MECHANOMYOGRAPHIC AND ELECTROMYOGRAPHIC AMPLITUDE AND FREQUENCY RESPONSES DURING FATIGUING ISOKINETIC MUSCLE ACTIONS OF THE BICEPS BRACHII

by

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The purpose of the present investigation was to examine the mechanomyographic (MMG) and electromyographic (EMG) amplitude and frequency responses of the biceps brachii muscle during fatiguing isokinetic muscle actions of the forearm flexors. Ten adults [three women (mean ± SD age = 20 ± 2 yrs) and seven men (mean ± SD age = 23 ± 3 yrs)] volunteered to perform 50 consecutive maximal, concentric isokinetic muscle actions of the dominant forearm flexors at 180°•s⁻¹. Piezoelectric MMG recording sensors were placed over the belly of the biceps brachii muscle between bipolar surface EMG electrodes (Ag-AgCl). Isokinetic peak torque (PT), as well as MMG and EMG root-mean-square (rms) amplitude and mean power frequency (MPF) values were calculated for each of the 50 muscle actions and averaged across all subjects. Polynomial regression analyses indicated a cubic (p < 0.05) reduction in PT across the 50 repetitions. There were linear (p < 0.05) decreases in both MMG amplitude and MMG MPF throughout the test. The results for EMG amplitude demonstrated a cubic (p < 0.05) pattern, where EMG amplitude increased during repetitions 1-20, remained stable during repetitions 20-40, and increased during repetitions 40-50. There was a quadratic (p <
0.05) decrease in EMG MPF across the repetitions. These findings indicated differences between the MMG and EMG time and frequency domain responses during the test, which suggested that MMG and EMG each provide unique information regarding muscle function during fatiguing, dynamic muscle actions. The MMG amplitude and MPF patterns across the repetitions may have reflected de-recruitment of fast fatiguing motor units, a decrease in muscular compliance, or the effects of “muscle wisdom.” The relationship between EMG amplitude and repetition number may have been influenced by non-maximal efforts by the subjects or peripheral fatigue. The factor(s) that contributed to the decrease in EMG MPF across the repetitions is unclear, although a decrease in muscle fiber action potential conduction velocity may have been partially responsible for the pattern.
LAY ABSTRACT

Mechanomyography (MMG) is the recording of low frequency vibrations generated by the lateral oscillations of active muscle fibers. Electromyography (EMG) involves detecting the muscle action potentials that pass lengthwise through muscle fibers to stimulate contraction. It has been suggested that MMG and EMG reflect the mechanical and electrical activities of motor units, respectively. The applications of MMG include describing motor unit activation strategies, monitoring muscle fatigue, discriminating between muscle fiber types, and examining various neuromuscular disorders. Furthermore, EMG has been used to identify changes in torque production, examine muscular fatigue and various neuromuscular disorders, as well as characterize the neural adaptations that occur during strength training. Previous studies have reported that the MMG and/or EMG amplitude responses during sustained or repeated muscle actions were dependent on the torque level and the rate at which fatigue develops. During fatiguing dynamic muscle actions at high torque levels, MMG amplitude decreases, while EMG amplitude has been reported to increase, decrease, or remain unchanged. Furthermore, it has been suggested that the frequency contents of the MMG and EMG signals may provide information regarding motor unit firing rates and muscle fiber action potential conduction velocity, respectively. Therefore, the purpose of the present investigation was to examine patterns of the MMG and EMG amplitude and mean power frequency (MPF) responses from the biceps brachii during 50 consecutive maximal, concentric isokinetic muscle actions at 180°•s \(^{-1}\).
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CHAPTER I

INTRODUCTION

Mechanomyography (MMG) records and quantifies the low-frequency lateral oscillations of active skeletal muscle fibers (5,62,88), and Gordon and Holbourn (35) indicated that these oscillations reflect the “mechanical counterpart” of the motor unit electrical activity as measured by electromyography (EMG). Barry and Cole (4) and Orizio (62) have suggested that the lateral oscillations recorded as MMG are a function of: a) a gross lateral movement at the initiation of a contraction generated by the non-simultaneous activation of muscle fibers, b) smaller subsequent lateral oscillations generated at the resonant frequency of the muscle, and c) dimensional changes of the active fibers. The amplitude of the MMG signal, however, is influenced by many factors, including muscle temperature, stiffness, mass, intramuscular pressure, the viscosity of the intracellular and extracellular fluid mediums, and the firing rates of the active motor units (52,62,66,71,88).

The MMG signal can provide information about various aspects of muscle function. Simultaneous measurements of MMG and EMG have been used to monitor the dissociation between the electrical and mechanical events (excitation-contraction coupling) that occurs with fatigue (89) and to examine factors related to electromechanical and phonomechanical delay (81). In addition, recent investigations have examined the MMG amplitude and frequency responses during maximal concentric and eccentric isokinetic muscle actions (17,23,31) as well as maximal and submaximal cycle ergometry (38,74-76,84,90). Clinically, MMG may be used to examine neuromuscular disorders (82), including cerebral palsy (1), myotonic dystrophy (64),
cranio-mandibular disorders (49), chronic and severe low back pain (97), diaphragmatic fatigue (80), skeletal muscle atrophy (53), and as a control mechanism for externally powered prostheses (7).

Recent investigations have utilized isometric (6,34,45,61,67,69,71,83), concentric (77), or eccentric (78) muscle actions to determine the MMG responses during continuous fatiguing workbouts. Generally, previous studies have shown an increase in MMG amplitude across time at low levels of torque production [10-40% maximum voluntary contraction (MVC)] (34,69,83), and either no change (34,83) or a decrease in MMG amplitude (34,69) across time at moderate levels of torque production (50-80% MVC).

It has been suggested (34,62,69) that the increase in MMG amplitude at low levels of torque production may be due to the fatigue-induced recruitment of larger, peripherally located fast-twitch muscle fibers, as the low-threshold, deeply located slow-twitch muscle fibers fatigue and therefore cannot maintain the torque output. The decrease in MMG amplitude across time at higher levels of torque production has been attributed to an increase in muscle fiber relaxation time, which results in fewer lateral oscillations and pressure waves (recorded at the skin as MMG) per unit time (62). A lack of change in MMG amplitude during sustained isometric muscle actions may reflect a balance between the competing influences of motor unit recruitment (which can increase MMG amplitude) and firing frequency (which can decrease it).

Recent studies (77,78) have investigated the MMG and EMG amplitude responses during fatiguing concentric or eccentric isokinetic muscle actions. No previous studies, however, have simultaneously examined the amplitude and frequency responses of MMG
and EMG during repeated, fatiguing dynamic muscle actions. While MMG amplitude reflects motor unit recruitment, it has been suggested that MMG MPF may represent the global firing rate of the unfused, activated motor units (2,62,66,70). The amplitude of the EMG signal, on the other hand, reflects motor unit activation, including both motor unit recruitment and firing rate and EMG MPF provides information regarding the conduction velocity of the active muscle fibers (8). Thus, examination of the time and frequency domains of the MMG and EMG signals may provide insight regarding the motor control strategies (motor unit recruitment and firing rate) of the biceps brachii during fatiguing dynamic muscle actions. Therefore, the purpose of this investigation was to examine patterns of the MMG and EMG amplitude and MPF responses from the biceps brachii muscle during 50 consecutive maximal, concentric isokinetic muscle actions at 180°•s⁻¹.
Chapter II

REVIEW OF LITERATURE

Studies Investigating Repeated Isokinetic Muscle Actions and Fatigue

Thorstensson and Karlsson (1976)

The purpose of this investigation (92) was to examine the fatigability of the left quadriceps femoris muscles in 10 male subjects (mean age ± SD = 30 ± 2 yrs) during 50 and 100 consecutive maximal, isokinetic leg extensions performed on two separate days. The tests were performed on a Cybex II isokinetic dynamometer at a velocity of 180°•s⁻¹ with passive leg flexion being performed between maximal extensions. Isokinetic peak torque (PT) for each muscle action and the fatigue index (mean decline in peak torque over 50 muscle actions) were calculated following each test. The investigators also performed muscle biopsies from the vastus lateralis muscle in order to estimate the percentages of fast-twitch and slow-twitch muscle fibers. The results indicated that the average initial PT at the first muscle action for both tests was 130 ± 8 Nm. This declined to 72 ± 4 Nm after 50 muscle actions and 64 ± 4 Nm after 100 muscle actions. The average decrease in PT over the first 50 muscle actions was “about 45%” for both tests. There was substantial inter-subject variability in the fatigue index and a high correlation (r = 0.86, p < 0.01) between this parameter and the percentage of fast-twitch fibers in the vastus lateralis muscle. The authors (92) concluded that the development of muscular fatigue in the quadriceps femoris during repeated maximal, isokinetic leg extensions at a high velocity was more evident in individuals with a higher percentage of fast-twitch muscle fibers, which fatigue more rapidly than slow-twitch muscle fibers.
Nilsson, Tesch, and Thorstensson (1977)

