Neuromuscular Fatigue during Low-Intensity Dynamic Exercise in Combination with Externally Applied Vascular Restriction.

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ABSTRACT

The present study investigated neuromuscular fatigue during low-intensity resistance exercise (i.e., 20% 1RM) combined with (KAATSU) and without (control, CON) vascular restriction. Fourteen healthy males (mean ± SE age= 23.7±1.1 years) volunteered to perform 2 pre-exercise isometric maximum voluntary contractions (MVCs) before and after 5 sets of 20 dynamic constant external resistance (DCER) leg extension exercises at 20% of 1RM. During one of the two trials separated by at least 48 hours, vascular restriction (KAATSU) was applied to the proximal thighs using pneumatic cuffs (50 mm wide) connected to an electronic pressure control system (KAATSU-Master, Sato Sports Plaza, Tokyo, Japan). No KAATSU was applied to the CON condition. Surface electromyography (EMG) was recorded from the vastus lateralis during all MVCs and the DCER leg extensions. Twitch interpolation was used to assess the percent of maximal voluntary activation (%VA) during the MVCs. After the KAATSU condition, the decreases (p<0.05) in MVC force, %VA, EMG amplitude, and potentiated twitch force were more profound than the changes observed after the CON condition. However, during the DCER exercises, the increases (p<0.05) in EMG amplitude and decreases (p<0.05) in EMG mean power frequency were similar for both the KAATSU and CON conditions. These findings indicated that low-intensity leg extension exercises at 20% 1RM combined with KAATSU resulted in a greater post-exercise fatigue effect than the CON condition, despite the similar EMG changes during the DCER exercises. Our findings suggest that the KAATSU-induced fatigue may have been due to a combination of peripheral and central manifestations.

Key Words: Blood Restriction, EMG, dynamic knee exercises.
INTRODUCTION

Maximal or near-maximal effort is necessary to recruit all available motor units and generate a high level of force, which may be important to stimulate muscle hypertrophy (Wernbom et al. 2007). Goto et al. (2005) investigated the effects of metabolic stress on hormonal and hypertrophic responses, utilizing 3-5 sets of 10 repetitions at 10-repetition maximum (RM) with an interset rest period of 1 min. Even though the volume was matched between exercise groups, the group that rested for an additional 30 s in the middle of 10 repetitions for each set had less of a hypertrophic response (4.0% increase in quadriceps cross sectional area (CSA)) compared to those who performed each set of 10 repetitions in a continuous manner to muscular failure (12.9% increase in quadriceps CSA). The authors suggested that near-maximal effort may be necessary to maximize the recruitment of motor units and the subsequent hormonal responses, which might be responsible for a greater hypertrophic response.

Although the number of motor units recruited is lower during submaximal resistance exercise compared to more vigorous (>1-RM) training (i.e., due to the size principle), several studies using low-intensity resistance training exercise (i.e., 20% 1-RM) combined with vascular restriction (KAATSU) have observed increases in muscle size (Abe et al. 2006; Beekley et al. 2005; Takarada and Ishii 2002; Takarada et al. 2002; Takarada et al. 2000b) and strength (Shinohara et al. 1998; Takarada and Ishii 2002; Takarada et al. 2002). Several hypotheses have been proposed to explain the hypertrophic adaptations to low-intensity resistance training combined with KAATSU, which include motor unit recruitment patterns (Moritani et al. 1992; Takarada et al. 2000c; Yasuda et al. 2005) and increased metabolic stress (Sato et al. 2005; Takarada et al. 2000a; Yoshida
and Watari 1997). However, the precise mechanisms underlying these adaptations are still not clear.

Several different techniques have been used to investigate the muscular strength decrements associated with neuromuscular fatigue, such as surface electromyography (EMG) and twitch interpolation. The EMG signal reflects the linear algebraic summation of the electrical signals generated by the motor units within the electrode recording areas. The amplitude and frequency of the EMG signal may reflect motor unit activation (determined by motor unit recruitment and firing rate) and motor unit action potential conduction velocity (determined by the global shape of the action potentials) (Basmajian and De Luca 1985), respectively. Therefore, EMG signals have been used to investigate the physiological mechanisms underlying neuromuscular fatigue (Beck et al. 2004; Esposito et al. 1998; Krogh-Lund 1993; Pasquet et al. 2000; Perry-Rana et al. 2002).

