GENDER COMPARISONS AMONG PEAK TORQUE, MEAN POWER OUTPUT, MECHANOMYOGRAPHIC AND ELECTROMYOGRAPHIC RESPONSES DURING MAXIMAL, ECCENTRIC ISOKINETIC MUSCLE ACTIONS

by

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GENDER COMPARISONS AMONG PEAK TORQUE, MEAN POWER OUTPUT, MECHANOMYOGRAPHIC AND ELECTROMYOGRAPHIC RESPONSES DURING MAXIMAL, ECCENTRIC ISOKINETIC MUSCLE ACTIONS

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The purpose of the present investigation was to examine the velocity-related patterns for mechanomyographic (MMG) amplitude, electromyographic (EMG) amplitude, mean power output (MP), and peak torque (PT) of the superficial muscles of the quadriceps femoris (vastus lateralis=VL, rectus femoris=RF, vastus medialis=VM) in males and females during maximal, eccentric isokinetic muscle actions of the leg extensors. Thirteen females (mean±SD age=21±1 years) and eleven males (mean±SD age=21±2 years) volunteered for this investigation.

PT was measured on a calibrated Cybex 6000 dynamometer at randomly ordered velocities of 60, 120, and 180°·s⁻¹. Piezoelectric MMG recording sensors were placed between bipolar surface EMG electrodes (Ag-AgCl) over the VL, RF, and VM muscles. MP was determined by the dynamometer software. The results indicated no gender-related differences (p>0.05) for the patterns of PT, MP, MMG amplitude, or EMG amplitude. Furthermore, no muscle-related differences (p>0.05) were found for the patterns of MMG amplitude or EMG amplitude. The normalized values for MP and MMG amplitude increased (p<0.05) from 60 to 180°·s⁻¹ (60°·s⁻¹<120°·s⁻¹<180°·s⁻¹). PT
remained unchanged (p>0.05) across velocity, while EMG amplitude remained unchanged (p>0.05) from 60 to 120°·s⁻¹, but decreased (approximately 10%, p<0.05) from 120 to 180°·s⁻¹. The findings indicated a close association between the patterns for MP and MMG amplitude, and a similarity between the patterns for PT and EMG amplitude across velocity. Therefore, these findings suggested that EMG amplitude reflected force development, while MMG amplitude reflected power output. The amplitude and frequency domains of EMG and MMG signals may provide insight into the electrical and mechanical aspects of training-induced changes in muscle strength and power.
Mechnomyography (MMG) is the recording of low frequency sound waves generated by the lateral oscillations of a muscle during activity. Electromyography (EMG) is the recording of muscle action potentials (or their currents) that arise at the muscle fiber membrane (or sarcolemma) and pass lengthwise through the fiber in wavelike form as the fiber is stimulated to contract. It has been suggested that MMG reflects the mechanical properties of muscle activity, while EMG reflects the electrical properties of the muscle. MMG has been used to discriminate between muscle fiber types, monitor muscle fatigue, and evaluate the mechanical changes that occur with strength training. EMG has been used to monitor changes in muscle force output as well as the neural adaptations to strength training. Previous studies have reported dissociations among MMG amplitude, EMG amplitude, and peak torque, but close relationships between MMG amplitude and mean power output during maximal, concentric isokinetic muscle actions. That is, as the velocity of concentric muscle actions increased, MMG amplitude and mean power output increased, while peak torque decreased. Therefore, the purpose of the present investigation was to examine the relationships among MMG amplitude, EMG amplitude, mean power output, and peak torque for males and females during maximal, eccentric isokinetic muscle actions at 60, 120, and 180°·s⁻¹.
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CHAPTER I

INTRODUCTION

Mechanomyography (MMG) records and quantifies the low-frequency lateral oscillations of contracting skeletal muscle fibers (5-7,27,50,68,78). Gordon and Holbourn (28) suggested that MMG reflects the “mechanical counterpart” of motor unit activity as measured by electromyography (EMG). Barry and Cole (6,7) and Orizio et al. (49-51) have indicated that the lateral oscillations recorded as MMG are generated by: (1) a gross lateral movement of the muscle at the initiation of a contraction that is generated by non-simultaneous activation of muscle fibers, (2) smaller subsequent lateral oscillations occurring at the resonant frequency of the muscle, and (3) dimensional changes of the active muscle fibers. The MMG amplitude, however, is influenced by many factors including muscle stiffness, tension, length, mass, intramuscular pressure, the viscosity of the surrounding medium, and the motor unit firing frequency (5-7,27,41,50,51).

Most previous studies have examined MMG responses during isometric muscle actions (1,19-21,47,48,51,53,54,60,64,69,76). Recent studies, however, have investigated the MMG amplitude responses during isokinetic (14,15,22-24,62,63) and isotonic (17,55) muscle actions as well as cycle ergometry (61,70). Cramer et al. (14,15), Evetovich et al. (22-24), and Smith et al. (62,63) have reported velocity-related dissociations between MMG amplitude and peak torque (PT) during maximal, concentric isokinetic muscle actions. That is, as velocity increased, MMG amplitude increased, while PT decreased (14,15,22-24,62-63). Furthermore, Evetovich et al. (23) reported gender differences in the velocity-related pattern for MMG amplitude during concentric
isokinetic muscle actions. Recently, however, Bodor (9) suggested that MMG amplitude may be more closely related to muscle power output than isokinetic PT. Bodor’s (9) hypothesis was supported by Cramer et al. (14) who reported similar patterns of increase for MMG amplitude and mean power output during maximal, concentric isokinetic muscle actions. There have been no studies to date, however, that have examined these relationships during maximal eccentric muscle actions. Therefore, the present study was designed to test Bodor’s (9) hypothesis by determining the velocity-related patterns for MMG amplitude, EMG amplitude, mean power output (MP), and PT of the superficial muscles of the quadriceps femoris in males and females during maximal, eccentric isokinetic muscle actions of the leg extensors at 60, 120, and 180°·s⁻¹.
CHAPTER II

REVIEW OF LITERATURE

Mechanomyography Studies During Dynamic Muscle Actions

Dalton and Stokes Study (1991)

The purpose of this study was to determine the relationship between MMG and torque during dynamic, isotonic muscle actions. Eight male subjects (age=17 to 26 years) volunteered for this study. Simultaneous mechanomyography (MMG) (Tandy 270-090, Tandy Electronics, Brisbane) and electromyography (EMG) (surface bipolar configuration with an interelectrode distance of 15 mm) of the right biceps brachii muscle were measured during concentric and eccentric isotonic muscle actions. Three muscle actions of the forearm were performed to 90° by lifting and lowering each of the nine weights (0, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5, 7.5, and 8.5 kg) with a speed of three seconds for each direction and a three-second pause at the end of each movement. Five minutes of rest between sets was given to avoid fatigue. The results indicated that both the MMG and EMG signals demonstrated a positive linear relationship with increasing load for concentric (r=0.94 and 0.99, respectively) and eccentric (r=0.90 and 0.94, respectively) muscle actions. The authors concluded that MMG could be used to detect changes in torque during dynamic isotonic muscle actions.

Petitjean, Maton, and Cnockaert Study (1992)

Petitjean et al. (55) investigated the relationship between MMG and torque during dynamic, isotonic muscle actions. Eight male (n=6) and female (n=2) subjects (mean age
± SD=38.5 ± 7.7 yrs) volunteered to participate in this study. Electret condenser microphones (Yamashita Communications; bandwidth=5Hz-15kHz) and silver-silver chloride (Ag-Ag Cl), bipolar surface electrodes were used to record the MMG and EMG signals, respectively, from the biceps brachii, brachioradialis, and triceps brachii muscles during right forearm flexion at two different speeds (“fast” and “slow”). The results indicated a positive linear relationship between MMG versus torque ($r^2=0.85$) as well as a greater MMG amplitude during the fast versus slow speeds. Furthermore, phono- and electro-mechanical delays were measured and were defined as the time lag between the onset of MMG and onset of acceleration (phono-mechanical) or the onset of EMG and onset of acceleration (electro-mechanical). These results showed that phono-mechanical delay followed the electro-mechanical delay but preceded the onset of acceleration. The investigators concluded that MMG, like EMG, may reflect changes in muscle torque during dynamic muscle actions.