This investigation (60) examined fatigue and the electromyographic (EMG) responses of the vastus lateralis (VL) muscle in 12 adult males (mean age ± SD = 22 ± 3 yrs) during 100 consecutive maximal, isokinetic leg extensions at a velocity of 180°s⁻¹. Peak torque (PT), work, and power were calculated from each torque curve. The EMG signals were recorded from the VL muscle, and both peak EMG (highest point in the rectified and filtered curve) and integrated EMG (IEMG) were calculated. Muscle biopsies were also obtained from the VL muscle to determine fiber type composition. The results indicated that PT, work and power decreased rapidly until the 50th contraction, and then leveled off to approximately 45-55% of their initial values. There were significant correlations between the percentage of fast-twitch muscle fibers in the VL and the relative decreases in PT (r = 0.75, p < 0.01), work (r = 0.64, p < 0.02), and power (r = 0.73, p < 0.01) for the first 50 muscle actions. Peak EMG was significantly greater (p < 0.05) for the 25th and 50th muscle actions than it was at the beginning of the test. The peak EMG per unit of PT and IEMG per unit of work values, however, increased up to the 75th muscle action and then plateaued. It was concluded (60) that the discrepancy between the patterns of PT and EMG was due to fatigue within the muscle itself, with no involvement at the neuromuscular junction. Thus, the motor units were still conducting impulses to the muscle fibers, but the muscle fibers were unable to contract, resulting in decreased torque production. The authors (60) also suggested that factors such as exhaustion of the elastic component, a lack of energy substrates, and/or accumulation of metabolites may have caused fatigue within the muscle fibers.
Komi and Tesch (1979)

The purpose of this investigation (44) was to examine the electromyographic (EMG) spectral changes during repeated maximal, isokinetic leg extensions at a high velocity. Muscle biopsies were obtained from the vastus lateralis (VL) muscle of 11 male subjects, which were divided into two groups (Group I = <50% fast-twitch muscle fiber area, N = 5, mean age ± SD = 28 ± 3 yrs; Group II = >50% fast-twitch muscle fiber area, N = 6, mean age ± SD = 23 ± 1 yrs). Each subject performed 100 consecutive maximal, isokinetic leg extensions at a velocity of 180°•s⁻¹ as the EMG signal was recorded from the VL muscle. The power spectral density function as well as the IEMG and EMG mean power frequency (MPF) values were obtained during the middle phase of the range of motion for each muscle action. The results indicated a decline in isokinetic peak torque (PT) that was significantly greater (p < 0.01) in Group II than in Group I. Furthermore, there were significant decreases in both IEMG (p < 0.01) and EMG MPF (p < 0.001) for Group II, but no significant changes (no alpha levels reported) in these parameters for Group I. It was concluded (44) that the more pronounced decrease in PT, IEMG, and EMG MPF in Group II demonstrated that muscles composed of a higher percentage of fast-twitch fibers are more susceptible to fatigue than muscles with a higher percentage of slow-twitch fibers. Furthermore, the authors (44) concluded that fatigue-related contraction failure during dynamic muscle actions may be related to qualitative changes in motor unit recruitment patterns.

Horita and Ishiko (1987)

This investigation (37) examined the relationships between muscle lactate accumulation and electromyographic (EMG) median frequency (MF), electromechanical
delay (EMD), and the IEMG/peak torque ratio (E/T ratio) during fatiguing dynamic muscle actions. Eleven males (mean age ± SD = 24 ± 2 yrs) volunteered to perform repeated maximal, concentric isokinetic leg extensions at a velocity of 180°•s⁻¹ for 30-s (approximately 25 muscle actions) and 60-s (approximately 50 muscle actions) on two separate occasions. The EMG signals were recorded from the vastus lateralis (VL) muscle. The difference between the onset of electrical activity and torque production was defined as EMD. Biopsies from the VL muscle were used to measure muscle lactate accumulation. The results indicated a 59% decrease in peak torque and a 315% increase in muscle lactate during the 60-s test. The E/T ratio and EMD values also increased during the fatigue test, while EMG MF decreased. The authors (37) reported that the changes in muscle lactate “clearly corresponded” to the changes in EMG MF and EMD. Furthermore, the results for the EMG parameters suggested that the fatigue was “peripheral,” and not “central” in nature.

Patton, Hinson, Arnold, et al. (1978)

Patton et al. (72) examined the shape of the isokinetic fatigue curve during fatiguing maximal muscle actions of the forearm flexors. Sixteen men and sixteen women (age range = 18–24 yrs) volunteered to perform repeated maximal, concentric isokinetic muscle actions of the forearm flexors at 60°•s⁻¹ to exhaustion. “Fatigue” was defined as the point at which “torque production was significantly different (p < 0.01) from the initial torque production, while “exhaustion” was characterized as “the inability of the subjects to perform another contraction” (72). The subjects were divided into four groups, based on gender and strength level (high strength = HS; low strength = LS). Analyses of variance (ANOVA) were used to determine the shape of each fatigue curve
and differences between the curves for each group. The results indicated that the relationship between torque and time to exhaustion was quadratic \((p < 0.01)\) for the groups combined. When each individual group was analyzed, however, linear relationships \((p < 0.01)\) were found. Furthermore, the rate of fatigue development was significantly different \((p < 0.01)\) among each of the groups. The average torque values at each of the data points were significantly different \((p < 0.01)\) for each group, except between the LS males and the HS females. In addition, fatigue occurred for the HS males, LS males, and HS females at 30% of the total test time. The LS females, however, did not demonstrate fatigue. The authors (72) suggested that individuals with high strength levels fatigue more quickly than individuals with low strength levels. Furthermore, the shapes of the fatigue curves were a function of strength level, rather than gender, and reflected some of the characteristics present in the isotonic and isometric fatigue curves examined in previous studies.

Motzkin, Cahalan, Morrey, et al. (1991)

The purpose of this study (59) was to investigate the isometric and concentric, isokinetic endurance relationships for both the forearm flexors and extensors. Thirty-two adult males \((\text{age range} = 21–39 \text{ yrs})\) volunteered to perform maximal, isometric and concentric isokinetic endurance tests of the dominant and non-dominant limbs. The isometric muscle actions were performed at a joint angle of 90° between the arm and forearm, while the isokinetic muscle actions were performed at a velocity of 180°•s\(^{-1}\) through a range of motion from 45° to 135° of forearm flexion. Both the isokinetic and isometric endurance tests were performed until torque production was 50% of the initial peak torque value. The time duration of each test and torque production values were
normalized to the maximum values for each subject. Linear regression analysis was then performed on each endurance test to determine the slope coefficient, which was designated as the fatigue rate. Paired t-tests and regression procedures were used to examine significant differences and relationships between fatigue rates, respectively. The results indicated that there were significant differences (p < 0.05) between the isokinetic and isometric fatigue rates in both the dominant and the non-dominant limbs for forearm flexion, but no significant differences (p > 0.05) for forearm extension. Furthermore, no significant (p > 0.05) relationships were found between the isokinetic and isometric fatigue rates. The authors (59) concluded that there is not a direct relationship between isokinetic and isometric endurance testing of the forearm flexors. It was also hypothesized (59) that there may be a distinct difference in the physiological mechanisms of endurance between exercises that produce work (dynamic exercises) and those that do not (isometric exercises), which may have accounted for the different fatigue rates during the isokinetic and isometric muscle actions.

*Mechanomyography Studies During Dynamic Muscle Actions*

**Dalton and Stokes (1991)**

This study (18) examined the relationships between mechanomyographic (MMG) and electromyographic (EMG) amplitude and torque during submaximal, isotonic forearm flexion and extension. Eight male subjects (age range = 17–26 yrs) volunteered for this study. The MMG (Tandy 270-090, Tandy Electronics, Brisbane) and EMG (surface bipolar configuration with an interelectrode distance of 15 mm) signals were simultaneously detected from the biceps brachii muscle of the right arm. The subjects performed three concentric and three eccentric muscle actions by flexing to 90° and
extending to 0° each of nine weights (0, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5, 7.5, and 8.5 kg). The weights were lifted in a random order with each concentric and each eccentric movement lasting 3-s, and a 3-s pause at the end of each movement. A 5-min rest was allowed between sets to avoid fatigue. The results indicated that the MMG and EMG amplitude values increased linearly during both the concentric (r = 0.94 and 0.99, respectively) and eccentric (r = 0.90 and 0.94, respectively) muscle actions. The authors (18) concluded that MMG amplitude could be used to detect changes in force during dynamic muscle actions of the biceps brachii. Furthermore, it was suggested (18) that increases in MMG amplitude may be due to recruitment of additional motor units, rather than increases in motor unit firing rate.

Petitjean, Maton, and Cnockaert Study (1992)

The purpose of this study (81) was to examine the electromyographic (EMG) and mechanomyographic (MMG) amplitude versus torque relationships during isotonic muscle actions of the forearm flexors. Eight adult subjects (6 males and 2 females) (mean age ± SD = 39 ± 8 yrs) volunteered to perform isotonic forearm flexion without resistance, or with a 3-kg weight at two different speeds (“fast” and “slow”). Force was calculated as the product of inertia and acceleration. The EMG signals were detected with bipolar surface electrode arrangements placed over the biceps brachii (interelectrode distance = 3.0 cm) and brachioradialis (interelectrode distance = 2.0 cm) muscles. The MMG signals were detected with Electret condenser microphones (Yamashita Communications; bandwidth = 5 Hz – 15 kHz) placed near the EMG electrodes for each muscle. Along with EMG and MMG amplitude, the phono- and electro-mechanical delays were measured and defined as the time lag between the onset of MMG and onset
of acceleration (phono-mechanical) or the onset of EMG and the onset of acceleration (electro-mechanical). The results showed positive correlations ($r = 0.92$) between force production and MMG amplitude for both muscles. Positive correlations were also found between EMG amplitude and force for the biceps brachii ($r = 0.92$) and brachioradialis ($r = 0.90$) muscles. Furthermore, the phono-mechanical delay followed the electro-mechanical delay but preceded the onset of acceleration. It was concluded (81) that MMG, like EMG, may reflect changes in force production during dynamic muscle actions.

