "normalized" referred to percentages of pre-exercised values (i.e., normalized to pre-exercise). For ROM and upper arm circumference "normalized" referred to changes from pre-exercise values; however, in the case of these 2 criterion measures the differences were presented as actual units of measure (i.e., degrees for ROM and mm for circumference). Both plasma CK activity and soreness were analyzed with absolute values.

Changes in criterion measures over time were compared between groups using a between-within factorial analysis of variance (ANOVA). Two-way repeated measures ANOVA

were applied to the data to analyze the main and interaction effects. When the ANOVA showed a significant interaction effect, independent *t*-tests with Bonferroni correction were applied as a post hoc test. When the 2-way repeated-measures ANOVA showed a significant main effect for "within-group" comparisons, one-way repeated measures ANOVAs with Bonferroni corrected pairwise comparisons were applied to the absolute value data of each group to locate any significant differences over time. Independent *t*-tests with Bonferroni correction were applied to the subject characteristics and pre-exercise absolute values of the criterion measures between the groups. Statistical significance was set at $P \leq 0.05$ for all analyses. Data are presented as means \pm SEM, unless otherwise stated.

RESULTS

Pre-exercise Criterion Measures

No significant differences between the groups were evident for any of the pre-exercise criterion measures (Table 1).

Peak Torque and Work During Eccentric Exercise

Peak eccentric torque progressively declined for both groups over the 10 sets of eccentric exercise. When evaluated in terms of mean torque per set, Figure 1a shows that for both groups the last seven sets produced significantly ($P < 0.05$) lower torque than set one. During the course of the 10 sets of eccentric exercise, the mean torque per set for the untrained and trained groups decreased 33% and 22%, respectively. There was no significant difference between the groups in terms of mean torque over the 10 sets.

When the torque of the first and last of the 60 eccentric actions were expressed as a ratio of the pre-exercise isometric torque, it is noteworthy that the resulting ratios were less than one (inset in Figure 1a). Even when the peak eccentric torque for each group was considered, regardless of where it occurred during the 60 actions, the ratio to pre-exercise isometric torque was exactly one. Therefore, neither group was able to generate greater than isometric torque during eccentric actions of the elbow flexors. Independent *t*-tests revealed that the untrained group produced a significantly greater decline in eccentric torque than the trained group over the 60 actions when expressed as a ratio of pre-exercise isometric torque (inset in Figure 1).

Work output during the exercise protocol produced a similar pattern to torque, progressively decreasing during each successive exercise set. In percentage terms, both groups produced declines in work over the 10 sets that were identical to that reported previously for torque production (i.e., 33% for untrained and 22% for trained). The total work per set was significantly lower than baseline (set 1) by the third set for the trained group, but not until the ninth set for the untrained (Figure 1b). Despite the within group contrast, there were no significant differences between the groups for work production during any of the ten sets or for total work (Figure 1b and inset).

TABLE 1. Pre-exercise values (mean \pm SEM) of maximum isometric torque at 90° (ISO-90) and 150° (ISO-150), isokinetic torque at 30°·s⁻¹ (IK-30), 90°·s⁻¹ (IK-90), 150°·s⁻¹ (IK-150), 210°·s⁻¹ (IK-210), and 300°·s⁻¹ (IK-300), ROM, upper arm circumference (CIR: mean of the five sites), and plasma CK activity for the trained (T) and untrained (UT) groups.

Group	ISO90 (Nm)	ISO150 (Nm)	IK30 (Nm)	IK90 (Nm)	IK150 (Nm)	IK210 (Nm)
T	72.8 \pm 4.2	52.9 \pm 2.7	50.4 \pm 2.8	49.6 \pm 2.6	44.6 \pm 2.5	40.0 \pm 2.5
UT	68.4 \pm 3.2	47.3 \pm 3.4	48.6 \pm 3.2	42.6 \pm 2.7	38.1 \pm 2.5	35.1 \pm 2.4
Group	IK300 (Nm)	ROM (°)	CIR (mm)	CK (IU·L ⁻¹)		
T	35.1 \pm 2.2	128.3 \pm 1.8	299.5 \pm 6.4	370 \pm 73		
UT	31.6 \pm 2.5	132.1 \pm 2.1	283.1 \pm 5.8	144 \pm 16		