Allen et al. (1995) used twitch interpolation to determine maximal motor unit activation and the contributions of central and peripheral mechanisms. Twitch interpolation involves applying a supramaximal electrical stimulation to the muscle or peripheral nerve during an isometric maximal voluntary contraction (MVC) to estimate the voluntary level of muscle activation. As a result of the utility of the twitch interpolation technique, it has been used to examine neuromuscular fatigue (Biro et al. 2007), neural activation strategies (Desbrosses et al. 2006), neural resistance training adaptations (Jubeau et al. 2006), and clinical neural deficits associated with diseases (Molloy et al. 2006). Therefore, the simultaneous use of EMG and twitch interpolation may help to determine the mechanisms responsible for neuromuscular fatigue during dynamic muscle contraction combined with moderate vascular restriction (KAATSU).
When muscle is near fatigue, the number of motor units recruited and their firing rates during submaximal resistance exercise might elicit an intensity that is high enough to promote muscle hypertrophy and strength gains. Previous studies showed that even though subjects exercised at 20% of 1-RM, fatigue developed during low-intensity exercises when combined with vascular restriction (Takarada et al. 2000a; Takarada et al. 2004). Since the metabolic demand imposed by resistance exercise alters as a function of exercise mode (Kay et al. 2000) and velocity (Linnamo et al. 1998), blood flow restriction during low intensity exercise might also result in a greater metabolic demand and higher perceived intensity. Since neuromuscular fatigue is tightly coupled with metabolic demand, reduced blood flow during low-intensity exercise may alter the peripheral versus central manifestations of neuromuscular fatigue. Therefore, to elucidate the mechanisms responsible for neuromuscular fatigue during low-intensity exercise with blood flow restriction, the goal of this study was to investigate the effects of vascular restriction (KAATSU) on MVC force, %VA, EMG amplitude and frequency from the vastus lateralis before, during, and after 5 sets of 20 repetitions of the leg extension exercise performed at 20% 1RM.

METHODS

Study design. A randomized, counterbalanced, within-subjects experimental design was used to investigate the effects of KAATSU on neuromuscular function before, during, and after leg extension exercises. Each subject completed an informed consent, PAR-Q questionnaire, and 1-RM tests and was familiarized with the study procedure during a familiarization session. Each participant visited the laboratory two more times for the experimental trials separated by at least 48 h. The participants performed the same
exercise protocol with two randomized conditions, with vascular restriction (KAATSU) and control (CON). During the experimental trials, resting blood pressure was determined for each participant and a five-minute warm-up was completed on a stationary cycle ergometer with a power output of 50 W. The participants performed 2 pre-exercise isometric MVCs with 1 minute rest between trials. Then five sets of 20 dynamic constant external resistance (DCER) leg extension exercises at 20% 1-RM were performed with a 30-s inter-set rest period.

**Subjects.** Fourteen healthy men (mean ± SE age = 23.7±1.1 years) participated in this study. Even though the participants were active; none of them had participated in a regular resistance training program for at least 6 months prior to the study. Table 1 displays the physical characteristics of the participants. The study protocol was approved by the University Institutional Review Board for Human Subjects. An informed consent form and a health questionnaire (PAR-Q) were read and signed by participants prior to the start of the study.

**One repetition maximum testing (1-RM).** The participants were instructed with proper lifting technique and were familiarized with the strength-testing equipment at least 48 h prior to testing. Each subject performed 5 leg extensions at 50% of their perceived maximum and then rested for 1-min. The weight was increased progressively (maximum of 5 attempts) following each successful lift to reach the maximal weight that could be lifted using correct form once throughout the entire range of motion. Each participant rested approximately 1.5 - 2 min between attempts in order to ensure adequate recovery.

**Isometric Strength Assessment.** A DCER machine (TDS Fitness Equipment Corp. Elmira, NY 14904) was used to assess isometric MVC by connecting the lever arm to a load cell (Omega Engineering Inc. Stamford, CT). Each participant was seated in an
upright position in the chair and the left knee was aligned with the rotational axis of the lever arm and the leg was secured with a strap just superior to the malleoli.

Two 3-5 s MVCs were performed by each participant with a 1-min rest between trials. The MVC trials served two functions: a) to determine the participant's maximal voluntary isometric strength and b) to determine the extent of voluntary activation (explained below). The MVC trials were accompanied by verbal encouragement by the investigators to obtain a maximum effort from the participants.

