The relationships between skinfold, fatigue and the traditional and log-transformed electromyographic and mechanomyographic signal in the vastus lateralis and recuts femoris

By

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Chairperson Trent Herda

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Abstract

The relationships between skinfold, fatigue and the traditional and log-transformed electromyographic and mechanomyographic signal in the vastus lateralis and recuts femoris

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The University of Kansas, 2013

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INTRODUCTION: The purpose of the present study was to examine possible correlations between skinfold thicknesses and the *a* terms from the EMG_{RMS}- and MMG_{RMS}-force relationships for the vastus lateralis (VL) and rectus femoris (RF) and EMG M-Wave (EMG M-wave) and MMG gross lateral movement (MMG GLM) of the VL and RF from a non-voluntary single evoked potential. In addition, correlations were calculated between the *b* terms form the EMG_{RMS}- and MMG_{RMS}-force relationships and the fatigue index from the Thorstensson protocol. **METHODS:** Forty healthy subjects (age = 21 ± 2 yrs., weight = 73.5 ± 13.2 kg, height = 1.7 ± 0.09 m) performed a 6-second isometric ramp contraction followed by transcutaneous electrical stimuli at rest and a 50-repetition fatigue protocol. EMG and MMG sensors were placed on the VL and RF on the center of the muscle belly with skinfold thickness assessed at the site of the electrodes. Transcutaneous stimuli were delivered to the femoral nerve via a bipolar surface electrode that was placed over the inguinal space to assess EMG M-wave and MMG GLM. Simple linear regression models were fit to the natural log-transformed

EMG_{RMS} and MMG_{RMS}-force relationships. The *b* term and *a* term were calculated for each relationship. The fatigue index was calculated from the equation: ([Initial Peak Force - Final Peak Force]/Initial Peak Force) x 100. Pearson's product correlation coefficients were calculated comparing VL and RF skinfold thicknesses with the *a* terms from the EMG_{RMS}-and MMG_{RMS}-force relationships, EMG M-wave, and MMG GLM. In addition correlations were calculated comparing the *b* terms from the EMG_{RMS}- and MMG_{RMS}-force relationships terms for the VL and RF with the fatigue index. **RESULTS:** There were no significant correlations found between the *a* terms and the skinfold thicknesses for the RF ($p = 0.614$, $r = -0.082$) and VL ($p = 0.507$, $r = 0.108$) from the EMG_{RMS}-force relationships and the RF ($p = 0.508$, $r = 0.108$) and VL ($p = 0.546$, $r = 0.098$) from the MMG_{RMS}-force relationships. In contrast, there were significant correlations between skinfold thicknesses and the EMG M-waves for the RF ($p = 0.002$, $r = -0.521$) and VL ($p = 0.005$, $r = -0.479$) and for the MMG GLM for the RF ($p = 0.031$, $r = -0.376$) and VL ($p = 0.004$, $r = -0.484$). Finally, significant correlations were found between the *b* terms from the MMG_{RMS}-force relationships for the VL ($p = 0.007$, $r = 0.417$) and RF ($p = 0.014$, $r = 0.386$) with the fatigue index. In addition, the *b* terms from the EMG_{RMS}-force relationships for the RF ($p = 0.017$, $r = 0.375$) were correlated with the fatigue index, however, the *b* terms for the VL ($p = 0.733$, $r = 0.056$) were not correlated with the fatigue index. **DISCUSSION:** The correlations between the *b* terms and fatigue index suggested that the log-transformed MMG_{RMS}-force relationship model may reflect muscle fiber type composition. Regarding the EMG_{RMS}-force relationships, it is unclear why the *b* terms from the RF and not the VL were correlated with the fatigue index. The *a* terms from the log-transformed EMG_{RMS}- and MMG_{RMS}-

force relationships were not correlated with skinfold thicknesses, whereas, the EMG M-wave and MMG GLM produced from non-voluntary evoked twitches were correlated with skinfold thicknesses.