Evetovich et al. (24) examined the effects of muscle action velocity on the MMG responses to maximal, concentric isokinetic leg extension movements. Eight adult males (mean age ± SD=22.3 ± 1.3 yrs) performed maximal extensions of the dominant leg on a calibrated Cybex 6000 dynamometer at velocities of 60, 120, 180, 240, 300, and 360°⋅s$^{-1}$. Piezoelectric crystal contact sensors (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) were placed over the vastus lateralis muscle to record the MMG signal. The MMG amplitudes were analyzed from a sample corresponding to the middle 30° of the range of motion. Intraclass reliability correlations ranged from 0.90 to 0.99 for peak torque and
MMG amplitude values, respectively, with no significant differences (p>0.05) between the mean values for test versus retest at any contraction velocity. There was a velocity-related decrease (p<0.05) in peak torque from 60 to 240° s\(^{-1}\) with no significant difference (p>0.05) between 240 and 300° s\(^{-1}\) or 300 and 360° s\(^{-1}\). MMG amplitude increased significantly (p<0.05) with velocity from 60 to 360° s\(^{-1}\). The results of this study indicated a velocity-related dissociation between MMG amplitude and peak torque. The authors also hypothesized that the increases in the MMG amplitude were a result of velocity-related decreases in muscle stiffness.

Smith, Housh, Johnson, et al. Study (1997)

Smith et al. (63) examined the effects of forearm angular velocity on the MMG and EMG responses to concentric and eccentric isokinetic muscle actions. Ten males (mean age ± SD=23 ± 2 yrs) volunteered to perform maximal concentric and eccentric muscle actions of the forearm flexors at 30, 90, and 150° s\(^{-1}\). A piezoelectric crystal contact sensor (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) was used to measure MMG and a bipolar surface electrode (Quinton Quick Prep, Ag-Ag Cl) arrangement was used to measure EMG of the biceps brachii. MMG and EMG amplitudes were analyzed from a sample corresponding to the middle 30° of the range of motion. Peak torque decreased (p<0.05) across velocity during the concentric muscle actions, but remained unchanged (p>0.05) during the eccentric muscle actions. MMG amplitude increased (p<0.05) across velocity during either of the muscle actions, but there was no change (p>0.05) in EMG amplitude across velocity during the concentric or the eccentric muscle actions. The results showed velocity-related dissociations among the PT, MMG, and
EMG responses to maximal concentric and eccentric muscle actions of the biceps brachii.


The purpose of this study was to determine whether there was a gender difference in the velocity-related patterns of MMG responses to maximal, concentric and eccentric isokinetic muscle actions. Fifteen adult males (mean age ± SD=22.5 ± 1.7 yrs) and sixteen adult females (mean age ± SD=22.8 ± 3.4 yrs) volunteered to perform maximal, concentric and eccentric isokinetic muscle actions of the leg extensors on a calibrated Cybex 6000 dynamometer at velocities of 30, 90, and 150°·s⁻¹. The MMG signal was detected by a piezoelectric crystal contact sensor (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) placed over the vastus lateralis muscle. Peak torque decreased (p<0.05) as velocity increased during the concentric muscle actions but remained unchanged (p>0.05) during the eccentric muscle actions for both genders. The MMG amplitude increased (p<0.05) across velocity during both concentric and eccentric muscle actions for both genders. There was a significant gender difference (p<0.05) in the velocity-related patterns of MMG amplitude responses to maximal, concentric isokinetic muscle actions, but no significant (p>0.05) difference between genders for MMG amplitude across velocity during maximal eccentric muscle actions. The results indicated velocity-related dissociations between the MMG amplitude and peak torque for both males and females during concentric and eccentric muscle actions. The investigators concluded that the gender-specific differences in concentric muscle actions may have been attributable to a greater percent decline in concentric peak torque for the females than the males.
Furthermore, the males exhibited greater concentric and eccentric MMG amplitudes than the females at all muscle action velocities, possibly due to gender differences in muscle mass and/or thickness of the adipose tissue layer.


The purpose of this study was to examine the effects of concentric isokinetic strength training on the peak torque and MMG responses of the vastus lateralis muscle during knee extensions. Twenty-one males (mean age ± SD=23 ± 3 yrs) were randomly assigned into a training group (n=12) or a control group (n=9). The training group performed six sets of ten leg extensions three days per week for twelve weeks at 90°·s⁻¹. All subjects were tested every four weeks for peak torque and MMG responses at 90°·s⁻¹ on a calibrated Cybex 6000 isokinetic dynamometer. A piezoelectric crystal contact sensor (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) was used to detect the MMG signal. The two-way mixed factorial ANOVA (group x time) resulted in a significant increase (p<0.05) in peak torque over the twelve-week training period for the training group but no significant change (p>0.05) in peak torque for the control group. For MMG, there was no significant (p>0.05) interaction; therefore, the training and control groups exhibited the same pattern of MMG amplitude responses over the twelve-week training period. The results indicated that peak torque increased but there was no concurrent change in MMG amplitude responses. The authors concluded that the absence of change in MMG may be due to competing influences of training-induced hypertrophy and/or the contribution of other adjacent muscles during the leg extension action.
Shinohara, Kouzaki, Yoshihisa, et al. Study (1998)

Shinohara et al. (60) investigated the time- and frequency-domain responses of the MMG signals of the three superficial muscles of the quadriceps femoris (vastus lateralis=VL, rectus femoris=RF, and vastus medialis=VM) during intermittent, incremental isometric muscle actions to fatigue. Seven adult males (mean age ± SD=25 ± 1 yrs) volunteered to perform isometric knee extensions lasting 7.6 minutes. The intermittent, incremental isometric muscle actions started at 1% of the maximal voluntary contraction (MVC) for three seconds with a three-second relaxation period between each muscle action. The intensity was increased by 1% of MVC for every muscle action (or increased 10% of MVC per minute) until exhaustion. MMG signals were also recorded during separate, non-fatiguing muscle actions with rest periods that allowed for recovery but corresponded to the same percentage of MVC as the intermittent muscle actions. The results indicated that MMG increased linearly with force production for each muscle (VL, RF, and VM) when fatigue was not involved. When fatigue was introduced, MMG amplitude increased with force production to approximately 60% MVC and then decreased thereafter. This pattern was not the same, however, for each muscle. For the VL and VM, MMG amplitude was higher during the intermittent incremental muscle actions than the non-fatiguing muscle actions while for the RF, MMG amplitude was approximately the same during both the non-fatiguing and intermittent incremental muscle actions. The authors concluded that analysis of MMG in the time- and
frequency-domain during an incremental protocol is a useful way of characterizing the
motor unit recruitment strategy and fatigue properties of individual muscles.

**Kouzaki, Shinohara, and Fukunaga Study (1999)**

Kouzaki et al. (38) hypothesized that the superficial muscles of the quadriceps
femoris (VL, RF, and VM) may exhibit different non-uniform patterns of MMG
amplitude and/or frequency during fatiguing activity. Seven adult males (mean age ±
SD=24.4 ± 1.4 yrs) performed 50 maximal, unilateral isometric knee extensions lasting
three seconds each with a three-second relaxation period between contractions.
Piezoelectric microphones and bipolar configurations of Ag-Ag Cl electrodes were used
to measure MMG and EMG, respectively, from the VL, RF, and VM muscles of the right
thigh. Isometric tension was measured with a force transducer attached to the ankle. The
results showed that mean force decreased during fatigue to 49.5% MVC. Each muscle
exhibited the same pattern of decrease for integrated EMG (iEMG) during the fatiguing
activity. For integrated MMG (iMMG), however, there was a marked non-uniformity in
the pattern of decrease between muscles, that is, the fall in iMMG during fatigue was
most prominent for the RF, followed by the VM and VL. Furthermore, the MMG center
frequency and iEMG for the RF were significantly greater (p<0.05) than those recorded
for the VL and VM. Kouzaki et al. (38) concluded that these results suggested a
“divergence of mechanical activity” (p. 9) between the superficial muscles of the
quadriceps femoris during fatigue brought about by maximal, repeated isometric muscle
actions.