Isometric Torque

Isometric torque at angles of 90 and 150° of elbow extension for both groups showed similar patterns of strength loss and subsequent recovery after the eccentric exercise. Immediately after exercise, the maximum isometric torque of both groups

declined significantly ($P < 0.05$) with a significant difference between groups. Figure 2 shows changes in maximum isometric torque at 90°. The trained group exhibited a decline of approximately 25% whereas the untrained group decreased approximately 47%, which was significantly different

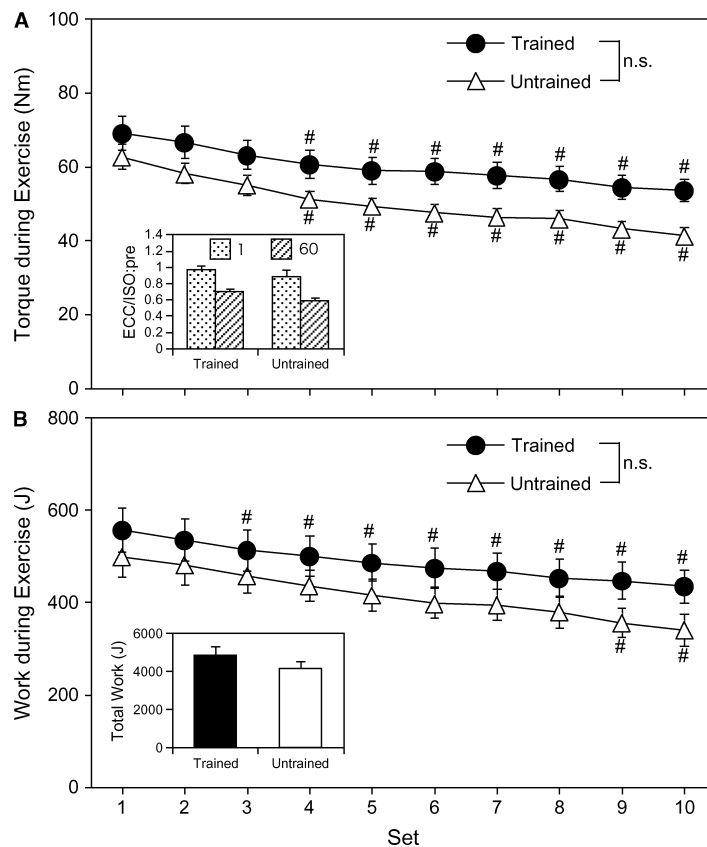


Figure 1. Changes in mean peak torque of 6 eccentric actions (a) and the total work per set (b) over 10 sets of eccentric exercise for the trained and untrained groups. n.s = not significantly different between groups. #Significantly different from the first set. In the inset graphs, comparisons between trained and untrained groups are shown for torque of the first and last of the 60 eccentric actions expressed as a ratio of the pre-exercise isometric torque (a), and total work for 60 eccentric actions (b). *Significantly different from the untrained group ($P < 0.05$).

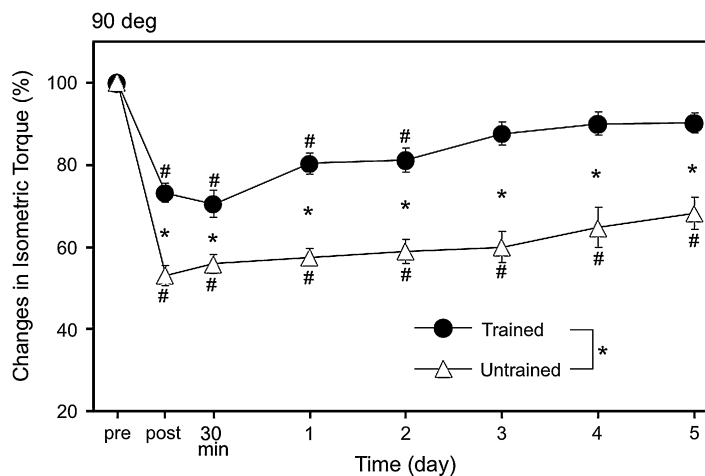


Figure 2. Changes in maximum isometric torque measured at 90° from baseline (pre: 100%) immediately (post) and 30 minutes after exercise, and 1–5 days after exercise for the trained and untrained groups. *Significantly different between groups (interaction: $P < 0.05$, each time point: $P < 0.007$), #Significantly different from pre-exercise value.