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Chapter I

Introduction

Surface electromyography (EMG) and mechanomyography (MMG) are noninvasive tools that have been used to study muscle function (Behm et al., 2001; Cramer et al., 2004; Evetovich et al., 2003; Orizio, 1993; Orizio et al., 1989). EMG is commonly defined as a measure of muscle activation that reflects the algebraic sum of muscle action potentials passing beneath the recording electrodes (Basmajian et al., 1985). The amplitude of the EMG signal is influenced by motor unit recruitment and the firing rates of the active motor units (Basmajian et al., 1985), and is often considered a global measure of motor unit activity, which contains information regarding both peripheral and central properties of the neuromuscular system (Farina et al., 2004). MMG, however, has been defined as the recording of low-frequency lateral oscillations of muscle fibers that occur during a contraction (Barry and Cole, 1990; Orizio, 1993). Barry and Cole (1990) and Orizio (1993) have suggested that these oscillations are manifested through (a) the gross lateral movement of the muscle at the initiation of the contraction, (b) smaller subsequent lateral oscillations occurring at the resonant frequency of the muscle, and (c) dimensional changes in the active fibers.

It has been suggested that skinfold thickness serves as a low-pass filter of the surface EMG and MMG signals (Petrofsky, 2008) and, in theory, would reduce the amplitude of the signals (Evetovich et al., 1998; Herda et al., 2010; Herda et al., 2011). For example, Herda et al. (2010), Herda et al. (2011), and Cooper and Herda (2012) reported that the amplitude of the EMG and MMG signals were reduced across the force spectrum in individuals and muscles with greater skinfold thicknesses during isometric muscle actions. However, no correlation analyses were performed among the EMG and MMG parameters and skinfold thickness. In contrast, Zuniga et al. (2011) indicated that differences in MMG amplitude between accelerometer placement sites during cycle ergometer were not due to the thickness of the subcutaneous fat layer as measured by skinfolds. Furthermore, Jaskolaska et al. (2004) reported limited evidence to indicate that skinfold thickness effects median frequency and suggested that further analysis was needed and encouraged further study into the effects of subcutaneous fat on MMG signal.

Previously, there have been numerous studies that examined the force-related amplitude responses of the EMG and MMG signal (Akataki et al., 2004; Akataki et al., 2003; Herda et al., 2009; Ryan et al., 2008; Ryan et al., 2007). It has been suggested that the MMG amplitude-force relationships may reflect the motor unit activation strategies of the muscle (Akataki et al., 2004; Ryan et al., 2008). Specifically, there are rapid rises in the amplitude of the MMG signal when the muscle is primarily using motor unit recruitment to increase force, while there is no change or even slight decreases in the amplitude of the signal when the modulation of firing rates is the primary mechanism to increase force (Orizio et al., 2003b; Ryan et al., 2007). Therefore, it has been suggested that the MMG amplitude-force relationships may be able to distinguish differences between muscles with known motor unit activation strategy differences (Akataki et al., 2003; Beck et al., 2008; Yoshitake and Moritani, 1999). In contrast, it has been hypothesized that the EMG amplitude-force relationship reflects the undistinguishable increases in both motor unit recruitment and the firing rates of the active motor units (Beck et al., 2009; Orizio et al., 2003a; Orizio et al., 1989). It has been suggested that the differences in linearity seen with increasing EMG amplitude-force relationships are due to the morphological differences between the muscles or activation capabilities of the individual (Akataki et al., 2004).

Herda et al. (2009) suggested that log-transformed MMG amplitude (or EMG amplitude)-force relationships might provide an alternative, quantitative method for describing the force-related patterns of responses for MMG or EMG amplitude. The log-transformation procedure yields the equation $Y = aX^b$ where Y = MMG or EMG amplitude, X = force, a = gain coefficient, and b = exponential coefficient. The b term of a linear relationship in which both X and Y variables are log-transformed indicates whether the original, non-transformed relationship is linear or nonlinear (Herda et al., 2009). If the b term is equal to 1 (or if the 95% confidence interval [CI] of the slope contains 1), then the rate of change in Y equals the rate of change in X. If the b term is less than 1 and the 95% CI of the slope does not contain 1, the rate of change in Y is less than the rate of change in X and the curve decelerates across the force spectrum. Previous studies have reported the MMG amplitude-force relationships as either linear or nonlinear with a plateau or decrease in MMG amplitude at higher force levels (Beck et al., 2008; Beck et al., 2004; Coburn et al., 2004; Ryan et al., 2007). Therefore, it would be expected that these patterns would have b terms of ≤ 1. Indeed, Herda et al. (2010) reported that b terms were ≤ 1 and were dependent on the fiber type composition of the vastus lateralis (VL). Individuals with a greater percentage of type I myosin heavy chain (MHC) had lower b terms than individuals with a greater percentage of type II MHC of the VL. In addition, previous studies have reported the EMG amplitude-force relationships as either linear or nonlinear with an acceleration in EMG amplitude at the higher force levels (Beck et al., 2007; Ryan et al., 2007) and, therefore, it would be expected that these patterns would have b terms either = 1 or >1. In support of this hypothesis, Herda et al. (2011) reported nonlinear (b terms > 1) patterns for individuals with high activation capabilities and linear (b terms = 1) patterns for individuals that did not possess high activation capabilities.