**Ebersole, Housh, Johnson, et al. Study (1999)**
The study by Ebersole et al. (19) investigated the MMG and EMG responses of
the VL, RF, and VM during incremental isometric muscle actions at leg flexion angles of
25°, 50°, and 75° below full extension. Eighteen adult male and female subjects (mean
age ± SD=23.3 ± 2.58 yrs) volunteered to perform isometric muscle actions of the leg
extensors at 25, 50, 75, and 100% MVC at leg flexion angles of 25°, 50°, and 75°.
Piezoelectric crystal contact sensors and bipolar surface electrode arrangements were
placed over the VL, RF, and VM to measure MMG and EMG, respectively. Isometric
torque was measured with a calibrated Cybex 6000 dynamometer. The results showed
that maximal isometric torque production increased as leg flexion angle increased. EMG
amplitude increased up to 100% MVC at each flexion angle (25°, 50°, and 75°) for each
muscle (VL, RF, and VM). MMG amplitude, however, increased up to 100% at 25° and
50° of leg flexion, but plateaued from 75-100% MVC at 75° of leg flexion. Therefore,
the pattern of MMG amplitude responses to increasing intensities of isometric torque
production was leg flexion angle specific. The authors concluded that the differences in
patterns of MMG amplitude responses to incremental isometric torque production were
due to leg flexion angle specific differences in muscle stiffness, intramuscular fluid
pressure, and/or motor unit firing frequency.


The purpose of this study was to investigate the MMG and EMG responses of the
superficial muscles of the quadriceps femoris during maximal, concentric isokinetic
muscle actions. Eleven adult males (mean age ± SD=22 ± 3 yrs) performed maximal,
concentric isokinetic leg extensions at velocities of 60, 120, 180, 240, and 300° s⁻¹ on a
calibrated Cybex 6000 dynamometer. Piezoelectric crystal contact sensors (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) and bipolar surface electrode (Quinton Quick Prep, Ag-Ag Cl) arrangements were placed on the VL, RF, and VM to measure the MMG and EMG signals, respectively. The results showed that peak torque decreased \((p<0.05)\) as muscle action velocity increased. The two-way interaction (muscle by velocity) indicated that MMG amplitude increased to \(180^\circ \cdot s^{-1}\) for each muscle (VL, RF, and VM) and continued to increase to \(240^\circ \cdot s^{-1}\) for the VL, plateaued from 180 to \(300^\circ \cdot s^{-1}\) for the RF, and increased to \(300^\circ \cdot s^{-1}\) for the VM. EMG amplitude increased to \(180^\circ \cdot s^{-1}\) and plateaued for each muscle. Cramer et al. (15) concluded that the differences in the velocity related patterns for MMG amplitudes of the superficial quadriceps femoris muscles may be attributable to differences in fiber type composition, muscle architecture, and/or tissue layer composition. Furthermore, the results suggested that there were muscle-specific, velocity-related differences in the association between motor unit activation (EMG) and the mechanical aspects of muscular activity (MMG).

**Mechanomyography and Muscle Power Studies**

Shinohara, Kouzaki, Yoshihisa, et al. Study (1997)

The purpose of this investigation was to examine the MMG and EMG responses of the vastus lateralis (VL) during maximal incremental cycle ergometry. Nine male subjects (mean age \(\pm SD=25.6 \pm 3.1\)) pedaled on an electronically braked cycle ergometer (232C Model50, COMBI, Japan) at 60 revolutions per minute (r.p.m.) while workload was increased by 20 watts (W) every minute until exhaustion. MMG
(piezoelectric contact microphone, 26 mm diameter, VINE, Japan) and EMG (bipolar configuration of surface Ag-Ag Cl electrodes, 5 mm diameter) amplitude for the right vastus lateralis muscle was determined by full-wave rectification and averaged across the last six muscle actions of each workload. In an attempt to investigate the noise component of the MMG signal, four subjects also completed passive cycling during the first half of each stage (i.e. without force production by the subjects, the pedals were rotated by an external force while their feet remaining in contact with the pedals). The mean duration, load and work rate of exercise at exhaustion were 13.3 min, 44.1 Nm, and 276.7 W, respectively. The results indicated that the MMG amplitude increased linearly with load to exhaustion ($r=0.868-0.995$). EMG amplitude, however, seemed to dissociate as the load became greater. Regarding noise artifact, the MMG amplitude during the lighter loads for the passive motion was approximately equal to the active motion, however, the increase in MMG amplitude during the higher loads for the active motions was much greater than the increase in MMG amplitude for the passive motions. Shinohara et al. (61) concluded that these results demonstrated a linear relationship between MMG amplitude of the VL and work rate (power) during maximal incremental cycle ergometry. Furthermore, the authors reported that the effect of movement noise cannot be disregarded, however, noise artifact in the present study was small and relatively stable throughout the load increases.

Stout, Housh, Johnson, et al. Study (1997)

The purpose of this investigation was to describe and compare the relationships for MMG and oxygen consumption rate ($\text{VO}_2$) versus power output during incremental
cycle ergometry to fatigue. Twenty-four adult males (mean age ± SD=22.1 ± 2.0 yrs) performed incremental cycle ergometry to exhaustion on a Coval 400 calibrated, electronically braked cycle ergometer (Quinton Instruments, Seattle, WA). A piezoelectric crystal contact sensor (Hewlett-Packard 2105A, bandwidth 0.2-2000 Hz) was used to measure the MMG signal for the vastus lateralis. Gas exchange parameters were recorded every 15 seconds using a calibrated Horizon Metabolic Measurement Cart (Sensormedics, Anaheim, CA). The results showed a positive linear relationship between MMG amplitude versus power output (r²=0.79-0.99) and VO₂ versus power output (r²=0.97-0.99). In 20 of the 24 subjects tested, there was no significant difference (p>0.05) between the slope values of the absolute versus relative (expressed as a percentage of maximum value achieved) expression of values for the MMG and VO₂ versus power output relationships. The authors suggested that MMG procedures could be used to monitor changes in exercise intensity during incremental cycle ergometry. Moreover, the results of this investigation indicated a close association between the mechanical aspects (MMG) and metabolic characteristics (VO₂) of muscle function during incremental cycle ergometry.

Bodor’s Letter to the Editor (1999)

In a recent letter to the editor of Muscle & Nerve, Bodor (9) hypothesized that the MMG amplitude may be more closely associated with muscle power than peak torque during maximal, dynamic isokinetic muscle actions. For this letter, data (MMG amplitude and maximal isokinetic torque versus contractile velocity) were extracted from articles by Evetovich et al. (24) and Smith et al. (62) that had previously demonstrated
velocity-related dissociations between MMG amplitude and peak torque during maximal, dynamic isokinetic muscle actions of the vastus lateralis and biceps femoris, respectively. To simulate a test for his hypothesis, Bodor (9) plotted MMG amplitude as a function of muscle power (determined by the product of force times velocity) from the extracted data (24,62). The results showed a positive linear relationship between MMG amplitude and muscle power for maximal, concentric isokinetic muscle actions of the vastus lateralis (24) as well as maximal, concentric and eccentric isokinetic muscle actions of the biceps brachii (62). Bodor (9) claimed that the relationship between MMG amplitude and muscle power is “. . . consistent with the laws of physics governing amplitude and power for vibrating systems.” (p. 650) An analogy was drawn to playing a violin which illustrated that the amplitude of a violin string can be increased by “. . . increasing the vertical pressure on the bow (force) or by bowing faster (velocity) or both.” (p. 650) For muscles, like other machines, power generation is often accompanied by vibration; therefore, Bodor (9) concluded that MMG amplitude may be proportional to muscle power during maximal, dynamic isokinetic muscle actions.