Cramer, Housh, Weir et al. (2002)

This study (17) examined the effects of gender and muscle on the velocity-related responses for peak torque (PT), mean power output (MP), mechanomyographic (MMG) and electromyographic (EMG) amplitude, and mean power frequency (MPF) for the three superficial quadriceps femoris muscles during maximal, concentric isokinetic muscle actions. Twelve women (mean age ± SD = 22 ± 3 yrs) and eleven men (mean age ± SD = 22 ± 3 yrs) volunteered to perform maximal, concentric isokinetic leg extensions at randomly ordered velocities of 60, 120, 180, 240 and 300°•s$^{-1}$. The EMG signal was detected with bipolar (7.62 cm, center-to-center) surface electrode arrangements placed along the longitudinal axes of the vastus lateralis (VL), rectus femoris (RF), and vastus medialis (VM) muscles, while MMG was detected with piezoelectric crystal contact sensors (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) placed in between the EMG electrodes. The results indicated no significant ($p > 0.05$) gender-related differences in the velocity-related patterns for MMG amplitude, MMG MPF, or EMG MPF. The MMG amplitude and MP values showed significant ($p < 0.05$) increases with velocity, but
MMG MPF increased only at the highest velocities. There were, however, significant (p < 0.05) gender- and muscle-related differences among the patterns for EMG amplitude across velocity. For all three muscles of the men and for the RF of the women, there were no significant (p > 0.05) changes in EMG amplitude across velocity. In addition, there was a significant (p < 0.05) decrease in EMG MPF across velocity for the VL muscle, but no significant changes (p > 0.05) for the RF or VM muscles. It was concluded (17) that there are muscle-specific, velocity-related differences in the associations among motor unit activation (EMG amplitude), motor unit action potential conduction velocity (EMG MPF), and the mechanical aspects of muscular activity (MMG amplitude and MPF). Furthermore, the velocity-related increases in both MP and the MMG amplitude values for each muscle suggested that MMG amplitude may be related to MP during maximal, concentric isokinetic muscle actions.

Smith, Housh, Johnson et al. (1998)

The purpose of this study (87) was to examine the mechanomyographic (MMG) and electromyographic (EMG) responses during maximal, eccentric and concentric isokinetic muscle actions of the biceps brachii. Ten males (mean age ± SD = 23 ± 2 yrs) volunteered to perform maximal, eccentric and concentric isokinetic muscle actions of the dominant forearm flexors at 30, 90, and 150°•s⁻¹. A piezoelectric crystal contact sensor (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) and bipolar surface electrode arrangement (7.62 cm, center-to-center) were used to detect the MMG and EMG signals, respectively. The results showed a significant (p < 0.05) decrease in isokinetic peak torque (PT) from 30 to 150°•s⁻¹ during the concentric, but not the eccentric muscle actions. Furthermore, there was a significant (p < 0.05) increase in MMG amplitude with
velocity during both the eccentric and concentric muscle actions, but no significant (p > 0.05) change in EMG amplitude. There were also no significant differences (p > 0.05) in MMG amplitude between the eccentric and concentric muscle actions at any velocity, but EMG amplitude was significantly greater (p < 0.05) during the concentric muscle actions for both 90 and 150°•s⁻¹. The results of this study (87) indicated that during maximal, eccentric and concentric isokinetic muscle actions of the biceps brachii, there were velocity-related dissociations among PT, MMG amplitude, and EMG amplitude.

Evetovich, Housh, Stout et al. (1997)

This study (30) examined the effects of velocity on the mechanomyographic (MMG) responses to maximal, concentric isokinetic muscle actions. Eight adult males (mean age ± SD = 22 ± 1 yrs) performed maximal, isokinetic leg extensions on a Cybex 6000 dynamometer at velocities of 60, 120, 180, 240, 300, and 360°•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. Reliability was assessed by re-examining the peak torque (PT) and MMG amplitude values 2-5 days after the initial test. The results indicated that the intraclass reliability correlations ranged from 0.84 to 0.97 for PT, and 0.90 to 0.99 for MMG amplitude, with no significant differences (p > 0.05) between the mean values for test versus retest at any velocity. Additionally, there were significant (p < 0.05) decreases in PT from 60 to 240°•s⁻¹, but no significant differences (p > 0.05) for 240 versus 300°•s⁻¹ and 300 versus 360°•s⁻¹. There was, however, a significant increase (p < 0.05) in MMG amplitude with velocity from 60 to 360°•s⁻¹. The results of this study indicated a velocity-related dissociation between PT
and MMG amplitude. It was hypothesized (30) that the increase in MMG amplitude with velocity may have been due to a decrease in muscle stiffness.


The purpose of this study (29) was to determine whether there are gender differences in the velocity-related patterns of mechanomyographic (MMG) responses to maximal, concentric and eccentric isokinetic leg extensions. Fifteen adult males (mean age ± SD = 23 ± 2 yrs) and sixteen adult females (mean age ± SD = 23 ± 3 yrs) volunteered to perform maximal, concentric and eccentric isokinetic muscle actions with the dominant leg extensors at randomly ordered 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. The results indicated significant (p < 0.05) decreases in peak torque (PT) with increases in velocity during the concentric muscle actions, but no significant (p > 0.05) changes during the eccentric muscle actions for both genders. The results for MMG amplitude, however, indicated significant (p < 0.05) increases across velocity in both genders for the concentric and eccentric muscle actions. Additionally, there was a significant (p < 0.05) gender difference in the velocity-related patterns of the MMG amplitude responses to the concentric muscle actions, but no significant (p > 0.05) difference during the eccentric muscle actions. The results indicated velocity-related dissociations between MMG amplitude and PT in both the males and the females during the concentric and eccentric muscle actions. It was concluded (29) that a greater percent decline in concentric PT for the females than the males may have contributed to the gender-specific differences in the velocity-related patterns of the MMG amplitude responses observed during the concentric
muscle actions. In addition, the males exhibited significantly greater (p < 0.05) MMG amplitude values than the females at all velocities for the concentric and eccentric muscle actions, which may have been due to gender differences in muscle mass and/or thickness of the subcutaneous adipose tissue layer.


This study (28) examined the effects of unilateral concentric isokinetic leg extension training on peak torque (PT) and mechanomyographic (MMG) responses during a twelve week training program. Twenty-one adult males (mean age ± SD = 23 ± 3 yrs) were randomly assigned to a training (n = 12) or a control group (n = 9). The training group performed maximal, concentric isokinetic leg extensions at a velocity of 90°•s⁻¹ on a Cybex 6000 isokinetic dynamometer. For the first week, the subjects performed three sets of leg extensions, for the second week, they performed four sets, for the third week, they performed five sets, and for weeks six through twelve, the subjects performed six sets. Each set consisted of ten repetitions, with 2-min of rest between sets. All the subjects were tested every four weeks for peak torque (PT) and MMG amplitude responses during maximal, concentric isokinetic muscle actions at 90°•s⁻¹. The MMG signal was detected with a piezoelectric crystal contact sensor (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) placed over the vastus lateralis (VL) muscle. Peak torque significantly increased (p < 0.05) over the twelve-week training period for the training group, but showed no significant change (p > 0.05) for the control group. The results for MMG amplitude, however, indicated that there was no significant (p > 0.05) interaction between the training group and the control group over the twelve-week training period. It was concluded (28) that the training-induced increase in PT without a corresponding
change in MMG amplitude may have reflected competing influences of muscle hypertrophy on the MMG signal. Specifically, hypertrophy of the muscle fibers in the VL during the training period may have decreased the distance between the muscle and the MMG sensor and increased muscle size, potentially augmenting MMG amplitude. On the other hand, training-induced hypertrophy may also have stretched the iliotibial band, resulting in a taut layer of fascia that compressed the muscle fibers of the VL, which restricted the vibrations of the active fibers and attenuated the MMG signal. The authors (28) also suggested that decreased co-activation of the hamstring muscles could, theoretically, have contributed to the training-induced increase in peak torque without a corresponding change in MMG amplitude.

Studies investigating MMG and EMG of the biceps brachii muscle


The purpose of this study (22) was to examine the effects of unilateral isometric training of the forearm flexors on strength and the electromyographic (EMG) and mechanomyographic (MMG) responses of the biceps brachii muscle. Seventeen adult women (mean age ± SD = 21 ± 2 yrs) were randomly assigned to a training (n = 10) or a control (n = 7) group. The training group performed eight weeks of isometric training of the non-dominant forearm flexors at a joint angle of 120° between the arm and the forearm. The training sessions were performed three times per week and consisted of three sets (for weeks 1-2), four sets (for weeks 3-4), or five sets (for weeks 5-8) of eight, 6-s isometric muscle actions at 80% of the maximum isometric voluntary contraction (MVC). All the subjects were tested at week 0, week 4, and week 8 for isometric strength, EMG, MMG, and flexed arm circumference. The EMG signal was detected
with a bipolar surface electrode (7.62 cm center-to-center) arrangement placed over the biceps brachii muscle, while the MMG signal was detected by a piezoelectric crystal contact sensor (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) placed between the EMG electrodes. The results indicated that both isometric strength and flexed arm circumference for the non-dominant limb in the training group significantly increased ($p < 0.05$) over the eight week training period. In addition, there were no significant changes ($p > 0.05$) in the EMG and MMG amplitude responses to increasing isometric torque levels (25, 50, 75, and 100% MVC) due to the training. It was hypothesized (22) that physiological factors associated with muscle fiber hypertrophy that either augment or attenuate MMG amplitude may have competed with each other and caused no change in the MMG amplitude responses due to the training protocol. Furthermore, it was suggested (22) that the lack of change in the EMG amplitude responses due to the training may have reflected increased activation of forearm flexor muscles other than the biceps brachii and/or decreased coactivation of the triceps brachii muscle, thereby increasing isometric torque production with no change in activation of the biceps brachii muscle.