Previous studies have reported differences in the fatiguability between type I and type II fibers (Burke et al., 1973; Hulten et al., 1975; Linssen et al., 1991). Thorstensson et al. (1976)

introduced a fatiguing protocol that included 50 maximal concentric contractions at 180°/s to calculate a fatigue index for an individual. The authors correlated the fatigue index with the fiber type composition of the individual and reported a positive correlation coefficient of 0.86. Thus, individuals with a greater percentage of fast-twitch fibers had a greater fatigue index than the individuals with a greater percentage of slow-twitch fibers. In theory, since the *b* term from the MMG_{RMS}-force relationships have been able to distinguish between fiber type compositions, it is plausible that the *b* terms may have a relationship with the fatigue index calculated from the Thorstensson test. However, it is unclear if there would be a relationship between the fatigue index and the *b* term from the EMG amplitude-force relationship, because the *b* term has not been able to distinguish between fiber types.

In addition, the antilog of the *a* term in the equation $Y = aX^b$ does not represent the *Y*-intercept, because the exponential model forces the *Y*-intercept through the origin ($X = 0$, $Y = 0$). Instead, the *a* term can be viewed as a "gain factor" that represents upward or downward shifts in the exponential relationship without changing the shape of the relationship. For example, previous studies reported differences in the *a* terms between individuals based on skinfold thickness (Cooper, 2012; Herda et al., 2010), such as, individuals with greater skinfolds had lower *a* terms than the individuals with lower skinfolds. In theory, subcutaneous fat acts as a low pass filter that may reduce the MMG signal and, therefore, a lower *a* term would reflect the reduction in amplitude of the signal as a result of subcutaneous fat. Although the distinction between skinfold thicknesses has been made with the *a* terms, no correlational analysis has been performed between skinfold thicknesses and *a* terms.

Herda et al. (2011) reported differences in the *a* terms for the EMG_{RMS}-force relationships between the soleus and medial gastrocnemius muscles and between the EMG M-waves (EMG M-wave) produced by an evoked stimulus. In addition, Tomazin et al. (2011) reported that the EMG M-wave diminished with increasing skinfold thickness. Therefore, there is evidence to suggest that the EMG M-wave produced from an evoked stimulus may be significantly correlated with the *a* term from the EMG_{RMS}-force relationships. There is, however, no evidence to indicate whether the evoked stimulus response (gross lateral movement) of the MMG signal reflects skinfold thickness in a similar manner to the EMG M-wave.

Statement of the Problem

Currently, there is limited literature that has examined the effects of skinfold thickness on the MMG and EMG signals (Jaskolska et al., 2004; Petrofsky, 2008; Zuniga et al., 2011). The purpose of the present study is to examine possible correlations between skinfold thickness and various parameters of the EMG and MMG signal. Specifically, correlations will be performed among the *a* terms from the log-transformed EMG and MMG amplitude-force relationships and the EMG M-wave and the MMG peak-to-peak gross lateral movement (MMG GLMS) produced from an evoked stimulus. In addition, correlations will be performed among the *b* terms from the EMG and MMG amplitude-force relationships and the fatigue index from the Thorstensson test.

Hypothesis and Specific Aims

Hypothesis

The hypothesis of this study is that there are significant correlations between subcutaneous fat and the EMG and MMG parameters.

Specific Aim #1

Determine if there are significant correlations between the *a* terms from the log-transformed MMG and EMG amplitude-force relationships and the skinfold measurement at the MMG and EMG electrode site for the vastus lateralis (VL) and rectus femoris (RF).

Specific Aim #2

Determine if there is a significant correlation between the *b* term in the log-transformed MMG_{RMS}/EMG_{RMS} versus force relationship and decline in the calculated fatigue index from the Thorstensson protocol.

Specific Aim #3

Determine if there is a significant correlation between the EMG M-wave and MMG GLM versus skinfold measurement of each muscle.

Definition of Terms

Surface Electromyography (EMG) – a recording of the muscle action potentials that sweep across the sarcolemma and pass through the surface electrode recording areas during a skeletal muscle action; contains physiological information in the time domain (amplitude) and the frequency domain (median power frequency; MDF), which may represent motor unit recruitment and muscle action potential conduction velocity, respectively; the raw signal is expressed in microvolts (μV).

Mechanomyography (MMG) – a recording of the lateral oscillations produced by contracting skeletal muscle fibers; contains physiological information in the time domain (amplitude) and the frequency domain (MDF), which may represent motor unit recruitment / muscle stiffness and firing rate, respectively; the raw signal is expressed in microvolts (m/s^2).

Peak Torque – the peak torque achieved during a maximal, voluntary muscle action; expressed in Newton-meters (Nm).

Peak to Peak m wave - the change in amplitude of the muscle compound action potential.

Peak to Peak gross lateral movement – the movement of the muscle belly at the initiation of a contraction generated by the non-simultaneous activation of the muscle fibers.

Assumptions

Theoretical Assumptions

1. Subjects accurately answered the health history questionnaire.
2. Subjects exerted maximal effort during each isometric test and fatigue test.
3. All equipment was calibrated and functioning properly for all testing sessions.

Statistical Assumptions

1. The population from which the samples were drawn is normally distributed.
2. The sample was randomly selected.
3. The data was based on either interval or ratio scale.
4. There is a linear relationship between the variables.
5. There are a limited number, or no outliers in the data.
6. There is homoscedasticity of the data; homoscedasticity requires that all data points have the same amount of variance.

Chapter II

REVIEW OF LITERATURE

Mechanomyography

Claudio Orizio (1993)

The author in this paper constructed a review of the literature examining vibromyography, acousticmyogram, phonomyogram, and soundmyogram. After this paper the term mechanomyography was coined and entered common phrase. The author stated that it was known that muscle sound is related to muscle activity and its properties are related to the properties of contraction. It was also noted that the advantage of using accelerometers is that the measurement is made in "physiological units (m/s^2) rather than in transducer dependent units" (mV). During single twitch elicited by supramaximal nerve stimulation the lateral displacement of the muscle surface is due to: 1) a slow bulk movement of the muscle related to the different regional distribution of contractile tissue; and 2) the excitation into ringing of the muscle at its own resonant frequency due to the forces associated with the slow bulk movement. It was found that the time and frequency domain properties of the muscle sound are clearly related to the number, the type, and the firing rate of the recruited motor units. Therefore, it was concluded that during steady voluntary contraction the main sound generation mechanism is related to the summation of the twitching of each individual motor unit.

Daniel Barry (1987)

The author examined the acoustic signals emitted from frog skeletal muscle. In this study an acoustic waveform produced by a muscle twitch is characterized by oscillations that initially increase in amplitude and then decrease. The author found that the oscillations that are seen from the muscle twitch are consistent with an etiology of muscle movement perpendicular to the long axis of the muscle producing muscle sounds. During this study the sounds that resulted from opposite sides of the muscle were 180 degrees out of phase, which is not consistent with etiology of muscle. However, the author explained that the lateral movement of the muscle is required to produce the phase relationship measured. The lateral movement of the muscle that emits the sounds seen should occur at a frequency corresponding to the resonant frequency of the muscle. The key development brought forth by this author was the qualitative observation that the acoustic signal increases in frequency as force increases.

Daniel Barry and Neil Cole (1988)

The authors examined how muscle vibrations work mechanically, the author described how the vibration is much closer to that observed happening in fluid as opposed to the way waves work in air. The authors saw that pressure waves were generated by lateral movements during isometric muscle contractions and the pressure waveform was directly related to the lateral acceleration of the muscle. In the article it was observed that the acoustic signal was proportional to acceleration, and that the higher frequency oscillations dominate the signal recorded. These superimposed, smaller, higher frequency oscillations appear to represent the natural mechanical response of the muscle to a step function input. During an isometric twitch the authors saw that the change in muscle stiffness was much greater than the change in any of the other parameters and may dominate the change in resonant frequency. If this is the case the sound signal could be used as a monitor of muscle stiffness changes during a twitch and therefore could provide information regarding crossbridge dynamics during a twitch.

Claudio Orizio, Renza Perini, and Arsenio Veicsteinas (1989)

In this study the authors purpose was to describe the relationship between the SMG amplitude and the intensity of contractions from 0% to 100% MVC. During this study the authors were able to indicate from their data that the SMG signal presents a high degree of reproducibility. The authors also found that the relationship between the integrated SMG amplitude and the intensity of isometric contraction from 0% to 80% MVC is comparable to that described for the integrated electromyogram (iEMG). Beyond 80% MVC, the high discharge rate of the activated MU, and the visco-elastic modifications in the muscle bodies are the basis for the divergent pattern between electric (iEMG) and acoustic variables (SMG). Therefore, from these findings we can presume that the motor unit activation pattern affects both EMG and SMG in a way that is dependent on the different natures of these two methods.

Claudio Orizio, Diego Liberati, Cecilia Locatelli, Domenico De Grandis, Arsenio Veicsteinas (1996)

The authors in this study looked to define the pattern of summation of the muscle fiber twitches during surface mechanomyography. The authors found from this study that surface MMG is a compound signal in which the mechanical activities of the active muscle fibers are summated. Also, the linear summation of the mechanical contribution of each active motor unit to the MMG signal is not allowed in the whole physiological range of motor units firing rates. This is what developed the idea of “fusion of twitch’s”, that at higher intensities of contraction, the initial firings and mechanical response of that firing is what causes the smaller mechanical response as you increase.

Trent Herda, Eric Ryan, Travis Beck, Pablo Costa, Jason DeFreitas, Jeffery Stout, Joel Cramer (2008)

The authors examined the reliability of mechanomyographic amplitude during isometric step and ramp muscle contractions. The authors found that at lower isometric force levels (<25% of MVC) during both the ramp and step muscle actions there were lower interclass coefficients. They hypothesized that this difference was seen due to lower between-subject variability, which may have been caused from the low signal-to-noise ratio that is seen at low force levels. The authors also found that overall, reliability was slightly higher during step muscle contractions as compared to ramp contractions and that the reliability of both of these muscle actions was greater at higher force levels. They concluded that mechanomyographic amplitude measured across multiple days using both isometric ramp and step contractions when examining the vastus lateralis has an acceptable level of reliability.

Effects of skinfold on mechanomyography and electromyography

Anna Jaskolska, Wioletta Brzenczek, Katarzyna Kisiel-Sajewicz, Adam Kawczynski, Jaroslaw Marusiak, Artur Jaskolski (2004)

The authors examined the effects of force and skinfold thickness in relation to age and gender for 79 healthy subjects broken into four groups: young females (age 20.1 ± 1.1 years), young males (age 23.4 ± 1.1 years), elderly females (age 64.9 ± 5.1 years), and elderly males (age 67.4 ± 6.2 years). They found that the tissue between the muscle and the skin surface might be acting as a low-pass filter on MMG frequency with a different effect on the median than on the peak frequency. However, they did see that under certain circumstances force or age might have a larger effect on frequency than skinfold measurements due to the fact that when the results were broken down by age groups there were positive, negative, and even no correlations found. In this study it was found that the brachioradialis differed from the triceps brachii and biceps brachii in the effects of skinfold thickness and force on the MMG frequency, as well as in the effect of age on the relationship between the MMG frequency and skinfold thickness and force, which the authors explained due to the fact that this muscle had the smallest range of skinfold thickness's. Another finding was that the effect of age on the relative contribution of skinfold and force to the MMG frequency is muscle and muscle function dependent. The authors suggested that in future studies the use of force and skinfold thickness as covariates is recommended when an MMG frequency is analyzed in subjects differing in the skinfold thickness.

Jorge M. Zuniga, Terry J. Housh, Clayton L. Camic, C. Russell Hendrix, Haley C. Bergstrom, Richard J. Schmidt, Glen O. Johnson (2011)

The authors examined how skinfold thicknesses and innervation zone altered the mechanomyographic signals. Significant correlations were found for skinfold thickness vs. MMG amplitude at two sites at one power output (out of 4 possible sites at 6 possible powers). The results indicated that for 90% of the regression analyses, there were no significant relationships between SF thickness and MMG amplitude or MPF. It was also found that the accelerometers placed proximal to the IZ and over the IZ resulted in significantly greater MMG amplitude and MPF values than the accelerometer placed distal to the IZ. The authors suggested that it is possible that the amount of muscle mass as well as the tendon and other non-contractile structures underlying the accelerometer may play a more important role affecting the MMG amplitude and MPF than the thickness of the subcutaneous fat layer and IZ.

Jerrold Petrofsky (2008)

The authors found in this study that there was an inverse relationship between subcutaneous fat and delivered current into the muscle. There was also a linear relationship between the time constant and body fat that was a highly significant correlation. This study showed that there was a high resistance to subcutaneous fat, the thickness of the fat layer, the greater the resistance and as such, the more the filtering from the skin into muscle. Another connection with fat in this study was found that the thicker the fat layer, there was a slower resistance capacitor time constant and less energy and therefore a greater amount of signal was lost. Body fat was observed to cause waveform distortion, which alters the transfer characteristics of current into tissue. The author stated that for a signal generated in muscle such as EMG, the signal recorded on the surface of the skin should also be filtered by the fat layer under the skin because the detection of the EMG pattern is altered in people with thicker subcutaneous fat layers.

Log-transformed MMG force-amplitude relationship

Trent Herda, Joseph Weir, Eric Ryan, Ashley Walter, Pablo Costa, Katherine Hoge, Travis Beck, Jeffrey Stout, Joel Cramer (2009)

The authors in this study examined the MMG amplitude signal after having first applied a log-transformation to the normal linear regression equation. In this log-transformed model the *a* terms can be viewed as "gain factors" that represent upward or downward shifts in the exponential relationship without changing the shape of the deceleration or acceleration, which are dictated by the *b* terms in the log transformed equation. In a log-transformed relationship, a change in the *a* term of the MMG amplitude versus torque (TQ) relationship may indicate an upward or downward shift in MMG amplitude across the TQ spectrum. The authors theorized that subcutaneous fat may act as a low-pass filter and reduce MMG amplitude across the force spectrum and because of this we can expect a lower *a* term for subjects that have more subcutaneous fat. The change in the *b* term is explained by the authors as reflecting increase, or plateau of the MMG amplitude signal. There is a plateau of the MMG-amplitude signal upon reaching 60-80% to 100% MVC that is attributed to the idea of fusion of twitches. Therefore in theory, because there would be an earlier plateau in the MMG-amplitude versus torque relationship for a type I muscle the log-transformed *b* term would be lower for the type I muscle than a type II muscle.

Trent Herda, Terry Housh, Andrew Fry, Joseph Weir, Brian Schilling, Eric Ryan, Joel Cramer (2010)

The authors reported that the *a* values from the muscle examined and MMG-force relationships were higher for endurance trained compared to sedentary individuals. The authors suggested the difference in the EMG and MMG amplitudes was the result of mean skinfold thickness differences between the groups (endurance trained = 8.7 mm, sedentary = 25.4 mm). The higher mean skinfold thickness for the sedentary individuals may have been enough to act as a low pass filter that reduced the EMG and MMG amplitudes compared to the endurance trained, which lowered the *a* values for sedentary subjects. The authors observed that the *a* terms seemed to be higher in the endurance trained group as compared to the sedentary group, however, correlation statistics were not run in this study. The other key result of this study was that the *b* term from the AT (endurance trained) group was lower than that for the RT (resistance trained) and SED (sedentary) groups. Since the AT group had a greater percentage of type I fiber area compared to the RT and SED groups, and the RT and SED groups had an equivalent percentage of total combined type II fiber area, the *b* term may be sensitive to the differences in motor unit activation strategies between individuals with predominately type I vs. type II fiber area in the vastus lateralis. The findings by these authors supported previous studies that qualitatively observed differences in motor unit activation strategies in muscles with different fiber type composition.

Cooper M, Herda T (2012)

The authors in this study examined the differences in the log transformed MMG amplitude versus force relationship between known fiber types. The authors observed that the *b* terms were sensitive to the earlier onset of rate coding in the FDI as the primary mechanism to increase force in comparison to the VL. This study along with previous ones performed by Herda et al. shows that the *b* term does reflect the change in motor unit recruitment and can therefore be used as a means of distinguishing between fiber type differences. Also in the study the authors examined the change in the *a* terms for the FDI and VL. The authors suggested that the change in *a* terms seen between the two sites was affected by the amount of subcutaneous fat at the sites. The authors suggested that in the future research is needed to further examine the effects of skinfold thickness on the *a* terms from the log-transformed MMG_{RMS}-force relationships.

Fiber Type Fatigue

Thorstensson A, Larsson L, Tesch P, