RESPONSES OF MECHANOMYOGRAPHY, ELECTROMYOGRAPHY, AND PEAK TORQUE TO THREE DAYS OF VELOCITY-SPECIFIC ISOKINETIC TRAINING

by

Jared Wayne Coburn

A DISSERTATION

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Interdepartmental Area of Psychological and Cultural Studies

Under the Supervision of Professor Terry J. Housh

Lincoln, Nebraska

May, 2005
CHAPTER I

INTRODUCTION

Recent studies have examined the effects of short-term resistance training on strength and muscular performance (1, 7, 40, 43). For example, Prevost et al. (40) found that 2 days of isokinetic training resulted in an increase in peak torque (22.1%) that was similar to that previously reported (13, 26, 31) after 6-10 weeks of resistance training. The potential for short-term training to enhance strength and muscular performance has implications for allied health professions such as physical medicine, physical therapy, and occupational therapy where managed care often limits access to patients. If short-term resistance training can lead to improved muscle integrity and enhanced muscular performance, a primary care physician may be willing to explore the effectiveness of a 1 or 2 week physical therapy program before opting for more expensive and intrusive alternatives such as surgery. In addition, patients may be more willing to comply with therapy programs if their rehabilitation goals can be met with fewer visits than previously thought necessary.

Short-term training studies have demonstrated increases in strength (1, 40, 43) and rate of velocity development (RVD) (7) after as few as 2 training sessions (7, 40). For example, Prevost et al. (40) assigned subjects to either slow (30°·s⁻¹) or fast (270°·s⁻¹) velocity training groups for 2 leg extension training sessions and found no torque increase at any test velocity (30, 150, or 270°·s⁻¹) for the slow velocity training group, but a significant increase in torque at 270°·s⁻¹ for the high velocity training group. Brown and Whitehurst (7) examined the effects of 2 days of isokinetic leg extension training on force and RVD. Slow (60°·s⁻¹) and fast (240°·s⁻¹) training groups performed 2 days of velocity-
specific training, while a control group did not train. The results indicated that there was no increase in force for any of the groups, but improved RVD for the slow training group at the slow velocity and for the fast training group at the fast velocity. Staron et al. (43) found increases in leg press strength and decreases in type IIb fiber percentages in female subjects after the first 4 training sessions of an 8 week resistance training program. Akima et al. (1) found that 9 days of isokinetic strength training over a 2 week period resulted in increases in isometric and isokinetic leg extension strength, as well as maximal muscle activation (assessed by magnetic resonance imaging). These studies (1, 7, 40, 43) indicated that there can be rapid (within 2 training sessions) neuromuscular adaptations to short-term resistance training.

The specific mechanisms underlying the increase in strength and muscular performance associated with short-term training are unknown. Prevost et al. (40) suggested that 2 training sessions may be too brief for substantial muscular adaptations to occur, and that strength gains specific to the trained velocity were indicative of neural, rather than hypertrophic adaptations. It was further suggested that the presence or absence of changes in peak torque at velocities other than the training velocity could help determine the relative contributions of hypertrophic and neural adaptations (40). Brown and Whitehurst (7) also suggested that neural adaptations may explain the training-induced increases in RVD. No studies, however, have investigated the specific physiological mechanisms underlying the training-induced adaptations associated with short-term resistance training.

Recent studies have used mechanomyography (MMG) and electromyography (EMG) to describe the motor control strategies used to modulate torque during isometric
and dynamic muscle actions (5, 6, 10-12, 33). It has been suggested that the amplitudes of the MMG and EMG signals are related to motor unit activation, while their frequencies may be related to the firing rate (38) and average action potential conduction velocity (3, 32) of the active motor units, respectively. Simultaneous examination of the MMG and EMG signals may contribute to our understanding of neural and mechanical adaptations to short-term resistance training. Therefore, the purpose of the present investigation is to determine the effects of 3 days of velocity-specific isokinetic training at either a slow \((30^\circ \text{s}^{-1})\) or a fast \((270^\circ \text{s}^{-1})\) velocity on peak torque as well as the time and frequency domains of the MMG and EMG signals. It is hypothesized that there will be: a) velocity-specific increases in peak torque (40); b) no change in MMG amplitude due to the competing influences of increased recruitment of high threshold motor units and increased muscle stiffness resulting from training-induced increases in torque production (18-20, 22, 37); c) velocity-specific increases in MMG mean power frequency (MPF) due to increased recruitment of high threshold motor units and/or increased global motor unit firing rates (9); d) velocity-specific increases in EMG amplitude due to increased recruitment of high threshold motor units and/or increases in global motor unit firing rates (28-30, 35, 36); and e) velocity-specific increases in EMG MPF due to increased recruitment of high threshold motor units (28-30, 35, 36).
CHAPTER II

REVIEW OF LITERATURE

Short-term Strength Training

*Staron et al. (43)*

The purpose of this study was to examine the time course for skeletal muscle adaptations in men and women during the early phase of 8 weeks of heavy resistance training. The resistance training group consisted of 13 men (mean age ± SD = 23.5 ± 3.2 y) and 8 women (mean age ± SD = 20.6 ± 1.5 y). The control group consisted of 7 men (mean age ± SD = 20.7 ± 1.4 y) and 5 women (mean age ± SD = 20.6 ± 1.6 y). Body composition (3 site skinfolds), thigh girth, fasting blood samples, and muscle biopsies were assessed at the beginning and every 2 weeks of the 8 week training program. Blood samples were analyzed for resting serum concentrations of cortisol, testosterone, and growth hormone. Muscle biopsies (80-160 mg) were extracted from the vastus lateralis muscle, and stained for myofibrillar adenosine triphosphatase (mATPase). Six fiber types were then distinguished based on their staining properties (I, Ic, Iac, IIa, IIab, IIb). The training protocol consisted of 8 weeks of high intensity resistance training. The squat, leg press, and leg extension exercises were performed twice per week (Monday and Friday) to strengthen the quadriceps femoris muscle group. Following the performance of warm-up sets, subjects performed 6-8 repetitions (Monday) or 10-12 repetitions (Friday) to failure for each of the exercises, with approximately 2 min rest between sets. Every other Wednesday was used for maximal dynamic strength (1-RM) testing. Results of the investigation revealed no changes over time for percent body fat, body mass, fat-free mass, or girth. For men, 1-RM strength (relative to fat-free body mass) increased
significantly (p \leq 0.05) after 4 weeks of training. For women, there were significant (p \leq 0.05) increases in relative 1-RM strength for the leg extension and squat exercises, however relative 1-RM strength for the leg press increased significantly after just 2 weeks of training. For both genders, relative 1-RM strength increased significantly throughout the duration of the study. Men and women responded similarly to the leg extension and squat exercises, however, there was a significant interaction over time for the leg press, indicating that women experienced a greater rate of strength gain for this exercise. There were no significant (p > 0.05) cross-sectional area changes for any fiber type for the training or control groups over time. There was a significant decrease (p \leq 0.05) in the percentage of type IIb fibers over time for both the training men (4 weeks) and training women (2 weeks), and a nonsignificant increase (p > 0.05) in the percentage of type IIa fibers. Testosterone increased significantly (p \leq 0.05) and remained elevated throughout the duration of the study for the training men, and their serum cortisol levels were significantly (p \leq 0.05) lower at weeks 6 and 8 than at the beginning of training. There were no significant changes (p > 0.05) in testosterone or cortisol for the training women or control subjects, nor were there significant changes (p > 0.05) in growth hormone for men or women in the training or control groups. It was concluded that men and women adapt similarly to heavy resistance training, and that contractile proteins adapt after only a few resistance training sessions. One possible gender difference was the increased testosterone and decreased cortisol levels which may favor protein synthesis for the men.
Akima et al. (1)