Orizio, Perini, and Veicsteinas (1989)

The purpose of this study (68) was to examine the mechanomyographic (MMG) and electromyographic (EMG) responses of the biceps brachii muscle to increasing levels of isometric force from 0% to 100% of the maximum isometric voluntary contraction (MVC). Seven male subjects (mean age ± SD = 22 ± 1 yrs) volunteered to perform ten randomly ordered isometric muscle actions of the right forearm flexors from 10% to 100% MVC at a joint angle of 115° between the arm and the forearm. The MMG signal
was detected with a piezoelectric crystal contact sensor (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) placed over the belly of the biceps brachii muscle, while the EMG signal was detected with a bipolar surface electrode arrangement (no interelectrode distance reported) placed near the MMG sensor along the longitudinal axis of the muscle. The results indicated that MMG amplitude increased curvilinearly up to 80% MVC and then decreased from 80% to 100% MVC, while EMG amplitude increased curvilinearly with force up to 100% MVC. It was suggested (68) that the similar patterns for MMG and EMG amplitude up to 80% MVC may have reflected recruitment of additional motor units and increases in the firing rates of slow-twitch motor units. Above 80% MVC, however, the continued increase in EMG amplitude and decrease in MMG amplitude may have reflected an increase in motor unit firing rate, rather than recruitment of new motor units. It was hypothesized (68) that high motor unit firing rates may have reduced the muscle fiber geometrical variations between successive motor impulses, thereby decreasing MMG amplitude. The authors (68) also suggested that increased intramuscular pressure and reduced muscle compliance from 90% to 100% MVC may have contributed to limiting the dimensional changes of the active fibers, thereby reducing MMG amplitude.

**Orizio, Gobbo, Diemont, et al. 2003**

This study (66) examined the changes in the electromyographic (EMG) and mechanomyographic (MMG) amplitude and mean power frequency (MPF) responses for the biceps brachii muscle during isometric forearm flexion from 15% to 85% of the maximum isometric voluntary contraction (MVC). In addition, the changes in the motor unit activation strategy of the biceps brachii following a series of fatiguing isometric
muscle actions were also investigated. Ten sedentary subjects (age range = 20–30 yrs) volunteered to perform isometric ramp muscle actions of the dominant forearm flexors at a rate of approximately 13.3% MVC/second from 0% to 90% MVC. Following the first isometric ramp, the subjects performed repeated, 6-s isometric muscle actions, followed by 3-s of rest, at 50% MVC until the force could no longer be maintained within ± 5% of the target value. This force was then designated as the new isometric MVC. Within 3-s after the fatiguing protocol, the subjects performed another isometric ramp muscle action from 0% to 90% of the new MVC value. The EMG signal was detected with a bipolar electrode arrangement (interelectrode distance = 1.0 cm), while the MMG signal was detected by an accelerometer (Entran EGA 25 D, bandwidth 0-800 Hz) placed between the EMG electrodes. Although isometric force was produced from 0% to 90% MVC, the EMG and MMG signals were only analyzed from 15% to 85% MVC to avoid the analysis of transient phenomena in passing from the relaxed to the contracted state. The results indicated that EMG amplitude increased curvilinearly with force up to 85% MVC in both the fresh and the fatigued states, while the fatiguing protocol reduced the EMG MPF values by approximately 25 Hz. In addition, MMG amplitude increased up to 65% MVC and then decreased to 85% MVC in the fresh state, but decreased continuously in the fatigued state. The results for MMG MPF indicated an increase up to 65% MVC, followed by a steeper increase up to 85% MVC. In the fatigued state, however, MMG MPF increased at approximately the same rate throughout the isometric ramp, but the frequency values were lower than in the fresh state. The authors (66) suggested that the EMG amplitude and MPF trends before, and after the fatiguing protocol may have reflected the possibility that a smaller number of motor units were available for
recruitment in the fatigued state. Furthermore, the MMG amplitude and MPF trends from 15% to 65% MVC in fresh muscle suggested that concurrent recruitment of additional motor units and increases in motor unit firing rates is used to increase isometric force up to 65% MVC. Beyond 65% MVC, however, increases in motor unit firing rates may have caused the decrease in MMG amplitude and rapid increase in MMG MPF. The authors (66) also suggested that the continuous decrease in MMG amplitude in the fatigued state may have reflected a lack of fast-twitch motor unit recruitment.

Esposito, Malgrati, Veicsteinas, et al. (1996)

The purpose of this study (26) was to examine the electromyographic (EMG) and mechanomyographic (MMG) amplitude and mean power frequency (MPF) responses during isometric muscle actions from 20% to 80% of the isometric maximum voluntary contraction (MVC) in elderly and young subjects. Twenty elderly subjects (10 men and 10 women, age range = 65-78 yrs) and twenty young control subjects (10 men and 10 women, age range = 20-34 yrs) volunteered to perform five isometric muscle actions in a random sequence from 20% to 100% MVC. Each muscle action was held for 4-s at a joint angle of 115° between the arm and the forearm. A probe consisting of the tip of a piezoelectric crystal contact sensor (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) placed in between two silver bars (interelectrode distance = 1.0 cm) was used to detect the MMG and EMG signals, respectively. The results indicated that EMG amplitude and MPF demonstrated similar patterns in both the elderly and the young men and women, although the amplitude and MPF values were always lower for the elderly subjects than for the young subjects. The MMG amplitude and MPF trends were also similar for the elderly and young subjects, although a decrease in MMG amplitude from 80% to 100%
MVC for the young subjects was not as evident in the elderly subjects. The authors (26) suggested that the young subjects may have been able to attain higher overall motor unit firing rates than the elderly subjects, causing the more prominent decrease in MMG amplitude above 80% MVC. Overall, however, similar patterns were found for both EMG and MMG in the elderly and the young subjects, which suggested that age does not affect the motor control strategies that modulate isometric torque production.

Studies investigating MMG and muscle fiber type

Yoshitake and Moritani (1999)

This study (96) examined the relationships among motor unit activity, muscle fiber type composition, and muscle sound characteristics. Six male subjects (mean age ± SD = 30 ± 8 yrs) volunteered to perform random isometric plantar flexion muscle actions at 20%, 40%, 60%, and 80% of the maximum isometric voluntary contraction (MVC). Electrical stimulation of the tibial nerve was also performed on two subjects to obtain electrically-evoked action potentials. Surface electromyographic (EMG) signals were detected with bipolar electrode arrangements (interelectrode distance = 35 mm) placed over the bellies of the soleus and medial gastrocnemius muscles, while mechanomyographic (MMG) signals were detected with microphone sensors (Daia Medical, bandwidth 5-2000 Hz) placed near the EMG electrodes. Two subjects also volunteered to perform isometric muscle actions at a constant force level while intramuscular EMG and surface MMG signals were recorded. The results indicated that EMG amplitude increased from 20% to 80% MVC in both the medial gastrocnemius and soleus muscles, while MMG amplitude increased up to 80% MVC in the medial gastrocnemius. In the soleus muscle, however, MMG amplitude increased up to 60%
MVC and then decreased to 80% MVC. The results for MMG MPF demonstrated an increase up to 80% MVC in both muscles. Furthermore, during electrical stimulation, the stimulation frequency nearly matched MMG MPF, until high rates were administered (medial gastrocnemius = 25 Hz, soleus = 10 Hz). The authors (96) suggested that the twitch amplitudes and durations from individual motor units recorded in MMG could be influenced by the contractile properties of the muscle fibers in the motor unit. Furthermore, the different MMG responses from the medial gastrocnemius and soleus muscles suggested that the amplitude and MPF of the MMG signal may provide information regarding muscle fiber type. It was concluded (96) that MMG MPF reflected the firing rates of the active motor units, while MMG amplitude represented the mechanical properties of contraction, muscle fiber type composition, and firing rate during both voluntary and electrically-induced contractions.


The purpose of this study (56) was to examine the relationship between the frequency characteristics of the MMG signal and the muscle fiber type composition found in postural and non-postural human muscles. Eighteen healthy male subjects (age range = 20-40 yrs) volunteered to perform sustained isometric muscle actions of the forearm flexors and the plantar flexors at 50% of the isometric maximum voluntary contraction (MVC) until this force output could no longer be maintained. The MMG signal was detected with a piezoelectric contact microphone placed over the biceps brachii muscle (during forearm flexion) or the soleus muscle (during plantar flexion). The results indicated that the power density spectrum of the MMG signal for the soleus muscle had less power above 10 Hz than the power density spectrum for the biceps
brachii muscle. Furthermore, wide frequency bands were found for both muscles in some of the subjects. It was concluded (56) that the frequency components of the MMG signal may have reflected muscle fiber type composition differences between the postural muscles composed of mainly slow-twitch fibers and non-postural muscles containing a mixed population of fast-twitch and slow-twitch fibers.

Studies Investigating MMG and EMG responses during fatigue

Barry, Geiringer, and Ball (1985)

This study (6) examined the electromyographic (EMG) and mechanomyographic (MMG) responses during isometric fatigue of the biceps brachii muscle. Five male subjects (descriptive data not reported) volunteered to perform isometric muscle actions of the forearm flexors while holding 0, 5, 10, 12.5, 15, or 20 lbs. in their hand. Each weight was held for 20-s, followed by a 10-s rest in between weights. The entire cycle of weights was repeated five times, with 15-s of rest in between each cycle. Ten other volunteers (descriptive data not reported) performed sustained isometric muscle actions of the forearm flexors at 75% MVC until only 35% MVC could be maintained. The EMG signal was detected with surface electrodes (interelectrode distance not reported), while the MMG signal was detected with a heart sounds microphone (Irex Medical Systems, bandwidth 20-1500 Hz). The results indicated that both the EMG and MMG amplitude values increased with force. During the sustained isometric muscle actions at 75% MVC, however, MMG amplitude decreased along with the force output, while EMG amplitude decreased only below 45% MVC. It was concluded (6) that MMG amplitude was highly correlated with the amount of force produced by the muscle, and
simultaneous EMG and MMG detection can be used to monitor the dissociation
between the electrical and mechanical events that occurs during fatigue.