TABLE 2. Normalized changes in isokinetic torque (mean \pm SEM) at 30°·s⁻¹(IK30), 90°·s⁻¹(IK90), 150°·s⁻¹(IK150), 210°·s⁻¹(IK210) and 300°·s⁻¹(IK300) from the baseline (100%) immediately after (post), 30 min, and 1, 2, 3, 4, and 5 days after exercise for the untrained (UT) and trained (T) groups.

Velocity	Group	Time after exercise							Group \times time effect
		Post	30 Min	1	2	3	4	5	
30°·s ⁻¹	UT	58.5*† ±4.0	57.5*† ±2.6	58.3*† ±2.7	60.4*† ±2.9	66.2*† ±2.8	66.7*† ±4.3	71.8*† ±4.5	$P < 0.05$
	T	79.5† ±2.8	77.1† ±4.0	83.7† ±3.6	86.5 ±3.7	90.4 ±4.2	94.5 ±4.2	94.1 ±3.6	
90°·s ⁻¹	UT	60.4† ±4.8	58.1† ±3.7	55.0*† ±3.2	60.9*† ±3.7	65.9*† ±3.4	66.5*† ±4.5	69.2*† ±4.8	$P < 0.05$
	T	74.4† ±3.5	68.9† ±2.9	78.7† ±4.3	82.6 ±4.9	89.0 ±5.3	89.7 ±5.5	92.0 ±5.4	
150°·s ⁻¹	UT	56.8*† ±3.0	59.3† ±3.8	57.3*† ±3.3	64.7*† ±4.1	66.8*† ±3.7	69.8† ±4.8	72.7† ±4.6	$P < 0.05$
	T	76.2† ±3.5	72.3† ±3.3	80.7† ±4.3	82.8 ±4.3	91.3 ±4.3	89.4 ±4.9	92.0 ±5.2	
210°·s ⁻¹	UT	59.9*† ±3.9	64.2† ±4.2	63.8*† ±4.4	62.7*† ±3.4	70.0*† ±4.8	72.5† ±5.1	77.0 ±5.6	$P < 0.05$
	T	78.2† ±3.3	73.2† ±2.8	84.7 ±4.0	87.7 ±4.6	90.8 ±4.3	90.7 ±4.1	94.8 ±5.5	
300°·s ⁻¹	UT	60.1† ±4.5	62.8† ±4.5	63.5*† ±3.6	64.5*† ±4.0	72.2*† ±4.4	74.2† ±5.1	77.7† ±5.7	$P < 0.05$
	T	75.3† ±3.6	73.5† ±2.8	85.3 ±3.6	86.5 ±3.3	91.7 ±5.1	92.0 ±4.6	95.9 ±6.2	

The group by time interaction effect by a 2-way ANOVA is shown in the right column.
 *Significantly different between groups after Bonferroni correction ($P < 0.05$).
 †Significantly different from pre-exercise ($P < 0.05$). Absolute values used for within-group comparisons.

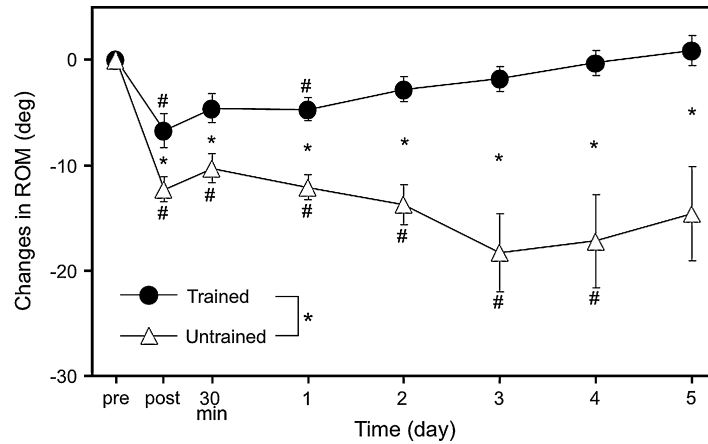


Figure 3. Changes in ROM from baseline (pre: 0) immediately (post) and 30 minutes after exercise, and 1–5 days after exercise for the trained and untrained groups. *Significantly different between groups (interaction: $P < 0.05$, each time point: $P < 0.007$), #Significantly different from pre-exercise value.

between groups ($P < 0.05$). The differences between the groups remained significant for all subsequent tests through day 5 ($P < 0.05$). By day 3 after exercise, the isometric torque of the trained group was not significantly different from the baseline. In contrast, the torque of the untrained group remained significantly lower than baseline for 5 days following exercise, and was still depressed by approximately 30% at day 5.

similar among the different velocities, and to those observed for the isometric torque. Torque at all velocities decreased significantly from pre-exercise levels for both groups after exercise ($P < 0.05$), but the decreases were significantly greater for the untrained group compared with the training group. The untrained group did not show a full recovery by 5 days after exercise, whereas no significant difference from the baseline was evident for trained group.

Isokinetic Torque

Table 2 shows changes in isokinetic concentric torque at each angular velocity. The changes in concentric torque were

ROM

Figure 3 shows that the change in ROM from pre-exercise levels was significant for both the untrained and trained

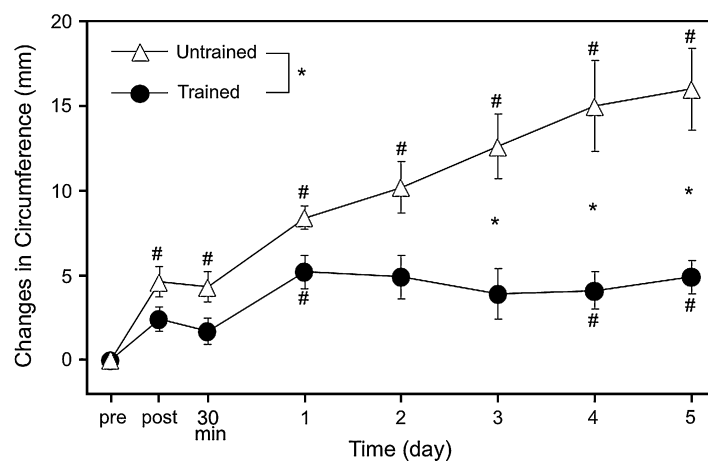


Figure 4. Changes in upper arm circumference from baseline (pre: 0) immediately (post) and 30 minutes after exercise, and 1–5 days after exercise for the trained and untrained groups. *Significantly different between groups (interaction: $P < 0.05$, each time point: $P < 0.007$), #Significantly different from pre-exercise value.

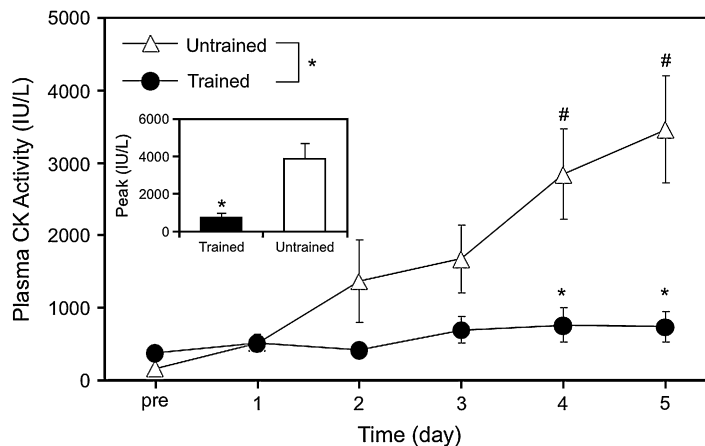


Figure 5. Changes in plasma CK activity before (pre), and 1–5 days after exercise for the trained and untrained groups. *Significantly different between groups (interaction: $P < 0.05$, each time point: $p < 0.007$), #Significantly different from pre-exercise value. In the inset graph, comparison of peak CK activity between groups is shown. *Significantly different from the untrained group.