Electromyography Studies

Barnes Study (1980)

The investigation by Barnes (3) was designed to examine two primary issues: a) the relationship between iEMG and muscle action velocity, and b) the relationships between mechanical work, power output, peak torque, and mean torque versus muscle action velocity and iEMG. Six adult male subjects volunteered to perform four maximal,
concentric isokinetic muscle actions of the forearm flexors at speeds of 60, 120, 180, 240, and 300°·s⁻¹ on a Cybex II isokinetic dynamometer. Torque production curves were recorded by a multichannel recording device (Beckman 612R Dynagraph) while EMG was measured by a bipolar arrangement of surface electrodes (frequency spectrum=5.3-1000 Hz) placed over the belly of the right biceps brachii muscle. The results showed that peak torque and iEMG decreased as muscle action velocity increased. There was a positive linear relationship (r=0.95) between peak torque and iEMG and a positive linear relationship (r=0.93) between average torque and average iEMG. The ratio of mechanical work to iEMG decreased as muscle action velocity increased while the ratio of muscle power output to iEMG remained unchanged as muscle action velocity increased. Barnes (3) suggested that “... power output of the muscle is associated with similar amounts of electrical activity regardless of contraction speed.” (p. 1155). Furthermore, the author suggested that a velocity-related decrease in iEMG may have resulted from (a) the existence of “qualitative recruitment,” (b) the faciltitory or inhibitory effects of peripheral feedback acting upon the motor-neuron pool, (c) possible cross-talk as a result of agonist-antagonist cocontractions at the slower velocities, and/or (d) velocity-related differences in neurological recruitment patterns.

Lawrence and De Luca Study (1983)

The purpose of this investigation was to compare the EMG amplitude-isometric force relationship in different human muscles in order to determine if the relationship is influenced by training level and rate of force production. The subjects consisted of sixteen males representing four distinct populations: 1) untrained normal subjects (n=6;
age=21-34 yrs), professional pianists (n=3; age=24-52 yrs), elite long distance swimmers (n=4; age=17-19 yrs), and elite power lifters (n=3; age=20-35 yrs). Surface EMG recordings were measured from the first dorsal interosseous (FDI), deltoid, and biceps brachii muscles during separate isometric muscle actions. Two MVC’s separated by 30 minutes rest were performed for each muscle. The highest force output of the two trials was used to determine a force output equal to 80% MVC. Each subject then performed two ramped force output muscle actions up to 80% MVC at rates of 10, 20, and 40% MVC/second with fifteen minutes of rest between repetitions. The isometric muscle actions for each muscle were performed in the following positions: (a) for the biceps brachii, the forearm was semipronated and flexed to a joint angle of 90° while lying supine on a padded table, (b) for the FDI, isometric abduction muscle actions were performed such that the plane of attempted movement of the second digit was parallel to the hand, and (c) for the deltoid, isometric abduction muscle actions of the arm were performed in the coronal plane with the forearm fully extended and pronated while supine on a padded table. The results indicated that for the biceps brachii and the deltoid, there was a nonlinear increase in EMG amplitude up to 80% MVC for each ramped force output. For the FDI, the EMG amplitude-force relationship was described as quasilinear. As a result of the EMG similarity between the groups and the muscles tested, it was suggested that the EMG amplitude-force relationship was not influenced by fiber-type composition. Lawrence and De Luca (39) hypothesized that the EMG amplitude pattern was due to changes in firing rate and motor unit recruitment patterns which were not related to fiber type.
Rothstein, Delitto, Sinacore, et al. Study (1983)

Rothstein et al. (57) examined 1) the iEMG responses of the quadriceps femoris during maximal, concentric isokinetic muscle actions at speeds of 30, 60, 90, and 120°·s⁻¹ and 2) the relationship between muscle power output and peak torque at each muscle action velocity. The subjects consisted of a group of rheumatic diseased patients (n=19; age ± SD=47 ± 14; male=3, female=16) and a group of normal adult females (n=11; age ± SD=45 ± 9). Torque production was measured with a Cybex II isokinetic dynamometer connected to a Gould high-speed pen recorder. Bipolar arrangements of Beckman surface electrodes (Ag-Ag Cl type) were used to record the raw EMG signals for the VM and the RF muscles. Each subject first performed three maximal isometric muscle actions of the quadriceps femoris at 65° below full extension (for normalization). The test protocol called for three maximal, concentric isokinetic muscle actions at velocities of 30, 60, 90, and 120°·s⁻¹ preceded by several submaximal and two maximal familiarization trials at each speed. Furthermore, only the middle 70° window of the position, torque, and iEMG signals were analyzed to avoid the effects of acceleration and deceleration.

The results indicated no significant change (p>0.05) in iEMG across velocity for the rheumatic or the normal group, and there were no significant differences (p>0.05) for iEMG values between groups. Therefore, the authors suggested that both groups exhibited approximately the same maximal effort across all velocities. Moreover, the lack of change in iEMG across velocity supported previous hypotheses that a maximal effort exhibited in the absence of fatigue should result in a relatively constant EMG amplitude regardless of the muscle action velocity tested. Furthermore, Rothstein et al.
(57) concluded that the linear regression equations that were constructed to predict muscle power from peak torque can be useful, however, the equations are population- and velocity-specific.

**Westing, Cresswell, and Thorstensson Study (1991)**

The aim of this investigation was to study the relationships between velocity, torque output, and EMG activity of the knee extensor muscles under eccentric and concentric loading. Fourteen male subjects (age ± SEM=27 ± 0.9 yrs) performed maximal, concentric and eccentric isokinetic muscle actions at velocities of 45, 90, 180, and 360°·s\(^{-1}\). Bipolar surface electrodes were placed over the VL, RF, VM, and “. . . the bulk of the hamstrings” muscles to measure EMG activity. Each subject performed two maximal trials at each randomly ordered muscle action velocity (preceded by several submaximal familiarization trials) on a Spark System isokinetic dynamometer. To avoid acceleration and deceleration effects, torque and full-wave rectified EMG signals were amplitude-averaged through the middle half (30°-70° below full extension) of the range of motion.

The results indicated that for each testing velocity, eccentric torque was greater than (p<0.05) concentric torque (range of mean differences: 20-146%). EMG activity, however, was lower (p<0.05) under eccentric loading than the velocity-matched concentric loading (range of mean differences: 7-31%). Torque output and EMG remained constant (p>0.05) for each muscle (VL, RF, and VM) across all eccentric test velocities (45, 90, 180, and 360°·s\(^{-1}\)). During concentric loading, however, there was a velocity-related dissociation between EMG amplitude and torque production, i.e., as
muscle action velocity increased, EMG activity increased and torque production decreased. The authors suggested that under certain high-tension loading conditions (slower velocities) there was a torque-related restriction in neural drive. Thus, despite the voluntary maximal effort, this neuromuscular phenomenon may intrinsically protect the musculoskeletal system from injury that could result if the muscle were to become fully activated under high-tension conditions.

**Seger and Thorstensson Study (1994)**

Seger and Thorstensson (59) designed this study to investigate the torque-velocity, EMG-velocity, and torque-EMG relationships during maximal isokinetic muscle actions of the knee extensors in prepubertal and adult males and females. Forty subjects divided into four groups: (a) prepubertal females (n=10; age=11 yrs), (b) prepubertal males (n=10; age=11 yrs), (c) adult females (n=10; age ± SEM=27 ± 4 yrs), and (d) adult males (n=10; age ± SEM=27 ± 3 yrs) performed maximal, voluntary, concentric and eccentric unilateral (right) muscle actions of the knee extensors at randomly ordered testing velocities of 45, 90, and 180° s⁻¹. Familiarization trials and adequate warm-ups at each velocity preceded the actual tests with two-minute rest periods between each maximal effort. Bipolar surface electrodes (Ag-Ag Cl type) were used to measure EMG activity for the VL and VM while a Spark System isokinetic dynamometer was used to measure torque output. Only the middle 40° (between 30°-70° below full extension) was used to analyze the torque and EMG signals to avoid the effects of acceleration and deceleration.
The results showed that for both prepubertal and adult males and females there was a velocity-related dissociation between concentric EMG and torque, that is, as velocity increased, concentric EMG increased while concentric torque decreased. This was not the case, however, for eccentric muscle actions. Eccentric torque was consistently greater than (p<0.05) concentric torque while eccentric EMG was consistently less than (p<0.05) concentric EMG for each corresponding velocity. Torque output per unit of EMG activity was clearly greater for eccentric than for concentric muscle actions at each velocity, however, the difference was of similar magnitude for all groups. Seger and Thorstensson (59) concluded that these results supported the previous hypothesis of Westing et al. (72) that torque-related restrictions in neural drive may have been present to prevent musculoskeletal injury during high-tension conditions. Furthermore, the authors suggested that due to the pattern similarities between groups, the relationships among EMG, torque, and velocity do not appear to be age- and/or gender-dependent.
CHAPTER III
METHODS

Subjects

Thirteen females (mean ± SD age = 21 ± 1 years) and eleven males (mean ± SD age = 21 ± 2 years) volunteered to participate in the investigation. The study was approved by the University Institutional Review Board for Human Subjects and all subjects completed a health history questionnaire and signed written informed consent prior to testing.