The purpose of this study (77) was to examine the patterns of the
electromyographic (EMG) and mechanomyographic (MMG) responses from the
superficial quadriceps femoris muscles [vastus lateralis (VL), rectus femoris (RF), and
vastus medialis (VM)] during isokinetic fatiguing muscle actions. Ten adults (mean age
± SD = 22 ± 2 yrs) volunteered to perform 50 consecutive maximal, concentric isokinetic
leg extensions at 60, 180, and 300°•s^{-1}. The EMG signals were detected with bipolar
(7.62 cm, center-to-center) electrode arrangements, while the MMG signals were
detected by piezoelectric crystal contact sensors (Hewlett-Packard 21050A, bandwidth
0.02-2000 Hz) placed between the EMG electrodes. Torque, EMG amplitude, and MMG
amplitude were normalized to their maximum values for each subject and then averaged.
The relationships between torque and each variable were examined using polynomial
regression models. The results indicated that the relationship between isokinetic torque
at 60°•s^{-1} and muscle action number was best fit by a quadratic model, while the
relationships at 180 and 300°•s^{-1} were best fit with cubic models. Cubic models were
also the best fit for the relationships between EMG amplitude and repetition number for
each muscle and each velocity. The relationships between MMG amplitude and
repetition number, however, showed muscle and velocity-specific differences. At 60 and
300°•s^{-1}, quadratic models provided the best fit for the VL and VM muscles, but a linear
model was the best fit for the RF muscle. At 180°•s^{-1}, however, linear models were the
best fit for the VL and RF muscles, while a quadratic model provided the best fit for the
VM muscle. The authors (77) suggested that the lower fatigue rate at 60°•s⁻¹ compared to the higher velocities, and the similarities in the relationships at 180 and 300°•s⁻¹, indicated a greater reliance on more fatigable, fast-twitch muscle fibers at high velocities. Furthermore, the VM muscle maintained the highest EMG amplitude at the end of each test. The VM muscle typically contains a higher percentage of slow-twitch fibers than either the RF or VL muscles. Therefore, the higher percentage of slow-twitch fibers in the VM muscle may have contributed to the ability to maintain a high level of activation throughout the tests. The authors (77) also suggested that the decreases in MMG amplitude for each muscle throughout the test may have reflected a decrease in muscular compliance during the continuous muscle actions, or a phenomenon known as “muscle wisdom.” Muscle wisdom suggests that during a fatiguing task, there are decreases in torque, muscle relaxation rates, and motor neuron firing rates in order to optimize torque production. Theoretically, this would result in a decrease in MMG amplitude as the motor neuron firing rate decreases and the motor unit twitches fuse. Furthermore, the authors (77) concluded that MMG amplitude tracked the changes in torque more closely than EMG amplitude, which suggested that MMG amplitude may be useful as an estimate of torque production during repeated dynamic muscle actions. Additionally, differences between the muscles in the MMG amplitude responses during the tests suggested that MMG may have been able to detect the contribution of the individual quadriceps femoris muscles to torque production.

Kouzaki, Shinohara, and Fukunaga (1999)

This study (45) examined the electromyographic (EMG) and mechanomyographic (MMG) responses from the vastus lateralis (VL), rectus femoris (RF), and vastus
medialis (VM) muscles during fatiguing isometric leg extensions. Seven male subjects
(mean age ± SD = 24 ± 1 yrs) volunteered to perform a series of 50 repeated maximal,
isometric muscle actions at 90° of leg extension. Each maximal muscle action was held
for 3-s, followed by a 3-s relaxation period. The EMG signals were detected with bipolar
electrode configurations (interelectrode distance = 50 mm) located over the belly of each
muscle, while the MMG signals were detected with piezoelectric microphones
(bandwidth 5-100 Hz) placed in between the EMG electrodes. The results indicated that
leg extension torque decreased to 49.5% of the initial value at the end of the protocol.
Integrated EMG (iEMG) also decreased, but the rate was not significantly different (p >
0.05) between the three muscles. Integrated MMG (iMMG) also decreased for all three
muscles, but the magnitude of the decrease was significantly greater (p < 0.05) for the RF
muscle than for the VM muscle for most of the test. The median frequency (f_{med}) of the
EMG signal also decreased for all three muscles, although a greater reduction occurred
for the RF than for the VM and VL. Furthermore, the f_{med} of the MMG signal decreased
at a similar rate for all three muscles, although it was always higher in RF than in VL or
VM. The authors (45) suggested that the greater relative decline in iMMG for the RF
muscle than for the VL or VM muscles may have reflected a greater decline in force
production from the RF. The authors (45) also suggested that the RF muscle may be
composed of a greater relative percentage of fast-twitch muscle fibers than the VL and
VM muscles.

Vaz, Zhang, Herzog, et al. (1996)

The purpose of this study (93) was to compare the behavior of the
electromyographic (EMG) and mechanomyographic (MMG) signals from the rectus
femoris (RF) and vastus lateralis (VL) muscles during an isometric fatiguing protocol. Eleven male subjects (age range = 22-35 yrs) volunteered to perform isometric muscle actions of the leg extensors at a knee joint angle of 90° on a Cybex II isokinetic dynamometer. Following determination of the maximum isometric voluntary contraction (MVC), the subjects performed three isometric muscle actions at 70% MVC, each lasting 10-s and separated by 2-min of rest. Then, the subjects performed a fatigue test by holding an isometric muscle action at 70% MVC until only 50% MVC could be maintained. A 10-s isometric muscle action at 70% MVC was then performed 20-s, 50-s, 2-, 3-, 4-, 5-, 6-, 7-, 8-, 9-, 10-, and 15-min after the end of the fatigue test. The EMG signals were detected with bipolar (interelectrode distance = 3.0 cm) surface electrode arrangements placed over the distal third of the RF and VL muscles, while the MMG signals were detected with miniature accelerometers (Dytran 3115A, bandwidth 1 Hz – 20 kHz) placed between the EMG electrodes. The results indicated that the EMG and MMG median frequency (MDF) values from both the VL and RF muscles decreased during the fatiguing protocol, reached a minimum towards the end of the fatigue test, and then returned to the pre-fatigue values during the recovery period. The amplitude of the EMG signals from the RF and VL muscles, however, increased from the beginning to the end of the fatigue test and remained elevated after 15-min of recovery. The results for MMG amplitude, however, showed a decrease during the fatiguing test in the RF muscle, but an increase in the VL muscle. The authors (93) suggested that muscle tremor may have affected the MMG signal from the VL muscle. Additionally, increases in EMG and MMG MDF, along with EMG amplitude, suggested that recruitment of new motor units and increases in motor unit firing rates occurred throughout the fatigue test (93).
Orizio and Veicsteinas (1992)

This study (71) examined the influence of different muscle fiber type compositions of the vastus lateralis muscle on the mechanomyogram (MMG) time and frequency domain characteristics. Seven sprinters [(SPR) age range = 18-22 yrs], seven sedentary individuals [(SED) age range = 20-24 yrs], and seven long distance runners [(LDR) age range = 25-30 yrs] volunteered to perform maximal isometric leg extensions to exhaustion. The MMG signal was detected by a piezoelectric crystal contact sensor (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) placed over the belly of the vastus lateralis muscle. Torque, MMG amplitude and MMG mean frequency (MF) were calculated throughout the fatiguing protocol. In addition, the power density spectrum was divided into a high frequency portion (15-60 Hz) and a low frequency portion (6-60 Hz). Linear regression procedures were used to find the best fit functions for the decrease in MMG MF. The results indicated that the average times to exhaustion were 48-, 62-, and 95-s for the SPR, SED, and LDR, respectively. Furthermore, MMG amplitude decreased throughout the test for both SPR and SED, but remained relatively stable for LDR. The MMG MF decreased for all three groups throughout the test, but was always higher in the SPR than in the SED and LDR. Furthermore, the power in the high frequency portion of the power density spectrum at the beginning of the test was greater for the SPR than for the SED and LDR. The authors (71) concluded that the differences in the MMG time and frequency domain parameters between the three groups of subjects suggested that MMG may be used as an adjunct to EMG for non-invasive muscle fiber typing.
Orizio (1992)

The purpose of this study (61) was to examine the changes in mechanomyographic (MMG) amplitude, electromyographic (EMG) amplitude, MMG mean frequency (MF), EMG MF, characteristics of the power spectrum density (PSD), and the EMG-MMG cross spectrum (CS) during fatigue. Twelve medical students (age range = 22-24 yrs) volunteered to perform maximal isometric muscle actions of the dominant forearm flexors. The MMG signal was detected with a piezoelectric crystal contact sensor (Hewlett-Packard 21050A, bandwidth 0.02-2000 Hz) placed over the belly of the biceps brachii muscle, while the EMG signal was detected with a bipolar (interelectrode distance = 1.0 cm) surface electrode arrangement placed near the MMG sensor. The results indicated that the MMG and EMG amplitude values, the MMG and EMG MF values, and the MMG-EMG CS decreased throughout the test. Furthermore, examination of the PSD indicated that the greatest power reduction in the high frequencies occurred during the first 50% of the test. It was suggested (61) that the decrease in EMG amplitude may have reflected decreases in motor unit firing rates, average motor unit spike amplitudes, and a de-recruitment of the larger motor units. The reduction in MMG amplitude, however, may have reflected dissociation between the electrical and mechanical properties of motor units with fatigue, reducing the amplitude of the mechanical twitch. The decrease in EMG MF and the shift in the PSD toward lower frequencies may have reflected decreases in muscle fiber action potential conduction velocity and motor unit firing rates, or de-recruitment of fast-twitch motor units. The decrease in MMG MF and the shift in the PSD toward the lower frequencies, however, may have reflected elongation of the motor unit force twitch, a decrease in
motor unit firing rates, and synchronization of motor units. Furthermore, it was concluded (61) that the decrease in the EMG-MMG CS as the muscle fatigued reflected a decrease in motor unit firing rates.
CHAPTER III

METHODS

Subjects

Ten adults [three women (mean ± SD age = 20 ± 2 yrs) and seven men (mean ± SD age = 23 ± 3 yrs)] 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 a written informed consent document before testing.

Isokinetic Testing

Each subject visited the laboratory on two occasions. This first visit was an orientation session, during which, the subjects were allowed to practice a series of 25 consecutive maximal, concentric isokinetic muscle actions of the dominant forearm flexors at a velocity of 180°•s⁻¹ on a calibrated Cybex II isokinetic dynamometer. Passive extension followed each concentric muscle action and the range of motion was standardized from 90° to 180° of forearm flexion. During the next session, data was collected as the subjects performed 50 repeated maximal, concentric isokinetic muscle actions at a velocity of 180°•s⁻¹. For all muscle actions, the subjects were in a supine position and used a neutral handgrip in accordance with the Cybex II instruction manual (40). Prior to the maximal muscle actions, the subjects performed a warm-up of 10 submaximal isokinetic muscle actions.

Electromyography Procedures

Bipolar (7.62 cm center-to-center) electrode (Quinton Quick prep Ag-AgCl, Santa Barbara, CA) arrangements were placed on the dominant arm over the midportion of the
biceps brachii muscle (61,65,67,68,87). The reference electrode was placed over the anterior distal end of the forearm between the styloid processes of the radius and ulna. The interelectrode distance was selected to allow the MMG sensor to be placed between the active EMG electrodes. Careful skin abrasion was performed to keep interelectrode impedance below 2,000 Ω and the EMG signal was preamplified (gain: × 1,000) using a differential amplifier (EMG 100, Biopac Systems, Inc., Santa Barbara, CA, bandwidth 1.0-5,000 Hz).

**Mechanomyography Procedures**

A piezoelectric crystal contact sensor (Hewlett-Packard, 21050A, bandwidth 0.02-2,000 Hz, Andover, MA) was placed between the proximal and distal active EMG electrodes to detect the MMG signal (22,87). A stabilizing ring, double-sided adhesive tape, and microporous tape were used to ensure consistent contact pressure of the MMG sensor (12,15,16,21).

**Signal Processing**

The raw MMG and EMG signals were digitized at 1,000 Hz and stored in a personal computer (Macintosh 7100/80 AV Power PC, Apple Computer, Inc., Cupertino, CA) for subsequent analysis. All signal processing was performed using custom programs written with LabVIEW programming software (version 6.1, National Instruments, Austin TX). The MMG and EMG signals were bandpass filtered (fourth-order Butterworth) at 5-100 Hz and 10-500 Hz, respectively, and the amplitude (root-mean-square, rms) and mean power frequency (MPF) values for the isokinetic muscle actions were calculated for a time period that corresponded to a 30° range of motion from approximately 120° to 150° of forearm flexion. Thus, at 180°•s⁻¹, the amplitude and
MPF values for 0.167 seconds were calculated. This portion of the range of motion was selected to avoid the acceleration and deceleration phases of movement which are typical of isokinetic dynamometers (13). For the MPF analyses, each data segment was processed with a Hamming window and discrete Fourier transformations (DFT). The MPF was selected to represent the power spectrum on the basis of the recommendations of Diemont et al. (20) and was calculated as described by Kwatny et al. (48).

Statistical Analyses

The average torque, EMG amplitude, MMG amplitude, EMG MPF, and MMG MPF in relation to muscle action number were examined using polynomial regression models (linear, quadratic, cubic; SPSS software program, Chicago, IL). Using $X = \text{muscle action number}$, $Y = \text{torque, EMG amplitude, MMG amplitude, EMG MPF, or MMG MPF}$, and $a_0, a_1, a_2, a_3 = \text{statistically determined regression coefficients}$, these models are:

- $Y = a_0 + a_1X$ (linear model)
- $Y = a_0 + a_1X + a_2X^2$ (quadratic model)
- $Y = a_0 + a_1X + a_2X^2 + a_3X^3$ (cubic model)

The statistical significance ($p \leq 0.05$) for the increment in the proportion of the variance that would be accounted for by a higher-degree polynomial was determined using the following F-test (73):

$$F = \frac{(R_2^2 - R_1^2)/(K_2 - K_1)}{(1 - R_2^2)/(n - K_2 - 1)}$$
CHAPTER IV
ANALYSIS OF DATA

Results

Torque

Figure 1 shows the cubic \((R^2 = 0.994)\) relationship between isokinetic PT and repetition number. The percent decline (mean ± SD) in isokinetic PT was 70 ± 17%.

Mechanomyography

Figures 2 and 3 provide the MMG amplitude and MPF versus repetition number relationships, respectively. There were linear decreases in both MMG amplitude \((r^2 = 0.774)\) and MMG MPF \((r^2 = 0.238)\) across repetitions.

Electromyography

As shown in Figure 4, the relationship between EMG amplitude and repetition number was best fit with a cubic model \((R^2 = 0.707)\), where EMG amplitude increased during repetitions 1-20, remained stable during repetitions 20-40, and increased during repetitions 40-50. Figure 5 shows that the EMG MPF versus repetition number relationship was best fit with a quadratic \((R^2 = 0.939)\) model.
Figure 1. The cubic relationship between isokinetic peak torque (Nm) and repetition number.

\[ Y = 0.0001X^3 - 0.0057X^2 - 0.4114X + 29.9182 \]

\[ R^2 = 0.9936 \]
Figure 2. The linear relationship between MMG amplitude (mVrms) and repetition number.

\[ Y = -2.5943X + 231.0973 \]

\[ r^2 = 0.774 \]
Figure 3. The linear relationship between MMG MPF (Hz) and repetition number.

\[ Y = -0.0345X + 14.9298 \]

\[ r^2 = 0.238 \]
Figure 4. The cubic relationship between EMG amplitude (µVrms) and repetition number.

Y = 0.0180X^3 - 1.7133X^2 + 53.8771X + 1105.2638

R^2 = 0.707
Figure 5. The quadratic relationship between EMG MPF (Hz) and repetition number.

\[ Y = 0.0093X^2 - 0.9592X + 66.4542 \]

\[ R^2 = 0.939 \]
Discussion

Torque

In previous investigations of repeated isokinetic muscle actions of the forearm flexors, the fatiguing task has been performed until PT reached a predetermined level, such as 50% of the initial PT value (59), or to “exhaustion” (inability of the subjects to perform another contraction) (72). Motzkin et al. (59) reported that PT decreased more rapidly for a fatiguing maximal, isokinetic test than for an isometric test. Patton et al. (72) found greater decreases in PT for high strength individuals than for low strength individuals during repeated maximal isokinetic muscle actions at 60°•s⁻¹. In the present study, forearm flexion PT decreased 70 ± 17%, and the isokinetic PT versus repetition number relationship (Figure 1) was best fit with a cubic model. These findings were similar to those of Perry-Rana, et al. (77), who reported a cubic decrease (65 ± 14%) in isokinetic PT during 50 consecutive maximal leg extensions at 180°•s⁻¹. Thorstensson and Karlsson (92) demonstrated a positive correlation between the percent decline in leg extension PT and the proportion of fast-twitch fibers in the contracting muscle. Therefore, the consistency for the percent decline in PT in the present study, and that of Perry-Rana et al. (77), may reflect the similarities in fiber type distribution characteristics for the biceps brachii and quadriceps femoris muscles (24,42).

MMG amplitude and MPF

The amplitude of the MMG signal is determined by the number of oscillating motor units and their discharge rates (62,66). Although it has not been directly verified (2), it has been suggested that the frequency content of the MMG signal may qualitatively reflect the global firing rate of the unfused activated motor units (9,10,62,66). Thus,
simultaneous examination of MMG amplitude and MPF may provide information regarding motor control strategies (motor unit recruitment and firing rate) during various types of fatiguing tasks.

Previous investigations (34,69,83) have shown that the patterns of MMG amplitude responses to sustained, fatiguing isometric muscle actions were dependent upon the level of torque production and the rate at which fatigue develops. From these investigations, a general pattern emerged which includes: a) an increase in MMG amplitude across time at low levels of torque production (10 – 40% of maximal voluntary contraction, MVC) (34,69,83), and b) either no change (34,83), or a decrease in MMG amplitude (34,69) across time at higher levels of torque production (50 – 80% MVC). Orizio (62) attributed these torque-dependent patterns to fatigue-induced changes in motor unit recruitment and/or motor unit discharge rates which “may determine an increase or a decrease” in MMG amplitude.