**Percent Voluntary Activation.** The percent of voluntary activation (%VA) was measured using the twitch interpolation protocol (Allen et al. 1995). Doublet stimuli were administered to the femoral nerve approximately 350 ms into the MVC plateau. A second doublet was applied approximately 5 s after the cessation of the MVC (see figure 1) (Shield and Zhou 2004). The stimuli were rectangular pulses of 200 μs duration and were delivered using a high-voltage (maximal voltage= 400 V) constant-current stimulator (Digitimer DS7AH, Hertfordshire, UK). The femoral nerve was stimulated by a cathode probe (8 mm diameter). The tip of the cathode was covered in a saline-soaked sponge and pressed over the femoral nerve in the lateral portion of the femoral triangle. The anode (9 x 5 cm, Durastick Supreme, Chattanooga Group, Hicton, TN) was positioned according to the protocol described previously by Babault et al. (2006). The optimal probe location was determined by using a single stimulus (30mA). Once the optimal probe location was determined and marked based on the M-wave response, the intensity of stimulus was increased progressively until the highest twitch torque was achieved. An additional 20% was added to the highest amperage to ensure a supramaximal stimulus. The doublet consisted of two single stimuli that were delivered successively at 100 Hz to increase the signal-to-noise ratio and minimize the series elastic effects on torque production.
(Desbrosses et al. 2006). %VA was determined by the equation below where the
superimposed twitch and potentiated twitch were obtained during the MVC plateau and
after the MVC trial at rest, respectively (Allen et al. 1995):

\[
\%VA = \left[ 1 - \left( \frac{\text{superimposed twitch}}{\text{potentiated twitch}} \right) \right] \times 100
\]

**Dynamic Exercise.** Each participant performed the exercise session, which consisted of
five sets of 20 repetitions of DCER leg extension exercises at 20% of the 1-RM with 30-s
rest between each set. The intensity (20% 1-RM) was decided based on the exercise
protocol of previous studies (Takarada et al. 2000a; Takarada et al. 2004). Each
participant was able to complete the 20 repetitions of exercise for each set with the
exception of one participant who did not complete the entire 20 repetitions during the 5th
set. Each session of DCER leg extension exercises lasted approximately 8 min.

**Blood Flow Restriction Protocol.** A specially designed elastic belt (50 mm width)
containing a pneumatic bag was placed around the most proximal portion of each thigh to
restrict blood flow. The KAATSU device (KAATSU-Master, Sato Sports Plaza, Tokyo,
Japan) has a pneumatic bag along the inner surface connected to an electronic air pressure
control system that monitors the restriction pressures set by the investigator. The
following equation was used to determine the cuff pressure:

\[
\text{Kaatsu Pressure} = (SBP \times 1.2) \times 1.2
\]

A standard protocol was followed to reach the appropriate pressures by increasing the
pressure by 20 mmHg (starting at 120 mmHg), holding for 30 s and releasing for 10 s
between increments until the desired target exercise pressure was reached (Abe et al.
2006). The MVC trials were performed with the cuffs inflated and the pressure was released after the completion of the last post-exercise MVC trials.

**EMG Measurements.** Bipolar (5 cm center-to-center) surface EMG electrode (Ag-Ag Cl, Quinton Quick Prep, Quinton Instruments Co., Bothell, WA) arrangements were placed along the longitudinal axis of the vastus lateralis (VL) of the left thigh. The electrode placements on the VL were 25 mm distal and proximal to a mark that was made at 50% of the distance between the greater trochanter and the lateral femoral epicondyle. The reference electrode (Ag-Ag Cl, Quinton Quick Prep, Quinton Instruments Co., Bothell, WA) was placed on the cleaned and lightly abraded skin over the spinous process of the 7th cervical vertebrae. The EMG signals were pre-amplified (gain: x1000) using a differential amplifier (MP100A, Biopac Systems Inc., Santa Barbara, CA).

**Signal Processing.** The EMG (µV) and force (kg) signals were recorded and stored on a personal computer (Intel Pentium 4 CPU, Dell Computer Corp., Austin, TX) with a custom written software program (LabVIEW v 7.1 Professional Instruments, Austin, TX) for subsequent analysis. All signal processing was performed off-line using additional custom written software (LabVIEW v 7.1, National Instruments, Austin, TX). The EMG signal was digitized at 2 kHz and filtered (zero-phase 4th-order Butterworth filter) with a pass band of 10-500 Hz. The load cell signal was low-pass filtered with a 10 Hz cutoff (zero-phase 4th-order Butterworth filter) (Figure 1).