This study examined the effects of a short period of isokinetic resistance training on muscle use and strength. Seven men (mean age ± SD = 24.1 ± 2.0 y; mean height ± SD = 175.6 ± 3.7 cm; mean weight ± SD = 71.1 ± 6.8 kg) trained the right quadriceps femoris muscles nine times over 13 days performing 10 sets of 5 leg extensions each day, at an angular velocity of 120°·s\(^{-1}\). Peak torque was assessed before and after training during isometric (0·s\(^{-1}\), 90° angle at knee joint), and isokinetic leg extensions at 60, 90, 120, 180, 240, and 300°·s\(^{-1}\). Magnetic resonance imaging (MRI) was used to determine the cross-sectional area (CSA) of the quadriceps femoris. T2-weighted MR images were calculated at rest and immediately after repetitive isokinetic leg extensions to determine activation of the quadriceps femoris (10 sets of 10 repetitions at 120°·s\(^{-1}\)). Biopsies were taken from the right vastus lateralis ten days prior to training, and on the second day after training ended in order to determine muscle fiber type, fiber area, and phosphofructokinase (PFK) activity. Results of the study indicated significant increases (p ≤ 0.05) in isometric and isokinetic peak torque at all tested velocities. The relative area of the quadriceps femoris that was activated by leg extensions also increased significantly (p ≤ 0.05) after the training period. There were no changes (p > 0.05) in muscle CSA, muscle fiber type, fiber area, or PFK activity. The authors suggested that the strength gains following the brief training period were due to increased activation of the quadriceps femoris, rather than hypertrophy.

Prevost et al. (40)

This investigation examined the effects of velocity specific isokinetic training on leg extension strength. Two groups of nine males (19-35 y) performed either slow
velocity (3 sets of 10 reps at 30° s\(^{-1}\), SVT) or fast velocity (3 sets of 10 reps at 270° s\(^{-1}\), FVT) training for 2 days. Leg extension peak torque was measured at 30, 150, and 270° s\(^{-1}\) on 3 separate days. Strength was assessed on days 1, 4, and 11, while training was performed on days 7 and 9. There was no significant difference between leg extension peak torque values (p > 0.05) between days 1 and 4 at any of the three velocities. At day 11, there was no change in peak torque at any speed for SVT group, but FVT demonstrated a significant (p ≤ 0.05) 22.1 ± 10.0% increase in peak torque at 270° s\(^{-1}\).

The authors suggested that neural adaptations played a major role in the torque production improvements that were specific to a single velocity.

*Brown and Whitehurst (7)*

This study examined the effects of short-term isokinetic training on force and rate of velocity development (RVD) during the leg extension movement. Sixty subjects were assigned to either the control (n = 20, 10 men and 10 women), fast (n = 20, 10 men and 10 women), or slow (n = 20, 10 men and 10 women) group. All subjects were right hand dominant, and tested and/or trained with their right legs. The training groups performed two workouts separated by 48-72 hours, consisting of 3 sets of 8 repetitions at either 60° s\(^{-1}\) (slow) or 240° s\(^{-1}\) (fast), while the control group did not train. Pretesting and posttesting consisted of 5 maximal reciprocal leg extension and flexion repetitions, from 84° to 6° of leg flexion (0° being full leg extension) on a Kin-Com isokinetic dynamometer. Testing was performed in a fixed order of 60° s\(^{-1}\) and 240° s\(^{-1}\) with a 1-minute rest period between velocities. RVD was calculated as the movement (°) before reaching the predetermined velocity, while peak force was determined from the load range. Only repetitions 2, 3, and 4 were used for analysis. Four-way analysis of variance
results demonstrated significant (p ≤ 0.05) decreases in RVD between pre and posttests for the slow group at the slow velocity (RVD—1.25 ± 0.048° vs. 1.08 ± 0.038°) and for the fast group at the fast velocity (RVD—14.24 ± 0.338° vs. 13.59 ± 0.298°). There were no significant (p > 0.05) changes in force for any groups between testing days. The authors concluded that short-term isokinetic training led to velocity-specific increases in RVD for each training group, possibly due to neural adaptations.

Mechanomyographic/Electromyographic Responses to Dynamic Muscle Actions

_Barnes (2)_

This investigation examined 1) the relationship between motor unit activation as determined by integrated electromyography (EMG) and speed of contraction, and 2) the relationships between mechanical work, power output, peak torque, average torque, and both velocity of movement and integrated EMG recordings in the forearm flexor muscles (biceps brachii). Six male subjects performed four maximal concentric isokinetic muscle contractions of the forearm flexor muscles at 60, 120, 180, 240, and 300° s⁻¹. All reported measurements represented the mean of the four maximal contractions. Peak EMG was defined as the highest integrated voltage recorded through the entire range of motion. Mean integrated EMG was defined as the total integrated EMG divided by the contraction time. The results revealed that peak torque, average torque, total work, and average power decreased with increases in velocity. Linear regression analyses indicated a significant inverse relationship between peak torque (r = -0.97) and average torque (r = -0.97) and the contraction velocity. Both peak integrated EMG and average integrated EMG of the forearm flexor muscles decreased with increasing velocity (40.20 and 33.35% decreases, respectively), and demonstrated inverse relationships (r = -0.99 and r
= -0.98, respectively) with contraction velocity. Peak torque and peak integrated EMG were linearly related ($r = -0.95$), as were average torque and average integrated EMG ($r = -0.953$). The ratio of average power per contraction to average integrated EMG per contraction remained stable across contraction velocity, indicating that power output was associated with similar amounts of electrical activity regardless of velocity. The investigator concluded that the differences in electrical activity at different velocities may have been due to different neurological recruitment patterns.

Rothstein et al. (41)

The purposes of this study were to explore the per second integrated EMG activity of the quadriceps femoris at four isokinetic speeds (30, 60, 90, and $120^\circ \text{s}^{-1}$) and the relationship of power to peak torque at each speed. A group of patients with various rheumatic diseases and a group of “normal” healthy subjects participated in the study. The rheumatic disease group ($n = 19$) consisted of 3 men and 16 women with a mean age ± SD of 47 ± 14 y. The normal group consisted of 11 women with a mean age ± SD of 45 ± 9 y. Integrated EMG of the rectus femoris and vastus medialis were measured using Beckman Ag-AgCl electrodes. The subjects performed three maximal leg extension muscle actions on a Cybex II isokinetic dynamometer in the following order: 120, 90, 60, and $30^\circ \text{s}^{-1}$. Only data from the middle 70° of movement were used for analysis. The results indicated that the integrated EMG per second for the patients and normal subjects did not differ across the four speeds. Peak torque and power were highly correlated for the patients at all four speeds (range of $r = 0.93$ to 0.98). When the two groups were combined, the correlations between peak torque and power ranged from $r = 0.94$ to 0.96.
The regression equations used to predict power from peak torque differed for the four tested speeds, with slopes increasing at the higher speeds.

_Dalton and Stokes (17)_

This study examined the relationships between MMG, EMG, and force during submaximal dynamic contractions of the right biceps brachii of 8 healthy males (17-26 y). A wall pulley system with adjustable weights was used by the subjects to perform three concentric and eccentric contractions of 3 s duration, with a 3 s pause between repetitions. Nine weights were lifted in a randomized order: 0.0, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5, 7.5, and 8.5 kg. The middle 1 s of the 3 s concentric and eccentric contractions were used for analysis. The results of the analyses demonstrated positive linear relationships between MMG and load for both concentric ($r = 0.94$) and eccentric ($r = 0.90$) contractions. MMG activity was always significantly higher ($p \leq 0.05$) for concentric than eccentric contractions at any given load. The slopes of the concentric and eccentric regression lines were also significantly different ($p \leq 0.01$). As with MMG, the EMG signal increased linearly for the concentric ($r = 0.99$) and eccentric ($r = 0.94$) contractions. As with MMG, EMG activity was significantly higher ($p \leq 0.05$) for concentric than eccentric contractions with the exception of 0 kg. The difference between the slopes for the concentric and eccentric contractions was significant ($p \leq 0.01$). The authors concluded that MMG could be used to detect changes in force during dynamic contractions, and that the lower values for MMG and EMG during eccentric contractions may have been the result of fewer motor units being activated.
The purpose of this study was to investigate the relationships among velocity, torque, and EMG activity of the leg extensor muscles during concentric and eccentric muscle actions. Fourteen moderately to highly trained males (mean age $\pm$ SEM = 27 $\pm$ 0.9 y, mean height $\pm$ SEM = 186 $\pm$ 1.8 cm, mean weight $\pm$ SEM = 78 $\pm$ 1.3 kg) volunteered to perform maximal voluntary concentric and eccentric muscle actions at 45, 90, 180, and 360$^\circ$ s$^{-1}$ on a Spark System dynamometer. EMG signals were recorded from the vastus medialis, vastus lateralis, and rectus femoris using bipolar surface electrodes placed over the bellies of the muscles. Torque and EMG values were normalized by dividing all scores by the corresponding concentric 45$^\circ$ s$^{-1}$ values. The results indicated that eccentric torque values were greater ($p \leq 0.05$) than concentric torque values at each tested velocity. EMG activity, however, was lower ($p \leq 0.05$) during eccentric than concentric muscle actions at each velocity. Concentric torque output decreased with velocity, except between 45 and 90$^\circ$ s$^{-1}$. For eccentric muscle actions, EMG activity remained constant across velocity, except for a significantly lower value ($p \leq 0.05$) for the vastus medialis at 180$^\circ$ s$^{-1}$ and a significantly higher value ($p \leq 0.05$) at 360$^\circ$ s$^{-1}$ for vastus lateralis. EMG activity decreased significantly ($p \leq 0.05$) for the vastus medialis, vastus lateralis, and rectus femoris with decreasing velocity during concentric muscle actions. The authors concluded that neural drive to agonist muscles may be reduced during high tension loading to protect the musculoskeletal system from injury, despite maximal voluntary effort.
This study investigated the relationships between force, MMG, and EMG from the biceps brachii and brachioradialis muscles during dynamic muscle contractions. Eight healthy subjects, aged 25-48 y, agreed to perform forearm flexions against different inertias (“fast” and “slow”), with and without a 3 kg resistance attached. MMG was recorded using an Electret condenser microphone (Yamashita Communications, 5 Hz – 15 kHz). EMG was recorded using Ag-AgCl electrodes attached in bipolar arrangements to the bellies of the biceps brachii, brachioradialis, and triceps brachii muscles. The results indicated there were positive linear relationships between MMG and EMG and force ($r = 0.90$ to $0.92$), MMG and EMG and acceleration ($r = 0.84$ to $0.93$), and a greater MMG amplitude response to fast versus slow movements. Phono- and electromechanical delays were also measured, and defined as the time lag between the onset of MMG and acceleration (phonomechanical delay) or the onset of EMG and acceleration (electromechanical delay). The investigators found that electromechanical delay preceded phonomechanical delay, which came before acceleration. It was concluded that MMG, like EMG, could be used to measure changes in torque during dynamic muscle actions.

Seger and Thorstensson (42)

The purposes of this investigation were 1) to provide data on leg extensor torque-velocity and EMG-velocity relationships for prepubertal boys and girls and compare them to adult men and women, and 2) to investigate the possibility of age- or gender-related differences in electromechanical efficiency during eccentric and concentric muscle actions. Four groups of 10 subjects volunteered to participate in the study. Girls and boys aged (mean age ± SEM = 11 ± 0 y) volunteered from elementary schools. The
adult subjects were female (mean age $\pm$ SEM = 27 ± 4 y) and male (mean age $\pm$ SEM = 27 ± 3 y) physical education students. A Spark System isokinetic dynamometer was used to measure torque production of the right leg extensor muscles during maximal voluntary eccentric and concentric muscle actions at 45, 90, and 180° s$^{-1}$. EMG was recorded using Ag-AgCl electrodes placed in a bipolar arrangement over the bellies of the vastus lateralis and vastus medialis muscles. Torque, position, and EMG data were collected over the middle 40° of the entire range of motion (10° to 90° with 0° = straight leg). The results indicated that the torque-velocity relationships had similar shapes for all four groups. Eccentric torque did not (p $>$ 0.05) change with increasing velocity for any of the groups. Average concentric torque, however, decreased with increasing velocity. The decreases were significant (p $\leq$ 0.05) between 45 and 180° s$^{-1}$ as well as between 90 and 180° s$^{-1}$ for each of the groups. The decrease in torque between 45 and 180° s$^{-1}$ was larger for the girls and women (31% and 30%) than for the boys and men (each 25%). Eccentric torque was significantly greater (p $\leq$ 0.05) than concentric torque at each velocity for all groups. The differences ranged from 17 to 47%, and were largest at the highest velocity, particularly for the women and girls. Eccentric to concentric torque ratios were above 1.00 for all groups and velocities, and increased with velocity. For EMG (µV), there were no significant differences (p $>$ 0.05) with velocity for any of the groups for the eccentric muscle actions. EMG values increased with velocity for the concentric muscle actions, reaching significance (p $\leq$ 0.05) for the boys between 45 and 180° s$^{-1}$ and for the girls between 45 and 90° s$^{-1}$ and between 45 and 180° s$^{-1}$. Eccentric EMG values were lower than concentric EMG values except at 45° s$^{-1}$ for the boys and 45 and 90° s$^{-1}$ for the women. Eccentric to concentric EMG ratios were less than 1.00 at all velocities for all
four groups. Torque output per unit of EMG activity remained similar for all eccentric velocities in all four groups. Torque to EMG activity ratios gradually decreased with increasing velocity for all groups, resulting from the decreasing torque output and increasing EMG values. It was concluded that torque-EMG-velocity relationships are largely independent of gender and age.