Previous studies of repeated maximal isokinetic muscle actions have found linear (77,78), quadratic (77), or cubic (78) patterns for MMG amplitude across repetitions. Perry-Rana et al. (77) reported muscle-specific differences for the decreases in MMG amplitude during 50 consecutive maximal, concentric isokinetic leg extensions at 60, 180, and 300°•s⁻¹. Specifically, MMG amplitude decreased to a greater extent for the rectus femoris (RF) than for the vastus lateralis (VL) or vastus medialis (VM) muscles (77). It was suggested (77) that a greater percentage of highly fatigable fast-twitch muscle fibers in RF than in VL and VM may have been responsible for the larger decrease in MMG amplitude for RF. Perry-Rana et al. (78) also reported differences in the MMG amplitude versus repetition number relationships for the RF, VL, and VM
muscles during 25 consecutive maximal, eccentric isokinetic leg extensions at $120^\circ \text{s}^{-1}$.

Specifically, the changes in MMG amplitude across repetitions were best fit with linear models for the VL and VM and a cubic model for the RF (78). It was suggested (78) that differences in muscle fiber type composition and architecture may have been responsible for the different MMG amplitude patterns for each muscle.

In the present study, MMG amplitude and MPF for the biceps brachii both decreased linearly (Figures 2 and 3, respectively) across the repetitions. Orizio et al. (66) suggested that a decrease in MMG amplitude during sustained or repeated isometric muscle actions at high torque levels may reflect: a) de-recruitment of fast fatiguing motor units, b) decreases in motor unit firing rates, c) prolongation of the mechanical twitches, leading to better fusion of the mechanical events between one motor command and the following one, and/or d) increases in intramuscular pressure.

It has been suggested (54) that concurrent decreases in torque, muscle relaxation rates, and motor neuron discharge rates during a fatiguing task may represent a deliberate motor unit activation strategy known as “muscle wisdom.” Theoretically, muscle wisdom results in an economical activation of fatiguing muscle by the central nervous system to optimize torque production (25). Previous studies (14,27,38,62,74) have hypothesized that decreases in MMG amplitude during fatiguing tasks may be due to decreases in motor unit discharge rates as well as the fusion of motor unit twitches. It is also possible that these factors contributed to the concurrent decreases in MMG amplitude and MPF found in the present study. It has been suggested (25), however, that muscle wisdom may not be applicable to rhythmic activities, because a slower relaxation rate increases energy consumption as the muscle works against antagonist muscles.
Theoretically, this would “result in a decrease in the net torque exerted about a joint for a given level of muscle activation” (25, p. 1638), which could cause the nervous system to limit muscular activity as a protective mechanism against potentially damaging activity (32). Furthermore, Griffin et al. (36) reported that the majority of motor units in the triceps brachii muscle did not decrease their firing rates during fatiguing dynamic muscle actions of the forearm extensors. Further studies are needed to determine the effects of muscle wisdom on muscle function during various types of activities including dynamic muscle actions.

The decreases in MMG amplitude and MPF across repetitions in the present study may also have been due to de-recruitment of fast fatiguing motor units, or reduced muscular compliance. Peters and Fuglevand (79) reported that some motor units in the extensor digitorum and extensor indicis muscles ceased discharging prior to the end of a sustained isometric MVC of the finger extensors. Furthermore, Goldenburg et al. (34) suggested that a decrease in MMG amplitude for the abductor digiti minimi muscle during a prolonged isometric muscle action at 50% MVC may have reflected a “drop out” of fast fatiguing motor units. Theoretically, de-recruitment of fast-twitch motor units with high firing rates (52,56,71) would also reduce the global motor unit firing rate, thereby decreasing MMG MPF. Therefore, it is possible that derecruitment of fast-twitch motor units across repetitions in the present study may have caused the reductions in MMG amplitude and MPF.

The patterns for MMG amplitude and MPF in the present study may also have been due to decreases in muscular compliance. Prolonged static and dynamic muscle actions increase muscle thickness, fluid content, and intramuscular pressure, which
combine to reduce muscular compliance (3,41,85,86). A progressive decrease in muscular compliance throughout the 50 repetitions in the present study may have impaired the oscillations of the active muscle fibers, thereby reducing MMG amplitude and MPF.

**EMG amplitude and MPF**

The amplitude of the EMG signal reflects muscle activation and is determined by the number of active motor units and their firing rates (8). Furthermore, it has been suggested that the EMG power spectrum reflects muscle fiber action potential conduction velocity, (50) which, in turn, may provide information regarding fiber-type recruitment patterns (95). Specifically, the EMG center frequency (mean or median) is lower for low threshold, slow-twitch motor units, than high threshold, fast-twitch motor units. Thus, simultaneous examination of the time and frequency domains of the EMG signal may provide information regarding motor unit activation patterns during various types of fatiguing tasks.

Previous investigations (11,19,33,46,47,58,61,94) have shown that the changes in EMG amplitude during sustained, fatiguing isometric muscle actions were dependent on the torque level and rate of fatigue development. From these investigations, a general trend emerged which includes: a) an increase in EMG amplitude across time during submaximal muscle actions (19,33,47,94), and b) a decrease in EMG amplitude across time during maximal muscle actions (11,46,58,61). Orizio (63) attributed these torque-dependent patterns to fatigue-induced changes in the motor unit activation strategy.

Previous studies of repeated maximal isokinetic muscle actions have reported increases (60,77,91), decreases (44,77), or no change (43,44,77) in EMG amplitude
across repetitions. Perry-Rana et al. (77) reported cubic relationships for EMG amplitude for the RF, VL, and VM muscles during 50 consecutive maximal, concentric isokinetic leg extensions at 60, 180, and 300°•s\(^{-1}\). In addition, the VM muscle demonstrated the highest level of activation at the end of each test (77). It was suggested (77) that the higher percentage of slow-twitch muscle fibers in the VM than the VL and RF (42) may have contributed to the ability to maintain the activation level throughout the fatiguing workouts.

In the present investigation, EMG amplitude demonstrated a cubic pattern across repetitions (Figure 4), which consisted of an increase during repetitions 1-20, no change during repetitions 20-40, and another increase during repetitions 40-50. Nilsson et al. (60) suggested that an increase in EMG amplitude for the VL muscle during the initial repetitions of a test involving 100 consecutive maximal, concentric isokinetic leg extensions at 180°•s\(^{-1}\) may have been due to non-maximal efforts by the subjects. This could also have been the case in the present investigation, since torque values did not reach maximal for several repetitions.

The pattern for EMG amplitude across repetitions in the present study may also have reflected peripheral fatigue. Peripheral fatigue is most prominent during high intensity exercise (39) and may involve failure of the contractile processes within muscle fibers (51). Merton et al. (57) reported that a reduction in torque during a sustained isometric MVC of the adductor pollicis muscle could not be restored by direct stimulation of the muscle fibers themselves, which suggested that muscle contraction failure was at least partly responsible for the decrease in torque. Furthermore, Tesch et al. (91) suggested that a decrease in torque production and slight increases in EMG
amplitude for the RF and VL muscles during 32 consecutive maximal, concentric isokinetic leg extensions at 180°•s\(^{-1}\) may have been due to contractile failure. Therefore, the decrease in torque and cubic pattern for EMG amplitude across repetitions in the present study may have been due to an impairment of muscle contraction.

The results for EMG MPF in the present study demonstrated a quadratic decrease (Figure 5) across the repetitions. These findings were similar to the results from previous investigations (37,44,91) of repeated maximal, concentric isokinetic muscle actions. Traditionally, reductions in EMG center frequency (mean or median) during fatiguing isometric tasks have been attributed to a lowered intramuscular pH and the subsequent decrease in muscle fiber action potential conduction velocity (8). Recently, however, Masuda et al. (55) provided evidence that the relationship between action potential conduction velocity and EMG center frequency does not hold for fatiguing dynamic muscle actions by showing no change in action potential conduction velocity, but decreases in EMG median frequency for the VL muscle during repeated dynamic leg extensions. It was suggested (55) that action potential conduction velocity may not be the only factor responsible for changes in the EMG power spectrum during fatiguing dynamic muscle actions. Therefore, the findings of Masuda et al. (55) suggested that the decrease in EMG MPF for the biceps brachii muscle in the present study may not have been due solely to changes in action potential conduction velocity. Additional research is needed to clarify the relationship between EMG center frequency and action potential conduction velocity during fatiguing dynamic muscle actions.

In summary, the percent decline in forearm flexion PT and the relationship between PT and repetition number in the present study were similar to the results of
Perry-Rana et al. (77) during repeated maximal, concentric isokinetic leg extensions, which may have been due to the similarities in fiber type distribution characteristics for the biceps brachii and quadriceps femoris muscles (24,42). A number of phenomena may have been responsible for the decreases in MMG amplitude and MPF across repetitions, including de-recruitment of fast fatiguing motor units, a decrease in muscular compliance, or “muscle wisdom.” The relationship between EMG amplitude and repetition number in the present study may have been due to non-maximal efforts by the subjects or peripheral fatigue. Furthermore, the mechanism(s) that contributed to the decrease in EMG MPF across repetitions in the present study are unclear, although a decrease in muscle fiber action potential conduction velocity may have been at least partially responsible. Additional studies are needed to clarify the effects of motor unit de-recruitment, reductions in muscular compliance, and muscle wisdom on the MMG signal, and peripheral fatigue and decreases in action potential conduction velocity on the EMG signal during dynamic fatiguing tasks.
CHAPTER V
SUMMARY

Statement of Purpose

The purpose of the present investigation was to examine the mechanomyographic (MMG) and electromyographic (EMG) amplitude and mean power frequency (MPF) versus repetition number relationships during 50 consecutive maximal, concentric isokinetic muscle actions of the biceps brachii at 180°•s⁻¹.

Procedures for Collection of Data

Ten adults [three women (mean ± SD age = 20 ± 2 yrs) and seven men (mean ± SD age = 23 ± 3 yrs)] volunteered to perform 50 consecutive maximal, concentric isokinetic muscle actions of the dominant forearm flexors at 180°•s⁻¹. Piezoelectric MMG recording sensors were placed over the belly of the biceps brachii muscle between a bipolar surface EMG electrode (Ag-AgCl) arrangement.