(Insert Figure 1 here)

Isometric MVC force (kg) was represented as the average force value calculated during the 0.25-s epoch taken immediately prior to the superimposed twitch. Consequently, the same (concurrent) 0.25-s epoch was selected from the EMG signal to calculate the time and frequency domain estimates during the MVC trials (Figure 1). For
the DCER leg extension exercises, the EMG signal was analyzed separately for each of
the 20 repetitions for all 5 sets. The averages of 4 consecutive repetitions for the EMG
values were used to analyze the patterns of response across each set.

The time domain of the EMG signal epoch during the isometric and DCER
muscle actions was represented as the root mean square (RMS) amplitude value. For the
mean power frequency (MPF), each epoch was processed with a Hamming window and a
discrete Fourier transform and was calculated as described by Kwatny et al. (1970). The
MPF was used to represent the power spectrum according to the recommendations of
Hermens et al. (1999).

**Potentiated Twitch.**

The second supramaximal doublet administered 5 s after the MVC trial at rest was
defined as the potentiated twitch. The peak potentiated twitch force was calculated as the
highest average of 10 consecutive data points. Potentiated twitch signals were analyzed
by the same custom written software used to analyze EMG signals (LabVIEW v 7.1,
National Instruments, Austin, TX) (see percent voluntary activation section).

**Statistical Analyses.** Four separate two-way repeated measures ANOVAs (trial [pre- vs.
post-exercise] x condition [KAATSU vs. CON]) were used to analyze the MVC
torque, %VA, EMG amplitude, and EMG MPF values. For each subject, EMG values
during DCER leg extension exercises were normalized to the average values recorded
during pre-exercise MVCs and the values were averaged across all subjects. Two
separate three-way repeated measures ANOVAs (condition [KAATSU vs. CON] x sets
[1 vs. 2 vs. 3 vs. 4 vs. 5] x repetitions [approximately 1-4 vs 5-8 vs 9-12 vs. 13-16 vs 17-
20]) were used to analyze the EMG amplitude and MPF data during the DCER leg
extension exercises. When appropriate, post-hoc analyses were performed using
Bonferroni corrections. All data were expressed as means ± SE in the text, figures, and tables. An alpha of 0.05 was used to determine statistical significance. The data were analyzed using SPSS 14.0 for Windows (SPSS Inc., Chicago, IL).

RESULTS

Isometric Strength. There was a significant trial x condition interaction (p= 0.01). Isometric MVC force decreased from pre- to post-exercise for the KAATSU condition (p< 0.001) and for the CON condition (p= 0.02). There were no significant differences between pre-exercise MVC values (p= 0.2), but the post-exercise MVC force for the KAATSU condition was significantly lower than the CON condition (p= 0.02). Percent differences in MVC from pre- to post-exercise are displayed in Figure 2.

(Insert Figure 2 here)

Percent Voluntary Activation. There was a significant trial x condition interaction (p= 0.04). The post-hoc follow-up tests did not show a significant decrease for either the KAATSU (p= 0.08) or the CON (p= 0.2) conditions, however, there was a 11.3% decrease in %VA from pre- to post-exercise for the KAATSU condition, but a 4.8% increase in %VA for the CON condition (Figure 3).

(Insert Figure 3 here)

Potentiated Twitch. Figure 4 displays the percent differences in the peak potentiated twitch force from pre- to post-exercise for both conditions. A significant trial x condition interaction (p< 0.001) was observed. The KAATSU condition resulted in a 55.4% decrease (p<0.001), whereas the CON condition resulted in a 23.4% decrease (p< 0.01).

(Insert Figure 4 here)
Surface Electromyography. Figure 5 shows the percent differences in EMG amplitude and MPF values from pre- to post-exercise with and without KAATSU. There was a significant trial x condition interaction for EMG amplitude (p = 0.04), but post-hoc follow-up tests did not detect a significant difference for either the KAATSU (p = 0.08) or the CON (p = 0.56) condition. For EMG MPF, there was no significant trial x condition interaction (p = 0.19) and no main effects for either trial (p = 0.28) or condition (p = 0.98).