groups following exercise ($P < 0.05$). The largest decrease in ROM for the trained group occurred immediately following exercise, after which it recovered to pre-exercise levels by the final day of testing. In contrast, the untrained group showed a continuing decrease in ROM reaching a nadir of just greater than -18° on day 3 after exercise before recovering slightly over the final 2 days of testing. ROM in this group was significantly lower than pre-exercise levels at all points following the eccentric exercise intervention, with the exception of the final day of testing ($P < 0.05$).

Upper Arm Circumference

Upper arm circumference increased in both groups after the exercise treatment with the untrained group displaying significantly ($P < 0.05$) greater increases in circumference after exercise compared with the trained group (Figure 4). The increase in circumference was apparent immediately after eccentric exercise in both groups, with the peak increase of approximately 5 mm in the trained group occurring 1 day after exercise whereas the largest circumference of 16 mm was recorded on day 5 in the untrained group. In contrast to

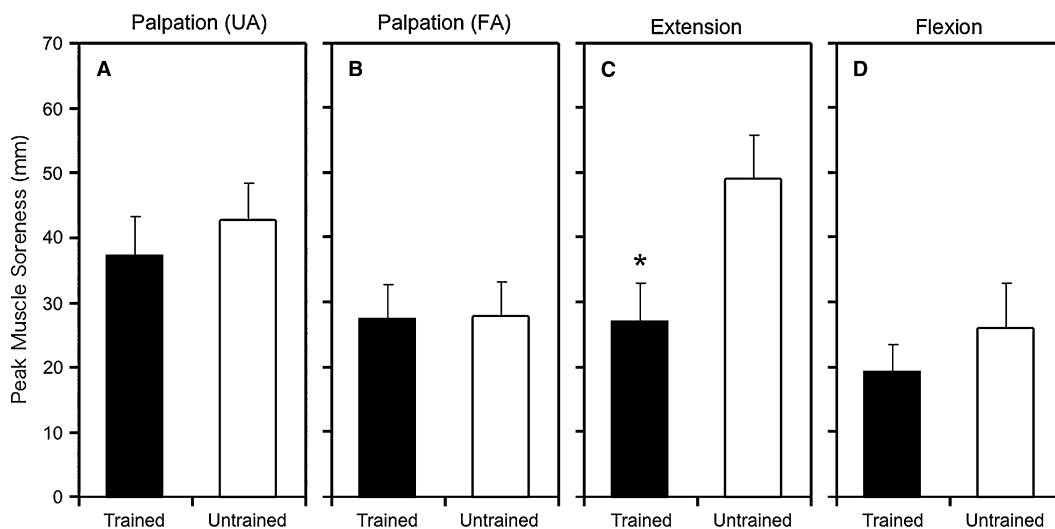


Figure 6. Peak muscle soreness upon palpation of upper arm (UA) and forearm (FA), extension and flexion of the elbow joint for the trained and untrained groups. *Significantly different from the untrained group.

the trained group, the untrained group showed significantly larger increases in circumference following exercise which was sustained through to day 5 ($P < 0.05$).

Plasma CK Activity

As shown in Figure 5, plasma CK activity was not significantly different between the groups prior to exercise; however, it is noteworthy that the mean reading of the trained group ($370 \text{ IU}\cdot\text{L}^{-1}$) was above the upper limit of the normal reference range of $220 \text{ IU}\cdot\text{L}^{-1}$ for healthy adult males. In the days after the eccentric exercise session, plasma CK activity was elevated, reaching a peak in both groups on day 5. There was a stark contrast in the CK responses between groups, with the untrained group recording over a 20-fold increase, compared with a doubling in the trained subjects. A significant difference between groups was evident at days 4 and 5 ($P < 0.05$).