Analysis

The average torque, EMG amplitude, MMG amplitude, EMG MPF, and MMG MPF in relation to muscle action number were examined using polynomial regression models (linear, quadratic and cubic). The statistical significance (p ≤ 0.05) that would be accounted for by a higher degree polynomial was determined using an F-test.
Findings

Torque

There was a cubic ($R^2 = 0.994$) relationship between isokinetic PT and repetition number. The percent decline (mean ± SD) in isokinetic PT was 70 ± 17%.

MMG Amplitude and MPF

There were linear decreases in both MMG amplitude ($r^2 = 0.774$) and MMG MPF ($r^2 = 0.238$) across repetitions.

EMG Amplitude and MPF

The relationship between EMG amplitude and repetition number was best fit with a cubic model ($R^2 = 0.707$), where EMG amplitude increased during repetitions 1-20, remained stable during repetitions 20-40, and increased during repetitions 40-50. The EMG MPF versus repetition number relationship was best fit with a quadratic ($R^2 = 0.939$) model.

Conclusions

The results of this study showed that forearm flexion PT decreased cubically (70 ± 17% decline) across the 50 repetitions. There were linear decreases in both MMG amplitude and MPF throughout the test. The relationship between EMG amplitude and repetition number was best fit with a cubic model, where EMG amplitude increased during repetitions 1-20, remained stable during repetitions 20-40, and increased during repetitions 40-50. There was a quadratic decrease in EMG MPF across the repetitions.

The percent decline in PT and relationship between PT and repetition number in the present study were similar to the results for repeated maximal, concentric isokinetic
leg extensions. The consistency between the results for the two muscle groups may have reflected the similarities in fiber type distribution characteristics for the biceps brachii and quadriceps femoris muscles. A number of hypotheses were proposed to explain the decreases in MMG amplitude and MPF throughout the test including de-recruitment of fast fatiguing motor units, a decrease in muscular compliance, and the effects of “muscle wisdom.” The pattern for EMG amplitude across repetitions in the present study may have reflected non-maximal efforts by the subjects or peripheral fatigue. The factors that contributed to the decrease in EMG MPF throughout the test are unclear, although a reduction in muscle fiber action potential conduction velocity may have been at least partially responsible. The findings of the present study also indicated differences between the MMG and EMG time and frequency domain responses across the repetitions, which suggested that MMG and EMG each provide unique information regarding muscle function during fatiguing, dynamic muscle actions. Additional research is needed on the effects of motor unit de-recruitment, muscle wisdom, and decreases in muscular compliance on the MMG signal. Furthermore, future studies should examine the influence of peripheral fatigue on EMG amplitude and attempt to identify the factor(s) that affect EMG MPF during fatiguing, dynamic muscle actions.
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_______________________   ( ) Feet

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

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

( ) High Blood Pressure   ( ) Acute Infection
( ) Heart Disease or Dysfunction   ( ) Diabetes or Blood Sugar Level
   Abnormality
( ) Peripheral Circulatory Disorder   ( ) Anemia
( ) Lung Disease or Dysfunction   ( ) Hernias
( ) Arthritis or Gout   ( ) Thyroid Dysfunction
( ) Edema   ( ) Pancreas Dysfunction
( ) Epilepsy   ( ) Liver Dysfunction
( ) Multiply Sclerosis   ( ) Kidney Dysfunction
( ) High Blood Cholesterol or   ( ) Phenylketonuria (PKU)
  Triglyceride Levels
( ) Loss of Consciousness
describe _________________________________
( ) Others That You Feel We Should Know
  About______________________________   ( ) Allergic Reactions to Any Other Substance
  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)

<table>
<thead>
<tr>
<th>MEDICATION</th>
<th>CONDITION</th>
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<tbody>
<tr>
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</tbody>
</table>

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))

<table>
<thead>
<tr>
<th>PA</th>
<th>SED</th>
<th>PA</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>( ) ( )</td>
<td>Chest Pain</td>
<td>( ) ( )</td>
<td>Nausea</td>
</tr>
<tr>
<td>( ) ( )</td>
<td>Heart Palpitations</td>
<td>( ) ( )</td>
<td>Light Headedness</td>
</tr>
<tr>
<td>( ) ( )</td>
<td>Unusually Rapid Breathing</td>
<td>( ) ( )</td>
<td>Loss of Consciousness</td>
</tr>
<tr>
<td>( ) ( )</td>
<td>Overheating</td>
<td>( ) ( )</td>
<td>Loss of Balance</td>
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<tr>
<td>( ) ( )</td>
<td>Muscle Cramping</td>
<td>( ) ( )</td>
<td>Loss of Coordination</td>
</tr>
<tr>
<td>( ) ( )</td>
<td>Muscle Pain</td>
<td>( ) ( )</td>
<td>Extreme Weakness</td>
</tr>
<tr>
<td>( ) ( )</td>
<td>Joint Pain</td>
<td>( ) ( )</td>
<td>Numbness</td>
</tr>
<tr>
<td>( ) ( )</td>
<td>Other</td>
<td>( ) ( )</td>
<td>Mental Confusion</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)

( ) Heart Disease
( ) Heart Attacks or Strokes (prior to age 50)
( ) Elevated Blood Cholesterol or Triglyceride Levels
( ) High Blood Pressure
( ) Diabetes
( ) Sudden Death (other than accidental)

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

( ) Regularly does manual garden or yard work
( ) Regularly goes for long walks
( ) Frequently rides a bicycle
( ) Frequently runs/jogs for exercise
( ) Regularly participates in a weight training exercise program
( ) Engages in a sports program more than once per week. If so, what does the program consist of? ____________________________
Title of Research Study
Mechanomyographic and electromyographic responses during fatiguing isokinetic muscle contractions of the biceps brachii.

Invitation to Participate
You are invited to participate in this research study. The following 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 were selected as a potential volunteer because you are between the ages of 19 and 29 years of age 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. Musculoskeletal disorders may also preclude you from participation in this study. 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 purpose of this study is to evaluate the electrical and mechanical activity of the biceps brachii muscle during fatiguing contractions at a speed of 180 degrees per second. This will be done by measuring the electromyographic (EMG) and mechanomyographic (MMG) signals from these muscles.

Explanation of Procedures
You will be asked to visit the Exercise Physiology Laboratory at the University of Nebraska-Lincoln (Mable Lee Hall-Room 141) on two separate occasions to complete the following one-arm strength tests.

Strength Test One (one hour)
The first session will be for orientation to the isokinetic dynamometer.

Strength Test Two (one hour)
During the second session, 15 to 25 minutes will be used for preparation of the biceps brachii muscle. Your skin will be scraped lightly with sandpaper at two locations on your arm and one location on your wrist. Electrodes will be placed over the scraped areas.
Wires from the electrodes are then hooked to a device which measures the electrical activity of your biceps brachii muscle as you are performing the test. In addition, one small microphone will be placed on your arm in-between the electrodes to measure the sound produced by your biceps brachii muscle. Following the placement of these devices, the speed of the isokinetic dynamometer will be set, and you will be allowed to practice contracting against that speed.

When preparation has been completed, you will perform 50 maximal contractions at 180 degrees per second. During this time, the EMG and MMG signals will be continuously recorded. During the test, if you do not feel well, you may stop the test at any time. Following the test, the microphones and electrodes will be removed.

**Potential Risks and Discomforts**

The following are the potential risks and discomforts you may experience during this study:

- **Electrode Preparation and Use**
  The use of electrodes and the preparation of the skin for their application may lead to the remote possibility of complications such as a rash or infection.

- **Strength Tests**
  Performing maximal strength tests may lead to muscle tears or soreness, dizziness, headache, acute elevation of blood pressure, heart attack, stroke, or sudden death.

**Protection Against Risks**

You will be given instructions for special stretches which may aid in the elimination of any muscle soreness as a result of the test. Upon completion of the test, an antibacterial salve will be applied to the electrode abrasion sites to reduce the chance of infection. Throughout the test, 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. If you feel unable to continue a test, you may stop at any time.

**Potential Benefits to Subjects**

Your main benefits from participating in this study will be feedback as to your muscular endurance and your muscle fiber type composition. This information will be explained to you as to how it relates to your performance in various activities.

**Potential Benefits to Society**

Society may benefit from this research by having a better understanding of how to conduct scientifically-based exercise programs in sport, rehabilitative, and recreational settings.
In Case of Emergency Contact Procedures
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, the acute medical care required to treat the injury can be provided at the University of Nebraska Health Center from the hours of 8 a.m. – 6 p.m. Monday through Friday, and 10:30 a.m. – 2 p.m. Saturday (for urgent care needs only). The cost of such medical care will be the responsibility of the subject, whether at the University Health Center or at other local health care facilities. If the health center is unable to treat you, emergency care is available at local community health providers.

Assurance of Confidentiality
Any information obtained from 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. All data collected as a result of your participation will be kept by the investigators in a locked cabinet in the office of the principal investigator. Your data will receive an identifying number and only the investigators will be able to identify you from your data. Your data will be compiled and only group data will be used for dissemination without identifying your name. For the purposes of future reference, your data will be stored for a minimum of three years.

Rights of Research Subjects
If you have any questions about your rights as a research participant that have not been answered by the investigator or to report any concerns about the study, you may contact the University of Nebraska-Lincoln Institutional Review Board, telephone (402) 472-6965.

Voluntary Participation Withdrawal
You are free to decide not to participate in this study, or to withdraw at any time without adversely affecting your 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.

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

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

Investigators:

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