(Insert Figure 5 here)

The average normalized EMG amplitude (%MVC) values were plotted for each set across repetitions with and without KAATSU (Figure 6). There was no significant three-way interaction for condition x sets x repetitions (p = 0.55), no significant two-way interactions for condition x sets (p = 0.15), condition x repetitions (p = 0.29), set x repetitions (p = 0.052), and no significant main effect for condition (p = 0.09). However, there were significant main effects for sets (p < 0.001) and repetitions (p < 0.001). Significant increases (p ≤ 0.05) were detected in EMG amplitude from set 1 to set 5, except between set 1 and 2 (p = 0.10) and set 3 and 4 (p = 0.21) (Figure 6). EMG amplitude increased from repetitions 1-4 (1st rep) to 5-8 (2nd rep) (p = 0.001), from 5-8 (2nd rep) to 9-12 (3rd rep) (p = 0.04), and from 9-12 (3rd rep) to 13-16 (4th rep) (p = 0.29), but decreased from repetitions 13-16 (4th rep) to 17-20 (5th rep) (p = 0.04) (Figure 6).

The average normalized EMG MPF (%MVC) values were plotted for each set across repetitions with and without KAATSU (Figure 7). There was no significant three-way interaction for condition x sets x repetitions (p = 0.99), no significant two-way interactions for condition x sets (p = 0.71), condition x repetitions (p = 0.32), set x repetitions (p = 0.13), and no significant main effect for condition (p = 0.09). However, there were significant main effects for sets (p < 0.001) and repetitions (p < 0.001). The
follow-up analyses (collapsed across condition) indicated that there were significant decreases in EMG MPF across sets (p ≤ 0.05), except between set 1 and 2 (p = 0.13) and set 4 and 5 (p = 0.08) and main effect decreases in EMG MPF between 3\textsuperscript{rd} rep, 4\textsuperscript{th} rep, and 5\textsuperscript{th} rep (p ≤ 0.04) and between 2\textsuperscript{nd} rep and 5\textsuperscript{th} rep (p > 0.002) (Figure 7).

(Insert Figure 6 here)

(Insert Figure 7 here)

**DISCUSSION**

The most important findings of this study were that low-intensity (20% of 1-RM) exercise combined with vascular restriction resulted in significant decreases in MVC force, %VA, peak potentiated twitch force, and EMG amplitude from pre- to post-exercise. These findings indicated that neuromuscular fatigue during the KAATSU session might be due to a combination of central and peripheral fatigue, whereas for the CON condition, significant declines in peak potentiated twitch values, but no change in %VA, from pre- to post-exercise indicated that peripheral fatigue may be primarily responsible for decreases in MVC force values.

Loss of muscle strength due to the previous exercises performed is defined as muscle fatigue (Perry-Rana et al. 2002). The present study reported a greater decrease in the MVC values following exercise performed with KAATSU (33.5%) compared to CON (14.1%). Since decreases in EMG activity and %VA may indicate an inhibition of central drive to motor units, central fatigue may be responsible for some of the declines in the force generation capacity following exercises with KAATSU. A proposed mechanism for the central fatigue is that the increased intracellular concentration in H\(^+\) and P\(_i\) may cause an inhibition of \(\alpha\)-motoneurons and a decline of supraspinal drive
(Babault et al. 2006). In a similar previous study, a greater decline was detected following low-intensity intermittent isometric exercise with KAATSU (even though the decreases in MVC values were not significant between conditions) (Karabulut et al. 2006). Generally, EMG amplitude values following fatiguing exercise decrease, which might be due to a reduced contribution from the slow twitch fibers. There were no changes in EMG MPF from pre- to post-exercise in the present study. Decrements in EMG MPF would have been expected during fatigue because of reduction in fiber conduction velocity and/or change in the shapes of the action potentials (Basmajian and De Luca 1985; Hermens et al. 1992). However, the present experiment did not detect any significant changes in EMG MPF from pre- to post-exercise for either condition.