Muscle Soreness

Muscle soreness for forearm, upper arm palpation, extension, and flexion was rated at 0 prior to exercise, which represented no pain at all. After exercise, both groups reported that muscle soreness was significantly greater than pre-exercise levels ($P < 0.05$), peaking at 1–3 days post exercise, and subsiding by 5 day after exercise. Figure 6 shows the peak soreness values. Except for the muscle soreness upon extension, no significant differences between groups were evident.

DISCUSSION

The purpose of the present study was to determine whether the changes in indirect markers of muscle damage differed between trained and untrained men after 60 maximal eccentric actions of the elbow flexors on a Cybex dynamometer. The results revealed that significant differences were evident between the trained and untrained groups for all of the criterion measures, with the exception of muscle soreness (Figures 2–6 and Table 2). Despite both groups performing similarly in terms of torque and total work during eccentric exercise (Figure 1), the trained group produced smaller changes in muscle function (muscle strength and ROM), upper arm circumference and plasma CK activity. These results suggest that the extent of muscle damage was less for the trained subjects compared with the untrained subjects.

Chronic high intensity resistance training has been shown to increase strength and lean muscle mass by a combination of neurological, endocrinological, and intramuscular adaptations (8,11,13,14). It was, therefore, somewhat surprising that the groups did not show significant differences in isometric or isokinetic torque, or upper arm circumference at the commencement of the study (Table 1). The absence of a strength difference between the groups may be attributable to the lack of specificity between the training and testing conditions. Rutherford and Jones (30) showed that dynamic resistance training produced increases in training weights of about 200% but this was associated with isometric force improvements of only 15–20%. Therefore, if the groups of the

present study were tested in terms of the weight they could lift in “traditional” resistance training exercises, we would have expected to see a far more pronounced strength differential. Circumference measurements are unlikely to differentiate between the relative amounts of fat and lean body mass of the upper arm, but have been used in this study to measure changes in arm volume associated with muscle swelling consequent to eccentric exercise.

Research focusing on whether previous concentric training attenuates the decrements in muscle function and other indirect markers of muscle damage after eccentric exercise has produced contradictory findings. Several studies (10,28,37) reported that the inclusion of concentric training for a period (days or weeks) prior to eccentric exercise increases the susceptibility of muscle to damage. However, Nosaka and Newton (26) reported that muscle damage was not exacerbated following maximal eccentric exercise when preceded by 8 weeks of concentric training. In the present study, the subjects were chronically trained, and performed both concentric and eccentric muscle actions as part of their regular training regimen. In light of the Nosaka and Newton (26) conclusion, the results of the present study are interesting as the protective effect seemed to be similar to that shown in other studies reporting the “repeated bout effect” using untrained subjects (5,19,22,23). It should be noted that changes in the criterion measures typically observed following a second bout do not appear to be as small as those seen after the eccentric exercise of the trained group, which would indicate that the protective effect against eccentric exercise induced muscle damage that the trained subjects experienced was greater than that the effect conferred by the initial eccentric exercise bout of the untrained subjects. For example, the torque loss experienced by the trained group immediately following the exercise showed a greater magnitude of protection compared to some of the “repeated bout” studies using maximal eccentric exercise in each bout (5,6,22).

Plasma CK activity demonstrated marked differences between the trained and untrained groups (Figure 5). The slightly higher but nonsignificant baseline CK activity in the trained group is probably a result of the resistance training undertaken prior to study commencement. The smaller changes in plasma CK activity in the trained group supported the work of Vincent and Vincent (34), who showed a small increase in CK activity in trained subjects after exercise compared with untrained subjects. Muscle strength and ROM recovered to the pre-exercise level by 3 days after exercise for the trained group (Figures 2 and 3). Together with the reduced swelling (Figure 4) and attenuated increase in plasma CK activity (Figure 5), the underlying mechanisms to explain the attenuated muscle damage in the trained group are speculative, but some explanations are possible.

Armstrong et al. (1) put forward a theory to explain the protective effect conferred by a single bout of eccentric exercise. They suggested that the fibers injured in the initial

eccentric exercise bout represented a population of “susceptible fibers” that were eliminated during a novel bout of eccentric exercise, and the remaining fibers were able to withstand subsequent eccentric exercise without further injury. If such a theory is correct, then the resistance training that the trained subjects had been performing may have removed stress susceptible fibers. Alternatively, the resistance training may have initiated structural reinforcement of the fibers themselves and/or connective tissue in the immediate vicinity (5,15,18,20,22,31). MacDougall et al. (18) showed an increase of absolute amounts of connective tissue following chronic resistance training. It has also been speculated that strengthening of the cell membrane may be implicated in the protective effect (5,34).