Evetovich et al. (24)

The purpose of this study was to examine the effects of velocity of contraction on the MMG responses to maximal concentric isokinetic leg extension muscle actions. Eight adult males (mean age ± SD = 22.3 ± 1.3 y; mean height ± SD = 179.4 ± 2.7 cm; mean mass ± SD = 82.1 ± 9.5 kg) volunteered for the study and performed maximal concentric isokinetic leg extensions at 60, 120, 180, 240, 300, and 360° s⁻¹ on a Cybex 6000 dynamometer. The MMG signal was detected by a piezoelectric crystal contact sensor (HP 21050A, bandwidth 0.02–2000 Hz) placed on the vastus lateralis muscle between the head of the greater trochanter and the lateral condyle of the femur. MMG amplitude was calculated for a time period that corresponded to a 30° range of motion. The results indicated there were significant (p ≤ 0.05) decreases in peak torque at all velocities except 240 versus 300° s⁻¹ and 300 versus 360° s⁻¹. The MMG analysis indicated the MMG amplitude was significantly (p ≤ 0.05) lower at 60° s⁻¹ than at 360° s⁻¹. It was suggested that the increase in MMG amplitude was due to decreased muscle stiffness, which led to greater muscle fiber oscillations.

Evetovich et al. (23)

The purpose of this investigation was to determine if there was a gender difference in the velocity-related patterns of MMG responses to maximal isokinetic
concentric and eccentric muscle actions. Fifteen adult males (mean age ± SD = 22.5 ± 1.7 y; mean height ± SD = 178.1 ± 5.8 cm; mean body mass ± SD = 79.2 ± 7.4 kg) and sixteen adult females (mean age ± SD = 22.8 ± 3.4 y; mean height ± SD = 168.4 ± 7.0 cm; mean body mass ± SD = 63.1 ± 9.4 kg) performed maximal concentric and eccentric isokinetic muscle actions with the dominant leg at 30, 90, and 150° s⁻¹ on a calibrated Cybex 6000 dynamometer. The MMG signal was detected by a piezoelectric crystal contact sensor (HP 21050A, bandwidth 0.02–2000 Hz) placed on the vastus lateralis muscle between the head of the greater trochanter and the lateral condyle of the femur. For both genders, the results indicated decreases in peak torque with increases in velocity for the concentric contractions, while peak torque remained constant across velocities for eccentric contractions. MMG amplitude during the concentric and eccentric contractions increased significantly (p ≤ 0.05) with increasing velocity for both genders. There were no gender-related differences in MMG responses to the eccentric contractions. There was a difference in the pattern of MMG responses to the concentric muscle actions, however, with the males exhibiting a greater rate of increase in MMG amplitude with increasing velocity. The males also had significantly greater (p ≤ 0.05) MMG amplitude values than the females at each velocity. It was concluded that the gender-related differences in concentric MMG responses may have been due to a greater percent decline in peak torque across velocity for females, or differences in muscle and/or thickness of skin and adipose tissue.

Cramer et al. (14)

The purpose of this investigation was to determine the velocity-related patterns for MMG amplitude, EMG amplitude, mean power output, and peak torque of the superficial
muscles of the quadriceps femoris (vastus lateralis, rectus femoris, and vastus medialis) during maximal, concentric, isokinetic leg extensions. Twelve adult women (mean age ± SD = 22 ± 3 y) performed leg extensions with the dominant leg at velocities of 60, 120, 180, 240, and 300° s⁻¹ on a Cybex 6000 dynamometer. The MMG signals were detected by piezoelectric crystal contact sensors (HP 21050A, bandwidth 0.02–2000 Hz). For each muscle, a sensor was placed between the active EMG electrodes. For the EMG measurements, bipolar (7.62 cm center-to-center) surface electrodes (Quinton Quick Prep Ag-AgCl) were placed along the longitudinal axes of the vastus lateralis, rectus femoris, and vastus medialis muscles of the dominant leg. The MMG and EMG amplitude values were calculated for a time period that corresponded to approximately a 90° range of motion. The results indicated there were significant decreases (p ≤ 0.05) in peak torque across all velocities except between 240° and 300° s⁻¹, and significant increases in mean power output from 60 to 120° s⁻¹, 60 to 180° s⁻¹, 60 to 240° s⁻¹, 60 to 300° s⁻¹, and 120 to 240° s⁻¹. A two-way repeated-measures ANOVA (velocity by muscle) for normalized MMG amplitude resulted in a nonsignificant two-way interaction and main effect for muscle, but a significant main effect for velocity. Post-hoc comparisons indicated significant increases in the marginal means of MMG amplitude (collapsed across muscle) from 60 to 180° s⁻¹, 60 to 240° s⁻¹, 60° to 300° s⁻¹, 120 to 240° s⁻¹, and 120 to 300° s⁻¹. Normalized MMG amplitude was significantly correlated (r = 0.52) with normalized mean power output. For normalized EMG amplitude, there was a significant (p ≤ 0.05) two-way velocity by muscle interaction. The statistical model was subsequently decomposed into three (one for each muscle) one-way repeated-measures ANOVAs across velocity with post-hoc comparisons. For the vastus lateralis, there was a significant
(p ≤ 0.05) increase in EMG amplitude from 60 to 240° s⁻¹, only. For the rectus femoris, there were no significant differences (p > 0.05) between the EMG amplitudes at any velocity. For the vastus medialis, there were significant increases (p ≤ 0.05) in EMG amplitude from 60 to 240° s⁻¹ and 60 to 300° s⁻¹. It was concluded that there were dissociations between EMG amplitude, MMG amplitude, and peak torque, and that MMG amplitude was more closely related to mean power output than peak torque during maximal, concentric isokinetic muscle actions.

Cramer et al. (15)
The purpose of this study was to examine the EMG and MMG responses of the superficial muscles of the quadriceps femoris to maximal concentric isokinetic leg extension muscle actions at velocities ranging from 60 to 300° s⁻¹. Eleven male subjects (mean age ± SD = 22 ± 3 y) volunteered to participate. Concentric isokinetic leg extension peak torque of the dominant leg was determined at randomly ordered velocities of 60, 120, 180, 240, and 300° s⁻¹. The MMG signals were detected by piezoelectric crystal contact sensors (HP 21050A, bandwidth 0.02–2000 Hz). For each muscle, (vastus lateralis, rectus femoris, vastus medialis) a sensor was placed between the active EMG electrodes. For the EMG measurements, bipolar (7.62 cm center-to-center) surface electrodes (Quinton Quick Prep Ag-AgCl) were placed along the longitudinal axes of the vastus lateralis, rectus femoris, and vastus medialis muscles of the dominant leg. The MMG and EMG amplitude values were calculated from time periods that approximated a 30° range of motion. The results indicated significant decreases (p ≤ 0.05) in peak torque across all velocities except between 240 and 300° s⁻¹. A two-way repeated measures ANOVA (velocity × muscle) resulted in a significant interaction (p ≤ 0.05). Three
subsequent one-way ANOVAs (one for each muscle across velocity) revealed that MMG amplitude increased for all muscles from 60 to 120° s⁻¹, 60 to 180° s⁻¹, and 120 to 180° s⁻¹. There was also a significant increase (p ≤ 0.05) in MMG amplitude for the vastus lateralis from 180 to 240° s⁻¹. For the vastus medialis, there was a significant increase (p ≤ 0.05) in MMG amplitude from 180 to 300° s⁻¹. The two-way repeated measures ANOVA (velocity × muscle) for the EMG amplitude value did not result in a significant interaction (p > 0.05), but found significant main effects (p ≤ 0.05) for both velocity and muscle. Post-hoc comparisons indicated significant increases (p ≤ 0.05) in EMG amplitude from 60 to 180° s⁻¹ and 120 to 180° s⁻¹. The authors concluded that the different patterns for MMG amplitude across velocity for the three muscles may have been due to different fiber type distributions, muscle architectures (unipennate versus bipennate, or degree of pennation), or the influence of the iliotibial band on the vastus lateralis. It was suggested that the velocity-related dissociation between MMG amplitude and peak torque may have been due to decreased muscle stiffness or an increased rate of actin-myosin cycling. The authors also concluded that there are velocity-related differences between motor unit activation (EMG) and the mechanical aspects (MMG) of muscle activity.

McHugh et al. (34)

The purpose of this investigation was to compare the frequency content of surface EMGs recorded from the quadriceps femoris muscles of 10 men (mean age ± SD = 31.0 ± 7.2 y; mean height ± SD = 1.79 ± 0.06 m; mean body mass ± SD = 88.6 ± 6.6 kg) during concentric and eccentric contractions of differing intensities at 1.05 rad s⁻¹. Each subject performed maximal voluntary contractions (MVC) of the knee extensors followed by submaximal contractions at 25, 50, and 75% of MVC. This sequence was performed
for eccentric, concentric and isometric contraction modes, and the order of contraction
mode was randomized. Eccentric and concentric muscle actions were performed between
0° and 100° of knee flexion, and isometric testing was performed at a joint angle of 70°.
For the submaximal muscle contractions, a visual display of the target force level was
provided by software (Biodex System 2). EMG activity was recorded from electrodes
placed on the vastus lateralis, rectus femoris, and vastus medialis. The telemetered EMGs
were bandpass filtered from 10 to 500 Hz and sampled at 1000 Hz, with a common mode
rejection ratio of 130 dB. EMG amplitude was computed as root mean square (rms) and
the mean frequency was computed from Fast Fourier Transforms (FFT). FFTs were
computed on 512 ms of activity between 30° and 60° of knee flexion for the concentric
and eccentric muscle actions. A 2 × 4 × 3 repeated measures ANOVA was used to
determine the interactions and main effects for the contraction mode (eccentric,
concentric), contraction intensity (25, 50, 75 and 100%), and muscle (vastus lateralis,
rectus femoris, vastus medialis) on mean frequency. The isometric data were not included
in the mean frequency analyses. For the EMG amplitude data, a 3 × 4 × 3 repeated
measures ANOVA was used to determine the interactions and main effects for the
contraction mode (including isometric contractions), contraction intensity, and muscle.
The results indicated that peak knee extension torque was significantly (p ≤ 0.05) lower
for concentric than for eccentric or isometric muscle contractions, which were similar.
Mean frequency was higher for eccentric than for concentric muscle contractions (p ≤ 0.05). The difference in mean frequency between contraction modes was greater at the
lower contraction intensities, and more apparent in the vastus lateralis and rectus femoris
than in the vastus medialis. Mean frequency increased with contraction intensity for the
concentric and isometric muscle contractions (only between 25 and 50% MVC), but not for the eccentric muscle contractions. EMG amplitude increased with contraction intensity for each contraction mode and similarly for each muscle. The EMG amplitude relative to torque was lower for eccentric than concentric muscle contractions. This difference was greater for lower contraction intensities. The authors concluded that the higher mean frequency values observed during eccentric muscle actions was indicative of more fast twitch motor units being active during eccentric contractions.

Cramer et al. (16)

This study examined the responses of peak torque, mean power output, MMG and EMG amplitude and mean power frequency (MPF) of the vastus lateralis, rectus femoris, and vastus medialis in males and females during maximal, concentric isokinetic muscle actions. Fourteen females (mean age ± SD = 22 ± 2 y) and 12 males (mean age ± SD = 22 ± 1 y) volunteered for the study. Concentric isokinetic peak torque was determined on a Cybex 6000 dynamometer at velocities of 60, 120, 180, 240, 300, 360, 420, and 480° s⁻¹. The MMG signals were detected by piezoelectric crystal contact sensors (HP 21050A, bandwidth 0.02–2000 Hz). For each muscle, a sensor was placed between the active EMG electrodes. For the EMG measurements, bipolar (7.62 cm center-to-center) surface electrodes (Quinton Quick Prep Ag-AgCl) were placed along the longitudinal axes of the vastus lateralis, rectus femoris, and vastus medialis muscles of the dominant leg. The MMG and EMG amplitude values were calculated for a time period that corresponded to approximately a 90° range of motion. The results indicated there were no gender differences but there were muscle specific differences in the MMG MPF, EMG amplitude, and EMG MPF responses. MMG amplitude and mean power output increased
from 180-240° s\(^{-1}\), plateaued, then decreased to 480° s\(^{-1}\). For the vastus lateralis and rectus femoris, MMG MPF remained stable to 300° s\(^{-1}\), then increased to 480° s\(^{-1}\). MMG MPF for vastus medialis did not change across velocity. EMG amplitude and MPF decreased across velocity for the rectus femoris and vastus lateralis, respectively. It was concluded that there were muscle- and velocity-specific dissociations among motor control strategies (EMG amplitude and MPF) and mechanical aspects (MMG amplitude and MPF) for the isokinetic muscle actions.

*Beck et al.* (4)

The purpose of this investigation was to examine the MMG and EMG amplitude and MPF versus torque relationships during isokinetic muscle actions of the biceps brachii. Following determination of peak isokinetic torque (at 30° s\(^{-1}\)), twelve subjects (mean age ± SD = 22.2 ± 2.7 y) performed submaximal isokinetic muscle actions with the dominant forearm flexors in random order from 20 to 80% peak torque in 20% increments. The MMG signal was detected by a piezoelectric crystal contact sensor (Hewlett-Packard, 21050A, bandwidth 0.02 – 2,000 Hz) placed over the belly of the biceps brachii muscle. Bipolar surface EMG electrodes (7.62 cm center to center) were placed over the biceps brachii, with the interelectrode distance selected to accommodate placing the MMG sensor between the active electrodes. The amplitude and MPF of the MMG and EMG signals were calculated from a time period that corresponded to a 50° range of motion from approximately 110° to 160° of forearm flexion. Polynomial regression analyses revealed that the MMG amplitude versus percent peak torque relationship was best fit with a linear model (\(r^2 = 0.984\)), while there was no significant (p > 0.05) relationship between MMG MPF and percent peak torque. The EMG
amplitude versus percent peak torque relationship was best fit with a linear model ($r^2 = 0.988$), while there was no significant ($p > 0.05$) relationship between EMG MPF and percent peak torque. The results were similar for MMG and EMG in both the time and frequency domains, and suggested that the dynamic muscle actions were modulated primarily by motor unit recruitment, while the global motor unit firing rate remained relatively unchanged.

*Beck et al. (6)*

The purpose of this study was to determine the MMG amplitude and MPF versus torque relationships during isokinetic and isometric muscle actions of the biceps brachii. Ten adults (mean age ± SD = 21.6 ± 1.7 y) performed submaximal to maximal isokinetic (at 30° s⁻¹) and isometric (at a joint angle of 115°) muscle actions of the dominant forearm flexors on a Cybex II dynamometer. Following determination of isokinetic peak torque and isometric MVC, the subjects randomly performed submaximal step muscle actions in 10% increments from 10 to 90% peak torque and MVC. The MMG signal was detected by a piezoelectric crystal contact sensor (Hewlett-Packard, 21050A, bandwidth 0.02 – 2,000 Hz) placed over the belly of the biceps brachii muscle. The MMG amplitude and MPF values for the isokinetic muscle actions were calculated over a 50° range of motion from approximately 110° to 160° of forearm flexion. Polynomial regression analyses indicated that MMG amplitude increased linearly with torque during both the isokinetic ($r^2 = 0.982$) and isometric ($r^2 = 0.956$) muscle actions. From 80% to 100% of isometric MVC, however, MMG amplitude appeared to plateau. Cubic models provided the best fit for the MMG MPF versus isokinetic ($R^2 = 0.786$) and isometric ($R^2 = 0.940$) torque relationships, although no significant increase ($p > 0.05$) in MMG MPF was found from
10% to 100% of isokinetic PT. For the isometric muscle actions, MMG MPF remained relatively stable from 10 to 50% MVC, increased from 50 to 80% MVC, and decreased from 80 to 100% MVC. The results indicated differences in the MMG amplitude and MPF versus torque relationships for the isokinetic and isometric muscle actions. These authors suggested that the time and frequency domains of the MMG signal may be useful for describing the motor control strategies that modulate dynamic versus isometric torque production.

Coburn et al. (10)

The purpose of this study was to examine the patterns for the MMG amplitude and MPF versus torque relationships during isokinetic and isometric muscle actions of the vastus medialis. Seven men and three women (mean age ± SD = 22 ± 1 y) volunteered to be subjects for this investigation. Concentric, isokinetic leg extension peak torque of the dominant limb (based on kicking preference) was measured using a calibrated Cybex II isokinetic dynamometer at 30° s⁻¹. During a separate visit, maximal isometric torque was determined at a leg flexion angle of 0.785 rad (45°) below the horizontal plane. Subjects were then asked to provide, in random order, concentric isokinetic or isometric muscle actions at 10, 20, 30, 40, 50, 60, 70, 80, and 90% of peak torque or MVC. A two-minute rest was allowed between muscle actions. The MMG signal was detected by a piezoelectric crystal contact sensor (Hewlett-Packard, 21050A, bandwidth 0.02-2000Hz) placed over the belly of the vastus medialis muscle. For the isokinetic muscle actions, the MMG amplitude and frequency values were calculated for a one second time period that corresponded to a 30° range of motion from approximately 120° to 150° of leg flexion. For the isometric muscle actions, the middle two seconds of the six second muscle action
were used for the MMG analyses. Polynomial regression analyses were used to determine the relationships for MMG amplitude and MMG MPF versus torque production. For the isometric muscle actions, the relationships for MMG amplitude ($R^2 = 0.998$) and MPF ($R^2 = 0.987$) versus torque were best fit with cubic models. For the isokinetic muscle actions, the relationships for MMG amplitude ($r^2 = 0.927$) and MPF ($r^2 = 0.769$) versus torque were linear. It was suggested that the differences may have been influenced by the level of muscle stiffness and intramuscular fluid pressure. Isokinetic PT was approximately 90% of the isometric MVC, and thus there may have been less muscle stiffness and intramuscular fluid pressure during the isokinetic than isometric muscle actions. As a result, the isokinetic muscle actions may not have exhibited the plateau and decrease in MMG amplitude that characterized the isometric muscle actions. It is also possible that differences in the motor control strategies may have influenced the MMG amplitude versus torque relationships. For the isokinetic muscle actions, the linear increases for both the MMG amplitude and MPF versus torque relationships suggested concurrent increases in the number of activated motor units and firing rate throughout the entire range of torque production. For the isometric muscle actions, the lack of change in MMG MPF, but increase in MMG amplitude, from 10-40% of peak torque may have reflected the exclusive recruitment of slow twitch motor units. The increased MMG MPF between 40-80% peak torque may have been due to a progressive increase in the recruitment of fast twitch motor units. The continued increase in MMG MPF above 80% peak torque may have reflected the end of motor unit recruitment and a reliance on increased firing rate to produce greater torque production.
Mechanomyographic/Electromyographic Responses to Training

Cerquiglini et al. (9)

The purpose of this study was to evaluate the “athletic fitness” of weight-lifters by evaluating their skill and muscle strength using EMG and MMG. Eleven subjects participated in the study, 9 weight-lifters and 2 subjects unaccustomed to physical exercise. The press, jerk, and snatch lifts were performed for “many days” using loads corresponding to 80% of each athlete’s personal record. EMG and MMG recordings were obtained from the gastrocnemius (medial head) and quadriceps femoris (vastus lateralis). Surface electrodes were used to record the EMG activity, and a microphone was placed between EMG electrodes to record the muscle sound. The results indicated increases in maximal voluntary activation, evidenced by an increased voltage (amplitude) and frequency of the EMG signals. MMG changes included a relative increase of higher frequencies (above 70 Hz). It was concluded that both EMG and MMG contained useful information regarding functional improvements in muscles following training.

Evetovich et al. (22)

The purpose of this investigation was to examine the effects of concentric isokinetic leg extension training on peak torque and MMG responses. Twenty-one adult males (mean age ± SD = 23 ± 3 y; mean height ± SD = 182.3 ± 7.6 cm; mean mass ± SD = 83.8 ± 13.4 kg) were randomly assigned into training (n = 12) or control (n = 9) groups. The training subjects performed 12 weeks of unilateral concentric-only isokinetic leg extensions of the nondominant limb on a Cybex 6000 dynamometer. The concentric isokinetic muscle actions were performed from 90° to full extension at 90°·s⁻¹. The subjects performed 3 sets the first week of training, 4 sets during week 2, 5 sets during
week 3, and 6 sets during weeks 4 through 12. Each set consisted of 10 repetitions, with 2 minutes rest between sets. The training subjects were tested at weeks 0, 4, 8, and 12 weeks. The control subjects were tested at the same time as the training group. The MMG signal was detected by a piezoelectric crystal contact sensor (HP 21050A, bandwidth 0.02–2000 Hz) placed on the vastus lateralis muscle. MMG amplitude values were calculated for a time period corresponding to the middle 30° range of motion, from approximately 60° to 30° of flexion at the knee. For the training group the results indicated a significant increase (p \leq 0.05) in peak torque between pretraining and 12 weeks, pretraining and 8 weeks, and 4 weeks and 12 weeks. For the control group, there was no significant change (p > 0.05) in peak torque over the 12 week period. There was no significant change (p > 0.05) in MMG amplitude for the training or control group over the course of the training period. The authors suggested that the increase in peak torque in the absence of MMG changes may have been due to hypertrophy of the trained muscles and/or changes in other muscles involved in the leg extension exercise.

Evetovich et al. (25)

The purpose of this study was to determine the effect of concentric isokinetic leg extension training on the MPF of the MMG signal. Twenty-one men were randomly assigned to either a training (n = 12) or control (n = 9) group. Subjects in the training group performed unilateral concentric isokinetic leg extensions with the nondominant quadriceps femoris for 12 weeks on a Cybex 6000 dynamometer. Training was performed 3 times per week, and consisted of maximal concentric isokinetic muscle actions at 90° s⁻¹. The subjects performed 3 sets the first week of training, 4 sets during week 2, 5 sets during week 3, and 6 sets during weeks 4 through 12. Each set consisted of
10 repetitions, with 2 minutes rest between sets. The training and control subjects were tested at weeks 0, 4, 8, and 12 weeks. The MMG signal was detected by a piezoelectric crystal contact sensor (HP 21050A, bandwidth 0.02–2000 Hz) placed on the vastus lateralis muscle. MMG MPF values were calculated for a time period corresponding to the middle 30° range of motion, from approximately 120° to 150° of flexion at the knee. The results revealed a significant increase (p ≤ 0.05) in peak torque from pretraining to 12 weeks, pretraining to 8 weeks, and between 4 and 12 weeks for the training group. There was no significant change (p > 0.05) in peak torque for the control group over the 12 week training period. However, there was no significant change (p > 0.05) in MMG MPF for either the training or control group. It was concluded that MMG MPF measured from the vastus lateralis was not sensitive to training-induced increases in leg extension strength, possibly due to hypertrophy and/or training-induced adaptations in other muscles. 

Evetovich et al. (21)

The purpose of this study was to determine the effects of unilateral concentric isokinetic leg extension training on peak torque and EMG responses in the trained and untrained limbs. Twenty adult men (mean age ± SD = 22.2 ± 2.8 y) volunteered and were randomly assigned to a training (n = 11) or control (n = 9) group. The training subjects performed 12 weeks of unilateral concentric-only isokinetic leg extension training of the nondominant limb on a Cybex 6000 dynamometer. Training was performed 3 times per week at a velocity of 90° s⁻¹. The subjects performed 3 sets the first week of training, 4 sets during week 2, 5 sets during week 3, and 6 sets during weeks 4 through 12. Each set consisted of 10 repetitions, with 2 minutes rest between sets. The training subjects were
tested at weeks 0, 4, 8, and 12 weeks. Both limbs were tested at a velocity of 90° s⁻¹ on the same Cybex 6000 dynamometer used for training. The control subjects were tested at the same time as the training group. For the EMG measurements, bipolar (7.62 cm center-to-center) surface electrodes (Quinton Quick Prep Ag-AgCl) were placed on the vastus lateralis muscle between the head of the greater trochanter and the lateral condyle of the femur. EMG amplitude values were calculated for a time period corresponding to the middle 30° range of motion, from approximately 120° to 150° of flexion at the knee. Mixed factorial ANOVAs indicated that for the training group, there were significant increases in peak torque of the trained limb for 0 vs. 4, 0 vs. 8, 0 vs. 12, and 4 vs. 12 weeks. Peak torque of the trained limb increased 15.5% over the 12 week training program. There was a 5.5% increase in peak torque for the untrained limb over the 12 week training program, with significant increases (p ≤ 0.05) for 0 vs. 12, 4 vs. 12, and 8 vs. 12 weeks. For the control group, there was no significant increase (p > 0.05) in peak torque for either limb over the 12 weeks. Results of a 3-way ANOVA for EMG amplitude showed there were no significant 3-way or 2-way interactions or main effects (p > 0.05) for group, week, or limb. It was concluded that the increase in peak torque in the absence of EMG changes resulted from hypertrophy of the trained limb or changes in other muscles involved in the leg extension exercise. It was suggested that such changes might include improved coordination of agonist muscles or decreased antagonist concontraction.

Ebersole et al. (18)

The purpose of this study was to examine the effects of unilateral, isometric training of the forearm flexors on the strength and the MMG and EMG responses of the
biceps brachii in the trained and untrained limb at three joint angles. Seventeen adult
women (mean age ± SD = 21 ± 2 y) volunteered for the study and were randomly
assigned to training (n = 10) and control (n = 7) groups. All subjects performed isometric
muscle actions of the dominant and nondominant forearm flexors on a Cybex II
dynamometer, at joint angles where the lever arm of the Cybex II was 30°, 60° and 90°
above the horizontal plane. After determination of the MVC, subjects performed
submaximal muscle actions at 25, 50, 75% MVC. The training and control subjects were
retested at 4 and 8 weeks following the initial testing. The training group performed
isometric training of the nondominant forearm flexors 3 times per week for 8 weeks.
Training consisted of isometric muscle actions at 80% MVC at a joint angle where the
Cybex II lever arm was 60° above the horizontal plane. The subjects performed 2 sets the
first 2 weeks of training, 4 sets during weeks 3 and 4, and 5 sets during weeks 5 through
8. Each set consisted of eight 6-second muscle actions. The MMG signal was detected by
a piezoelectric crystal contact sensor (HP 21050A, bandwidth 0.02–2000 Hz). The sensor
was placed between the active EMG electrodes. For the EMG measurements, bipolar
(7.62 cm center-to-center) surface electrodes (Quinton Quick Prep Ag-AgCl) were placed
over the belly of the biceps brachii muscle. MMG and EMG amplitude values were
calculated from a 2-second time period corresponding to the second and third seconds of
the 4-second isometric muscle actions. Flexed arm circumferences of the dominant and
nondominant arms were measured with a cloth tape at weeks 0, 4, and 8. The results
showed no change in the flexed arm circumference of the dominant or nondominant arm
of the control group, or of the dominant (untrained) limb of the training group. Flexed
arm circumference of the nondominant (trained) limb increased significantly (p ≤ 0.05)
from weeks 0 to 8 and weeks 4 to 8, however. For the control group, there were no
changes in isometric torque production across the 8 weeks. For the nondominant (trained
limb) of the training group, isometric torque production at 30° and 90° increased
significantly (p ≤ 0.05) from weeks 0 to 8, and at 60° from weeks 0 and 4 to 8. There
were no changes in MMG or EMG amplitude in the nondominant or dominant limb. The
authors concluded that the strength increases may have been due to hypertrophic, rather
than neural adaptations, and that the hypertrophy may have affected the MMG signal in
such a way that it prevented a training-induced change in the MMG amplitude.
CHAPTER III

METHODS

Subjects

Thirty adult subjects between the ages of 19 and 29 years of age will volunteer for this study. All subjects will complete a health history questionnaire and written statement of informed consent prior to testing and/or training. The subjects will be randomly assigned to one of three groups: 1) control group (n = 10); 2) slow velocity training group (n = 10); or 3) fast velocity training group (n = 10). The study will require two (control group) or five (slow velocity and fast velocity training groups) visits, lasting approximately one hour per visit. All subjects will be tested on visits 1 and 5, and the two training groups will train on visits 2, 3, and 4. There will be 48-72 hours between testing and/or training sessions.

<table>
<thead>
<tr>
<th>Testing</th>
<th>Training</th>
<th>Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control and Training Groups</td>
<td>48 to 72 hrs</td>
<td>Visit 2</td>
</tr>
<tr>
<td>Analysis Groups</td>
<td>48 to 72 hrs</td>
<td>Visit 3</td>
</tr>
<tr>
<td>Training Groups</td>
<td>48 to 72 hrs</td>
<td>Visit 4</td>
</tr>
<tr>
<td>Training Groups</td>
<td>48 to 72 hrs</td>
<td>Visit 5</td>
</tr>
<tr>
<td>Control and Training Groups</td>
<td>48 to 72 hrs</td>
<td></td>
</tr>
</tbody>
</table>

Strength Testing

Following a five-minute warm-up on a cycle ergometer, subjects will perform three maximal, concentric isokinetic muscle actions of the leg extensors of the nondominant leg (based on kicking preference) at each of three velocities (30, 150, and 270° s⁻¹) on a Cybex II dynamometer for the determination of peak torque (PT). The order of testing for velocities will be randomized. A two minute rest period will be
allowed between each tested velocity. The subjects will be verbally encouraged to produce as much torque as possible. During each isokinetic testing session, surface EMG and MMG will be measured from the vastus lateralis, rectus femoris, and vastus medialis muscles.

*Training Protocol*

The training groups will perform slow velocity ($30^\circ \cdot s^{-1}$) or fast velocity ($270^\circ \cdot s^{-1}$) training. The subjects in each training group will perform four sets of 10 maximal, concentric isokinetic leg extension muscle actions at their respective velocities on visits 2, 3, and 4.

*Electromyographic Measurements*

Three separate bipolar (4.2 cm center-to-center) surface electrode (Quinton Quick Prep silver-silver chloride) arrangements will be placed over the longitudinal axes of the vastus lateralis, rectus femoris, and vastus medialis muscles. The electrodes for the vastus lateralis will be placed over the lateral portion of the muscle at approximately the midpoint between the head of the greater trochanter and the lateral condyle of the femur. For the rectus femoris, the electrodes will be placed at 50% the distance between the inguinal crease and the superior border of the patella. The electrode placement for the vastus medialis will be 20% of the distance between the medial gap of the knee joint and the anterior superior spine of the pelvis (45). The reference electrodes will be placed over the iliac crest. Interelectrode impedance will be kept below 2000 Ohms by shaving the area and careful skin abrasion. The EMG signal will be preamplified (gain $1000 \times$) using a differential amplifier (EMG 100, Biopac Systems Inc., Santa Barbara, CA; bandwidth = 1-5000 Hz).
**Mechanomyographic Measurements**

The MMG signal will be detected by accelerometers (Entran, EGAS-FT-10-V05). The accelerometers will be placed over the bellies of the vastus lateralis, rectus femoris, and vastus medialis muscles between the active EMG electrodes. Double-sided foam tape will be used to fix the accelerometers to the muscles.

**Signal Processing**

The raw EMG and MMG signals will be stored and displayed on a personal computer (AcqKnowledge III, Biopac Systems Inc., Santa Barbara, CA). The sampling frequency will be 1000 Hz for all signals. The EMG and MMG signals will be bandpass filtered (fourth-order Butterworth filter) at 5-100 Hz and 10-500 Hz, respectively. The EMG and MMG amplitude and frequency values will be calculated for a time period that corresponds to a 50° range of motion from approximately 110° to 160° of leg flexion (i.e., at 30°s⁻¹ the amplitudes and frequencies for 1.67 s of the MMG and EMG signals will be calculated, at 150°s⁻¹ the amplitudes and frequencies for 0.33 s will be calculated, and at 270°s⁻¹ the amplitudes and frequencies for 0.19 s will be calculated). This range of motion will be selected to avoid the acceleration and deceleration phases that are typical of isokinetic dynamometers (8). The amplitude of the signals will be expressed as root mean square (rms) amplitude values. All frequency analyses will be performed with custom programs written with LabVIEW software (version 7.0, National Instruments, Austin, Texas) and expressed as hertz (Hz). Each EMG and MMG data segment will be processed with a Hamming window and Discrete Fourier Transformation (DFT). We will use DFT, as opposed to Fast Fourier Transformations (FFT), because the DFT is not constrained to 2ⁿ number of data points (27). Therefore, DFT analyses will be performed
without having to truncate the data segments or resort to zero padding. Frequency data will be expressed as mean power frequency (MPF).

*Statistical Analysis*

Prior to the statistical analyses, each subject’s data will be normalized to their highest recorded value during a 6 s isometric muscle action for PT, MMG amplitude, EMG amplitude, MMG MPF, and EMG MPF. Isokinetic PT data will be analyzed using a 3-way (velocity [30, 150, and 270° s⁻¹] × time [pretraining, posttraining] × group [slow velocity, fast velocity, control]) mixed factorial ANOVA. MMG and EMG data will be analyzed using 4-way (muscle [vastus lateralis, rectus femoris, vastus medialis] × velocity [30, 150, and 270° s⁻¹] × time [pretraining, posttraining] × group [slow velocity, fast velocity, control]) mixed factorial ANOVAs. An alpha of p ≤ 0.05 will be considered significant for all comparisons.
REFERENCES


27. GNIEWICK, M.T. *Waveform analysis using Fourier transform*: Dataq Instruments, 1991