Isokinetic Measurements

Eccentric isokinetic PT for the extensors of the dominant leg (based on kicking preference) was measured using a calibrated Cybex 6000 dynamometer (CYBEX Division of LUMEX, Inc., Ronkonkoma, New York) at randomly ordered velocities of 60, 120, and 180°·s⁻¹. The subjects were in a seated position with a restraining strap over the pelvis and trunk in accordance with the Cybex 6000 User’s Guide (16). The input axis of the dynamometer was aligned with the axis of the knee and the non-dominant leg was braced against the contralateral limb stabilization bar. Three submaximal warm-up trials preceded three maximal muscle actions at each velocity with the highest PT selected as the representative score. A two-minute rest was allowed between testing at each velocity. MP was derived by the Cybex 6000 software at each muscle action by dividing the work performed by the muscle action time.
**MMG measurements**

The MMG signals were detected by piezoelectric crystal contact sensors (Hewlett-Packard, 21050A, bandwidth 0.02-2000 Hz). For each muscle (vastus lateralis=VL, rectus femoris=RF, and vastus medialis=VM), a sensor was placed between the active EMG electrodes. A stabilizing ring, double-sided foam tape, and microporous tape were used to ensure consistent contact pressure of the MMG sensor (10,14,15,19).

**EMG Measurements**

Bipolar (7.62 cm center-to-center) surface electrode (Quinton Quick Prep silver-silver chloride) arrangements were placed along the longitudinal axes of the VL, RF, and VM muscles of the dominant leg (15,19). The interelectrode distances were selected to accommodate placing the MMG sensors between the EMG electrodes (15,19,62). The electrodes for the VL were placed over the lateral portion of the muscle at approximately the midpoint between the head of the greater trochanter and lateral condyle of the femur. The electrode placement on the VM was 20% of the distance between the medial gap of the knee joint and the anterior superior spine of the pelvis (77). For the RF, the electrodes were placed 50% of the distance between the inguinal crease and the superior border of the patella. For all EMG measurements, the reference electrodes were placed over the iliac crest. Interelectrode impedance for each muscle was kept below 2000 Ohms by shaving the area and careful skin abrasion. The EMG signals were preamplified (gain 1000 x) using a differential amplifier (EMG 100, Biopac Systems Inc., Santa Barbara, CA; bandwidth = 10-4000 Hz).
Signal processing

The raw MMG and EMG signals were stored on a personal computer (Macintosh 7100/80 AV Power PC) and expressed as root mean square (rms) amplitude values by software (AcqKnowledge III, Biopac Systems Inc., Santa Barbara, CA). The sampling frequency was 1000 points·s$^{-1}$ for all signals. The MMG and EMG signals were bandpass filtered (Blackman filter) at 5-100 Hz and 10-500 Hz, respectively. The MMG and EMG values were calculated for a time period that corresponded to a 90º range of motion from approximately 180º to 90º of flexion at the knee. For example, at 60º·s$^{-1}$, 1.5 s of the MMG and EMG signals were analyzed, while at 120º·s$^{-1}$, 0.75 s was analyzed (14). This allowed for comparisons among the velocities that were based on a standardized 90º range of motion.

Reliability

Previous test-retest reliability from our laboratory for PT, MMG amplitude, and EMG amplitude indicated that for eight male subjects measured 48 hours apart, the intraclass correlation coefficients (R) ranged from 0.88-0.97, 0.97-0.98, and 0.85-0.96, respectively, with no significant ($p > 0.05$) differences between mean values for test vs. retest at any velocity (60, 120, and 180º·s$^{-1}$).

Statistical Analyses

For each subject, the PT, MP, MMG amplitude, and EMG amplitude values were normalized to the highest recorded values (% max) prior to statistical treatment (8,14,65). Separate three-way mixed factorial ANOVAs (velocity by muscle by gender) were used to analyze the MMG and EMG amplitude data. Two-way mixed factorial ANOVAs
(velocity by gender) were used to analyze the PT and MP data. When appropriate, follow-up analyses included two-way and one-way repeated measures ANOVAs and Tukey post-hoc comparisons. An alpha of $p < 0.05$ was considered statistically significant for all comparisons.
CHAPTER IV
ANALYSIS OF DATA

Results

Isokinetic Measurements

The two-way mixed factorial ANOVAs (velocity by gender) for PT and MP indicated no significant interactions. Subsequent one-way repeated measures ANOVAs indicated no significant main effects for gender for either PT or MP, and no change in PT across velocity (Figure 1). For the marginal means for MP (collapsed across gender), however, 60°·s^{-1} was less than 120 and 180°·s^{-1}, and 120°·s^{-1} was less than 180°·s^{-1} (Figure 2).

MMG Amplitude

The three-way mixed factorial ANOVA (velocity by muscle by gender) indicated no significant three-way interaction. Subsequent two-way mixed factorial ANOVAs (velocity by gender and muscle by gender) and a two-way repeated measures ANOVA (velocity by muscle) indicated no significant two-way interactions or significant main effects for muscle or gender, but a significant main effect for velocity. The follow-up one-way repeated measures ANOVA for the marginal means of MMG amplitude (collapsed across muscle and gender) indicated that 60°·s^{-1} was less than 120 and 180°·s^{-1}, and 120°·s^{-1} was less than 180°·s^{-1} (Figure 3).
EMG Amplitude

The three-way mixed factorial ANOVA (velocity by muscle by gender) indicated no significant three-way interaction. Subsequent two-way mixed factorial ANOVAs (velocity by gender and muscle by gender) and a two-way repeated measures ANOVA (velocity by muscle) indicated no significant two-way interactions or significant main effects for muscle or gender, but a significant main effect for velocity. The follow-up one-way repeated measures ANOVA for the marginal means of EMG amplitude (collapsed across muscle and gender) indicated that $180^\circ \cdot s^{-1}$ was less than 60 and $120^\circ \cdot s^{-1}$ (Figure 4).
Figure 1. The relationship between the marginal means for isokinetic peak torque (collapsed across gender, expressed as a percentage of the highest recorded value, % max) and muscle action velocity (degrees per second). Values are mean ± SEM. See Results for significant differences between velocities.
Figure 2. The relationship between the marginal means for mean power output (collapsed across gender, expressed as a percentage of the highest recorded value, % max) and muscle action velocity (degrees per second). Values are mean ± SEM. See Results for significant differences between velocities.
Figure 3. The relationship between the marginal means for MMG amplitude (collapsed across muscle and gender, expressed as a percentage of the highest recorded value, % max) and muscle action velocity (degrees per second). Values are mean ± SEM. See Results for significant differences between velocities.
Figure 4. The relationship between the marginal means for EMG amplitude (collapsed across muscle and gender, expressed as a percentage of the highest recorded value, % max) and muscle action velocity (degrees per second). Values are mean ± SEM. See Results for significant differences between velocities.