Another adaptation that has been suggested to occur within the muscle fibre as a response to eccentric activity is the addition of sarcomeres in series (21). In a study involving incline and decline treadmill running by rats, Lynn and Morgan (16) showed evidence of such a change, lending support to Morgan’s earlier hypothesis. The effect of such an adaptation would be for the subsequent active lengthening of the sarcomere to occur on the ascending limb of the length tension curve thus avoiding the more damaging descending limb. Koh (12) hypothesized that muscle cells may be protected by the induction of heat shock proteins following mechanical loading caused by exercise. He suggested that the protection of muscle might be mediated by the heat shock proteins interacting with cytoskeletal elements and/or the glutathione system. Work by Thompson et al. (33) suggests that the heat shock protein system may adapt in such a way as to protect muscle during exposure to repeated bouts of exercise. As the trained subjects in the present study were exposed to repeated bouts of eccentric and concentric resistance training over a protracted period (i.e., years), it is tempting to speculate that adaptation to the heat shock system may be responsible, in part, for the attenuated responses in damage markers compared to the untrained group.

Neural adaptations caused by the chronic resistance exercise performed by the trained subjects may be partly responsible for the attenuated responses in many of the criterion measures in this group following exercise. Such adaptations could take the form of increased motor unit activation for a given torque, alterations to motor unit recruitment, or increased synchronization of motor unit activation (19). Warren et al. (36) demonstrated some evidence for an increased recruitment of slow motor units and a concomitant decrease in fast unit activation following a repeated bout of maximal voluntary eccentric exercise. McHugh et al. (19) reported no change in EMG per unit torque or median frequency between novel and repeated bouts of submaximal isokinetic eccentric exercise, and did not support the evidence of any neural adaptation accompanying the repeated bout effect.

It is interesting to note that muscle soreness in the trained group was not significantly different from that of the untrained group except for extension soreness, which was

significantly lower for the trained group (Figure 6). This soreness may be associated with the smaller changes in ROM for the trained group (Figure 3), reflecting a smaller change in muscle stiffness of the trained compared with the untrained subjects. It may be that the muscle soreness upon extension was reduced because of the less stiff muscle. It is important to note that both groups reported similar muscle soreness upon palpation and flexion, despite the vast difference between groups for the changes in other criterion measures. Nosaka et al. (27) reported that changes in indirect markers of muscle damage are not necessarily associated with the magnitude of DOMS. Warren et al. (35) also noted that soreness showed poor correlations with changes in muscle function following eccentric exercise. Vincent and Vincent (34) reported that resistance-trained men had a tendency to rate muscle soreness higher than untrained men. It is important to note that the magnitude of DOMS may not be a good indicator of the extent of muscle damage. From a training standpoint, the present results suggest that individuals performing resistance training on a regular basis should exercise caution using the degree of soreness to indicate the magnitude of damage and loss of muscle function.

In conclusion, the results of the present study show that chronically resistance trained men experienced smaller changes in muscle function, limb circumference, and CK activity after maximal eccentric exercise than untrained males. The aetiology of the protective effect in the trained individuals was unable to be determined in the present study, and warrants further investigation.

PRACTICAL APPLICATIONS

It is common practice for many athletes to incorporate resistance training into their exercise regimens in order to improve performance, however, as the loads lifted are usually dictated by the concentric 1 RM the resulting eccentric component of such training is submaximal in nature. Although findings from the present research are limited to the elbow flexor musculature the positive news for resistance trained athletes is that when compared to untrained individuals this type of training seems to be associated with lower levels of muscle damage after a bout of maximal voluntary eccentric exercise and a faster recovery to pre-damage (baseline) levels. The data also suggest that trained subjects should apply caution in using the extent of muscle soreness to predict the magnitude of muscle damage and loss of muscle function.

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