Increased EMG amplitude during the submaximal fatiguing exercises could be explained by additional motor unit recruitment (Krogh-Lund 1993; Weir et al. 2000). Yasuda et al. (2006) recorded EMG signals from the triceps brachii and the pectoralis major during dynamic bench press exercises at 30% 1-RM with and without KAATSU. Normalized integrated EMG (iEMG) was significantly higher during the KAATSU session. According to normalized iEMG values, the exercise intensity for the first set was the same for both the control and KAATSU sessions, but the mean exercise intensity was ~10-20% higher in the KAATSU session during the forth set compared with the control session. Previous studies reported that EMG amplitude increased across time during submaximal (Weir et al. 2000) and sustained isometric exercises (Krogh-Lund 1993). The present study also reported an increase in EMG amplitude across repetitions and a pattern of decline toward the end of 20, which may have indicated an impairment of motor unit recruitment and firing rate. Fatiguing exercise also usually results in decreases in EMG center frequency, perhaps due to changes in the shapes of the action potentials.
and/or decreases in muscle action potential conduction velocity (Basmajian and De Luca 1985; Hermens et al. 1992). EMG MPF decreased during static contraction with a greater decrements during contractions at higher intensity (Krogh-Lund 1993). Consistent with the previous findings, EMG MPF decreased significantly across sets and repetitions in the present study, but no significant difference between conditions was observed. This may suggest that the DCER exercises may have elicited similar fatiguing effects during the exercise for both the KAATSU and CON conditions. It was not until after the exercises were complete that a difference could be observed between conditions.

The extent of changes in the potentiated twitch amplitude may reveal the development of peripheral fatigue, which may be due to the alterations in excitation-contraction coupling and/or reduced number of strong binding cross bridges (Babault et al. 2006). The present study reported that there was a 32% greater decrease in potentiated twitch force following the KAATSU condition compared to the CON condition. These findings suggested that the KAATSU condition caused a greater peripheral change in muscle contractile properties than the CON condition. However, because %VA decreased after the KAATSU, but was unaltered after the CON, both peripheral and central mechanisms may have caused fatigue with KAATSU, whereas only peripheral mechanisms may have been involved with the CON.

Overall, these findings indicated that fatigue responses after the KAATSU condition could be due to a combination of central and peripheral mechanisms. Since KAATSU often results in blood pooling in the lower extremities, total concentration of metabolites might be higher and might cause an increase in the inhibitory effect of small diameter afferents (Gandevia 2001; Taylor et al. 2000). In addition, the alterations of the excitation-contraction coupling and reduced number of strong binding cross bridges
might be responsible mechanisms for peripheral fatigue. In conclusion, the results of the present study suggested that 5 sets of 20 dynamic knee extension exercises at 20% 1-RM with KAATSU may enhance the metabolic demands and intensity of exercises leading to a combination of central and peripheral fatigue, which may be partly responsible for why substantial increases in muscle strength and hypertrophy are observed at low-intensity resistance exercise loads combined with KAATSU.
References

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Table 1. Descriptive Statistics (mean ± SE).

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Table 2. The means (SE) for MVC, percent voluntary activation, potentiated twitch, EMG RMS, and EMG MPF.

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<td>Potentiated Twitch (Kg)</td>
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<td>EMG MPF (Hz)</td>
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**Figure 1.** An example of the electromyographic (EMG) signals from the vastus lateralis (VL) muscle during an isometric MVC for 1 participant. The shaded area A. represents the 0.5 sec epoch taken to determine the average torque as well as the time and frequency domain estimates for the EMG signals during the MVC trials. B. and C. represent the superimposed and potentiated twitches, respectively.

**Figure 2.** Percent (%) differences in maximal voluntary contraction (MVC) from pre- to post-exercise for the KAATSU (shaded) and CON (hatched) conditions. Values are means ± SE.

**Figure 3.** Percent differences in percent voluntary activation (% VA) from pre- to post-exercise for the KAATSU (shaded) and CON (hatched) conditions. Values are means ± SE.

**Figure 4.** Percent differences in potentiated twitch from pre- to post-exercise for the KAATSU (shaded) and CON (hatched) conditions. *= p< 0.01 (post-exercise values between conditions). Values are means ± SE.

**Figure 5.** Percent differences from pre-exercise MVC A. Averaged EMG amplitude and B. Averaged EMG MPF during the isometric MVCs for the KAATSU (shaded) and CON (hatched) conditions. Values are means ± SE.

**Figure 6.** Normalized EMG amplitude (%MVC) during the dynamic exercise repetitions for the A. KAATSU B. CON conditions. Values are means ± SE.

**Figure 7.** Normalized EMG frequency (%MVC) during the dynamic exercise repetitions for the A. KAATSU B. CON conditions. Values are means ± SE.
Figure 2.

% Difference in MVC From Pre- to Post-Exercise

KAATSU

CON
Figure 3.
Figure 4.