**Discussion**

The results of the present investigation indicated no gender differences in the velocity-related patterns for PT, MP, MMG amplitude, and EMG amplitude (Figures 1, 2, 3, and 4). These findings were consistent with previous gender comparison studies for peak torque (13,23,29,59,62,63,67,72-75), power output (75), MMG amplitude (23), and EMG amplitude (12,35,45,46,59) during maximal, eccentric isokinetic muscle actions. Furthermore, these results showed no differences among the VL, RF, and VM muscles for the patterns for MMG amplitude and EMG amplitude across velocity (Figures 3 and 4).

The findings of the present study indicated no velocity-related change in PT (Figure 1). These results agreed with previous studies (13,23,25,29,56,59,62,63,67,72-75) that have reported that PT during maximal, eccentric isokinetic muscle actions was independent of velocity. There were, however, velocity-related increases in MP in the present investigation (Figure 2). These results were also consistent with previous reports of the eccentric power-velocity relationship (26,56,75).

Like the pattern of increase for MP in the present study (Figure 2), MMG amplitude increased with velocity (Figure 3). These results were consistent with previous reports of velocity-related increases in MMG amplitude measured from the VL during maximal, eccentric isokinetic muscle actions in males (62) and females (23,25) as well as from the biceps brachii in males (63). Furthermore, we have recently tested the hypothesis of Bodor (9) that MMG amplitude is more closely related to MP than PT during maximal, concentric isokinetic muscle actions (14). Our findings (14) supported
Bodor’s (9) hypothesis in that MMG amplitude exhibited the same increasing pattern across velocity as MP, but was dissociated from the velocity-related decrease in PT. The results of the present study also supported Bodor’s (9) hypothesis in that MP as well as MMG amplitude of the VL, RF, and VM exhibited similar velocity-related patterns of increase, while PT remained unchanged during the eccentric muscle actions (Figures 1, 2, and 3).

Bodor (9) suggested that a positive relationship between MMG amplitude and muscle power would be “…consistent with the laws of physics governing amplitude and power for vibrating systems.” (p. 650) Specifically, for a vibrating system, amplitude is linearly proportional to the power generated or absorbed by the system (34). Bodor’s (9) analogy to playing a violin illustrated that the amplitude of a violin string can be increased by “…increasing the vertical pressure on the bow (force) or by bowing faster (velocity) or both.” (p. 650) An increase in power applied to the violin string results in an increase in amplitude or volume of the sound generated by the violin; therefore, power and amplitude are proportional. The application of this model may also explain the findings from Shinohara et al. (61) and Stout et al. (70) that have reported positive, linear relationships ($r^2 = 0.75-0.99$) between power output and MMG amplitude during incremental cycle ergometry.

Previous studies have proposed mechanisms to explain velocity-related increases in MMG amplitude including: a) actin-myosin cross-bridge interactions (14,15,22-25,52,62,63), b) interstitial fluid hydrodynamics (6,14,15,22-25,62,63), and c) motor unit recruitment strategies (62,63). Oster and Jaffe (52) suggested that the vibratory motions recorded by MMG may arise from intrinsic contractile processes, such as cross-bridge
recycling, during isometric muscle actions. Furthermore, Stauber (67) suggested that similar cross-bridge interactions occur during eccentric muscle actions. Thus, in the present study, it is possible that as the velocity of the eccentric muscle actions increased, the actin-myosin bindings were pulled apart more rapidly, which, in turn, caused increased vibration of the myosin heads and/or turbulence of the intracellular or extracellular fluid mediums (6), resulting in increased MMG amplitude. This hypothesis, however, is not supported by previous findings (68) using isometric muscle actions that suggested that the pattern of MMG activity arises from motor control mechanisms “…rather than intrinsic mechanisms of muscle contraction” (pg. 1912). Recent letters by Barry (4) and Herzog and Vaz (32) emphasize the ongoing debate regarding the specific physiological mechanisms responsible for the oscillations recorded by MMG.

Recruitment of muscle fibers generally follows the size principle of motor unit recruitment (11,31), which states that slow-twitch small-force units are recruited first, while demands for larger forces are met by recruitment of increasingly forceful fast-twitch units. Exceptions to this principle, however, have been reported (18,30,45,46). For example, Nardone and co-workers (45,46) found that as the velocity of eccentric muscle action increased, there was a derecruitment of slow motor units with selective activation of fast motor units during voluntary lengthening of the triceps surae. Smith et al. (62,63) hypothesized that if such recruitment strategies also occur in the VL (63) and biceps brachii (62) during maximal, eccentric isokinetic muscle actions, it is possible that the oscillations of the slow-twitch fibers, which are generally located deep within the muscle (33,40), at the slow velocity may have been dampened by the surrounding tissues (51), resulting in reduced MMG amplitude. At the fast velocity, however, the
oscillations from the fast-twitch fibers, which tend to be more superficially located (33,40), may not have been dampened to the same degree and, therefore, the MMG amplitude was greater. A recent study by Kernell et al. (36), however, questioned the hypothesis of distinct “regionalization” (p. 1) patterns of slow- and fast-twitch muscle fiber type distributions as proposed by Johnson et al. (33) and supported by Lexell et al. (40). Therefore, additional study of fiber type distribution patterns and regionalization within the VL, RF, and VM muscles is necessary to further explore the mechanical dampening that may occur as a result of a velocity-related derecruitment of slow motor units during maximal, eccentric isokinetic muscle actions.

More recent evidence (25) regarding the mean power frequency (MPF) of the MMG signal has indicated that factors other than motor unit recruitment strategies (62,63) may explain velocity-related increases in MMG amplitude during maximal, eccentric isokinetic muscle actions. Marchetti et al. (41) and Mealing and McCarthy (42) have reported higher MMG center frequencies (median or mean frequency) in muscles composed primarily of fast-twitch than slow-twitch fibers. Thus, if the velocity-related derecruitment of slow-twitch fibers and selective recruitment of fast-twitch fibers contributes to the increase in MMG amplitude during eccentric muscle actions, MMG MPF should increase with velocity. This was not the case in the study by Evetovich et al. (25), however, who reported increases in MMG amplitude, but no change in MMG MPF across velocity during maximal, eccentric isokinetic muscle actions at velocities ranging from 60 to 180º·s⁻¹. It was suggested that the “…increase in MMG amplitude was due to factors other than a velocity-related shift in the contribution of slow to fast-twitch fibers” (25; p. 126). Further investigation of motor unit recruitment patterns
during maximal, eccentric isokinetic muscle actions is necessary to better understand
the contribution, if any, to the velocity-related increase in MMG amplitude.

In the present study, EMG amplitude remained unchanged from 60 to 120°·s⁻¹, but decreased (approximately 10%) from 120 to 180°·s⁻¹. Westing et al. (72) also reported a similar decrease in normalized EMG amplitude for the VM, but no change for the VL and RF muscles across velocities ranging from 45 to 360°·s⁻¹. Colduck and Abernethy (12) indicated that “a reduction in EMG activity during rapid eccentric contractions may be indicative of fiber recruitment patterns that are markedly different from those associated with slower eccentric or concentric contractions” (p. 50). Their results (12), as well as those of Seger and Thorstensson (59) and Smith et al. (62), however, showed no change in EMG amplitude with changes in velocity during eccentric muscle actions. These conflicting findings may be related to differences in the fiber type proportions of the subjects tested. It has been suggested that the EMG power spectrum reflects motor unit action potential conduction velocity, which, in turn, may provide information about specific fiber-type recruitment patterns (2, 37, 44, 58, 66, 71). Therefore, future studies should examine both the velocity-related patterns for EMG amplitude and EMG center frequency to clarify the role of motor control strategies during maximal, eccentric isokinetic muscle actions.

In summary, there were no gender-related differences in the patterns for PT, MP, MMG amplitude, or EMG amplitude across velocity. Furthermore, no muscle-related differences in the patterns for MMG or EMG amplitude were found. These results indicated similar patterns of increase for MP and MMG amplitude across velocity (Figures 2 and 3). This supported Bodor’s (9) hypothesis that MMG amplitude is more
closely related to MP than PT during maximal, eccentric isokinetic muscle actions.
These findings also showed a general similarity between the patterns for EMG amplitude
and PT across velocity (Figures 1 and 4). Therefore, the present findings suggested that
EMG amplitude reflected force development, while MMG amplitude reflected power
output. The amplitude and frequency domains of EMG and MMG signals may provide
insight into the electrical and mechanical aspects of training-induced changes in muscle
strength and power.
CHAPTER V

SUMMARY

Statement of Purpose

The purpose of the present investigation was designed to examine the velocity-related patterns for mechanomyographic (MMG) amplitude, electromyographic (EMG) amplitude, mean power output (MP), and peak torque (PT) of the superficial muscles of the quadriceps femoris (vastus lateralis=VL, rectus femoris=RF, vastus medialis=VM) in males and females during maximal, eccentric isokinetic muscle actions of the leg extensors at 60, 120, and 180°·s⁻¹.

Procedures for Collection of Data

Thirteen females (mean ± SD age = 21 ± 1 years) and eleven males (mean ± SD age = 21 ± 2 years) volunteered for this investigation. PT was measured on a calibrated Cybex 6000 dynamometer during maximal, eccentric isokinetic muscle actions of the leg extensors at randomly ordered velocities of 60, 120, and 180°·s⁻¹. Piezoelectric MMG recording sensors were situated between bipolar arrangements of surface EMG electrodes (Ag-AgCl) placed over the VL, RF, and VM muscles. MP was determined by the dynamometer software.

Analysis

For each subject, the PT, MP, MMG amplitude, and EMG amplitude values were normalized to the highest recorded values (% max) prior to statistical treatment. Separate three-way mixed factorial ANOVAs (velocity by muscle by gender) were used to analyze the MMG and EMG amplitude data. Two-way mixed factorial ANOVAs (velocity by
gender) were used to analyze the PT and MP data. When appropriate, follow-up analyses included two-way and one-way repeated measures ANOVAs and Tukey post-hoc comparisons. An alpha of \( p < 0.05 \) was considered statistically significant for all comparisons.

Findings

**Isokinetic Measurements**

The two-way mixed factorial ANOVAs (velocity by gender) for PT and MP indicated no significant interactions. Subsequent one-way repeated measures ANOVAs indicated no significant main effects for gender for either PT or MP, and no change in PT across velocity. For the marginal means for MP (collapsed across gender), however, \( 60^\circ \cdot s^{-1} \) was less than \( 120^\circ \cdot s^{-1} \) and \( 120^\circ \cdot s^{-1} \) was less than \( 180^\circ \cdot s^{-1} \).

**MMG Amplitude**

The three-way mixed factorial ANOVA (velocity by muscle by gender) indicated no significant three-way interaction. Subsequent two-way mixed factorial ANOVAs (velocity by gender and muscle by gender) and a two-way repeated measures ANOVA (velocity by muscle) indicated no significant two-way interactions or significant main effects for muscle or gender, but a significant main effect for velocity. The follow-up one-way repeated measures ANOVA for the marginal means of MMG amplitude (collapsed across muscle and gender) indicated that \( 60^\circ \cdot s^{-1} \) was less than \( 120^\circ \cdot s^{-1} \), and \( 120^\circ \cdot s^{-1} \) was less than \( 180^\circ \cdot s^{-1} \).
**EMG Amplitude**

The three-way mixed factorial ANOVA (velocity by muscle by gender) indicated no significant three-way interaction. Subsequent two-way mixed factorial ANOVAs (velocity by gender and muscle by gender) and a two-way repeated measures ANOVA (velocity by muscle) indicated no significant two-way interactions or significant main effects for muscle or gender, but a significant main effect for velocity. The follow-up one-way repeated measures ANOVA for the marginal means of EMG amplitude (collapsed across muscle and gender) indicated that $180^\circ \cdot \text{s}^{-1}$ was less than 60 and $120^\circ \cdot \text{s}^{-1}$.

**Conclusions**

The results of the present study indicated no gender-related differences in the patterns for PT, MP, MMG amplitude, or EMG amplitude across velocity. Furthermore, no muscle-related differences in the patterns for MMG or EMG amplitude were found. These results indicated similar patterns of increase for MP and MMG amplitude across velocity. This supported Bodor’s (9) hypothesis that MMG amplitude is more closely related to MP than PT during maximal, eccentric isokinetic muscle actions. These findings also showed a similarity between the patterns for EMG amplitude and PT across velocity. Therefore, the present findings suggested that EMG amplitude reflected force development, while MMG amplitude reflected power output. The amplitude and frequency domains of EMG and MMG signals may provide insight into the electrical and mechanical aspects of training-induced changes in muscle strength and power.
APPENDIX A

UNIVERSITY OF NEBRASKA-LINCOLN
HUMAN PERFORMANCE LABORATORY

PRE-EXERCISE TESTING HEALTH STATUS QUESTIONNAIRE

Name____________________________   Date______________
Home Address______________________________________________________
Work Phone______________________ Home Phone____________________
Person to contact in case of emergency___________________________________
Emergency Contact Phone_________________________
Personal Physician___________________ Physician’s Phone_______________
Gender ____   Age ____(yrs)   Height ___(ft)___(in)   Weight______(lbs)
Does the above weight indicate:  a gain__   a loss__   no change__   in the past year?
If a change, how many pounds?___________(lbs)

A. JOINT-MUSCLE STATUS ( Check areas where you currently have problems)

Joint Areas
(  ) Wrist
(  ) Elbows
(  ) Shoulders
(  ) Upper Spine & Neck
(  ) Lower Spine
(  ) Hips
(  ) Knees
(  ) Ankles
(  ) Feet
(  ) Other_______________________

Muscle Areas
(  ) Arms
(  ) Shoulders
(  ) Chest
(  ) Upper Back & Neck
(  ) Abdominal Regions
(  ) Lower Back
(  ) Buttocks
(  ) Thighs
(  ) Lower Leg
(  ) Feet
(  ) Other_______________________

B. HEALTH STATUS ( Check if you previously had or currently have any of the following conditions)

(  ) High Blood Pressure
(  ) Heart Disease or Dysfunction
(  ) Peripheral Circulatory Disorder
(  ) Lung Disease or Dysfunction
(  ) Arthritis or Gout
(  ) Edema
(  ) Epilepsy
(  ) Multiply Sclerosis
(  ) High Blood Cholesterol or Triglyceride Levels
(  ) Loss of Consciousness
(  ) Others that you feel we should know about
(  ) Acute Infection
(  ) Diabetes or Blood Sugar Level Abnormality
(  ) Anemia
(  ) Hernias
(  ) Thyroid Dysfunction
(  ) Pancreas Dysfunction
(  ) Liver Dysfunction
(  ) Kidney Dysfunction
(  ) Allergic Reactions to Medication
(  ) Allergic Reactions to Any Other Substance
please describe____________________________
please describe____________________________
C. PHYSICAL EXAMINATION HISTORY

Approximate date of your last physical examination ____________________________

Physical problems noted at that time _________________________________________

Has a physician ever made any recommendations relative to limiting your level of physical exertion? _______YES _______NO

If YES, what limitations were recommended? __________________________________

D. CURRENT MEDICATION USAGE (List the drug name and the condition being managed)

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<thead>
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<th>MEDICATION</th>
<th>CONDITION</th>
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E. PHYSICAL PERCEPTIONS (Indicate any unusual sensations or perceptions. Check if you have recently experienced any of the following during or soon after physical activity (PA); or during sedentary periods (SED))

<p>| | | | |</p>
<table>
<thead>
<tr>
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<tbody>
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<td>SED</td>
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<tr>
<td>Chest Pain</td>
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<td>Nausea</td>
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<tr>
<td>Heart Palpitations</td>
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<td>Light Headedness</td>
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<tr>
<td>Unusually Rapid Breathing</td>
<td>( )</td>
<td>Loss of Consciousness</td>
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<td>( )</td>
<td>Extreme Weakness</td>
<td>( )</td>
</tr>
<tr>
<td>Joint Pain</td>
<td>( )</td>
<td>Numbness</td>
<td>( )</td>
</tr>
<tr>
<td>Other</td>
<td>( )</td>
<td>Mental Confusion</td>
<td>( )</td>
</tr>
</tbody>
</table>

F. FAMILY HISTORY (Check if any of your blood relatives . . . parents, brothers, sisters, aunts, uncles, and/or grandparents . . . have or had any of the following)

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>( ) Heart Disease</td>
</tr>
<tr>
<td>( ) Heart Attacks or Strokes (prior to age 50)</td>
</tr>
<tr>
<td>( ) Elevated Blood Cholesterol or Triglyceride Levels</td>
</tr>
<tr>
<td>( ) High Blood Pressure</td>
</tr>
<tr>
<td>( ) Diabetes</td>
</tr>
<tr>
<td>( ) Sudden Death (other than accidental)</td>
</tr>
</tbody>
</table>

G. CURRENT HABITS (Check any of the following if they are characteristic of your current habits)

<p>| |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>( ) Regularly does manual garden or yard work</td>
</tr>
<tr>
<td>( ) Regularly goes for long walks</td>
</tr>
<tr>
<td>( ) Frequently rides a bicycle</td>
</tr>
<tr>
<td>( ) Frequently runs/jogs for exercise</td>
</tr>
<tr>
<td>( ) Regularly participates in a weight training exercise program</td>
</tr>
<tr>
<td>( ) Engages in a sports program more than once per week. If so, what does the program consist of?</td>
</tr>
</tbody>
</table>
Statement of Informed Consent

Title of Research Study

GENDER COMPARISONS AMONG PEAK TORQUE, MEAN POWER OUTPUT, MECHANOMYOGRAPHIC AND ELECTROMYOGRAPHIC RESPONSES DURING MAXIMAL, ECCENTRIC ISOKINETIC MUSCLE ACTIONS

Invitation to Participate

You are invited to participate in this research study. The following information is provided in order to help you make an informed decision whether or not to participate. If you have any questions, please do not hesitate to ask.

Basis for Subject Selection

You are eligible to volunteer because you are between the ages of 19 and 29 years and are in good health. If you wish to participate you must fill out a health history questionnaire. You may be prevented from participating in this research study if there are indications from the questionnaire that you may have health risks. Such indications include symptoms suggestive of possible cardiopulmonary, metabolic, and/or coronary heart disease. If you have no musculoskeletal disorders or disease that will prevent you from engaging in moderate to vigorous physical activity, you will be asked to perform the test described below.

Purpose of the Study

The present study was designed to examine the velocity-related patterns for MMG amplitude, EMG amplitude, mean power output, and peak torque of the superficial muscles of the quadriceps femoris in males and females during maximal, concentric and eccentric isokinetic leg extensions at velocities of 1.05, 2.10, and 3.15 radians per second.

Explanation of Procedures

You will be asked to perform the tests described below. The exercise tests will be conducted in the Human Performance Laboratory located in Mabel Lee Hall (Room 141) on the UN-L campus.

Initials
Strength Test (one hour)

The strength of your quadriceps femoris will be measured. Your skin will be scraped lightly with emery paper at six locations (2 locations per muscle) on your thigh and on the front of your hip bone. Electrodes will then be taped to the scraped areas. Wires from the electrodes are hooked to a device, which measures the electrical activity of your vastus laterals, rectus femoris, and vastus medialis muscles while you are being tested on the CYBEX. The CYBEX is a machine that can be set so you can only move at a certain speed or contract at a specific angle. In addition, three small microphones will be placed on the thigh, one between each pair of electrodes, to measure the sound produced by the contracting muscle. Following the placement of the electrodes and microphone, you will lie quietly on a padded table to obtain a pre-exercise heart rate and your blood pressure will also be taken at that time. After you have warmed up, you will be asked to provide three maximal concentric (muscle shortening) and three maximal eccentric (muscle lengthening) muscle actions at speeds of 1.05, 2.10, and 3.15 radians per second.

Potential Risks and Discomforts

The following are the potential risks and discomforts you could experience during this study.

Isokinetic Tests
Muscle soreness, dizziness, temporary elevation of blood pressure, heart attack and sudden death.

Skin Abrasions
Infection and soreness.

Protection Against Risks
To minimize any potential risks and/or discomforts, you will be asked to perform a warm-up exercise on a cycle ergometer prior to the isokinetic tests. You will be given instructions for special stretches, which may aid in the elimination of any muscle soreness as a result of the tests. Upon completing all tests, an antibacterial salve will be applied to the electrode abrasion sites to prevent any possible infection. Throughout the tests, you will be monitored by laboratory personnel trained in CPR. In addition, you will be asked repeatedly during the tests how you feel in relation to your ability to continue the test.

Potential Benefits to Subjects

Your main benefit from participating in this study may be feedback on the strength of your leg.
Potential Benefits to Society

Society may benefit from this study by the development of scientifically based training and rehabilitation programs.

In Case of Emergency Contact Procedure

In the event of a research related injury, immediately contact one of the investigators listed at the end of this consent form.

Medical Care in Case of Injury

In the unlikely event that you should suffer an injury as a direct consequence of the research procedures described above, costs of medical care, if any, will be the responsibility of the subject (whether at the University Health Center or at other local health care facilities). Data will be collected during the hours of the University Health Center (8:00 AM – 6:00 PM Monday through Friday, 10:30 AM – 2:00 PM Saturday) so that care will be immediately available to you. However, no compensation for physical care, hospitalization, loss of income, pain and suffering, or any other form of compensation will be provided. None of the above shall be construed as a waiver of any legal rights or redress you may have.

Assurance of Confidentiality

Any information obtained during this study, which could identify you will be kept strictly confidential. The information may be published in scientific journals or presented at scientific meetings, but your identity will be kept strictly confidential.

Rights of Research Subjects

Your rights as a research subject have been explained to you. If you have any additional questions concerning your rights as a research subject, you may contact the University of Nebraska Institutional Review Board (IRB), telephone (402) 472-6965.

Voluntary Participation and Withdrawal

You are free to decide not to participate in this study or to withdraw at any time without adversely affecting you relationship with the investigators or the University of Nebraska. Your decision will not result in any loss of benefits to which you are otherwise entitled.

_________

Initials
YOU ARE VOLUNTARILY MAKING A DECISION WHETHER OR NOT TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE CERTIFIES THAT THE CONTENT AND MEANING OF THE INFORMATION ON THIS CONSENT FORM HAVE BEEN FULLY EXPLAINED TO YOU AND THAT YOU HAVE DECided TO PARTICIPATE HAVING READ AND UNDERSTOOD THE INFORMATION PRESENTED. YOUR SIGNATURE ALSO CERTIFIES THAT YOU HAVE HAD ALL YOUR QUESTIONS ANSWERED TO YOUR SATISFACTION. IF YOU THINK OF ANY QUESTIONS DURING THIS STUDY PLEASE CONTACT THE INVESTIGATORS. YOU WILL BE GIVEN A COPY OF THIS CONSENT FORM TO KEEP.

_______________________________________  __________________
Signature of Subject      Date

MY SIGNATURE AS WITNESS CERTIFIES THAT THE SUBJECT SIGNED THIS CONSENT FORM IN MY PRESENCE AS HIS/HER VOLUNTARY ACT AND DEED.

_______________________________________  __________________
Signature of Witness      Date

IN MY JUDGEMENT THE SUBJECT IS VOLUNTARILY AND KNOWINGLY GIVING INFORMED CONSENT AND POSSESSES THE LEGAL CAPACITY TO GIVE INFORMED CONSENT.

_______________________________________  __________________
Signature of Investigator     Date

Investigators:

Joel T. Cramer               work phone (402) 472-3846
                        home phone (402) 327-8058

Glen O. Johnson, Ph.D.     work phone (402) 472-1723
                        home phone (402) 423-6443

Terry J. Housh, Ph.D.       work phone (402) 472-1160
                        home phone (402) 477-6573
REFERENCES


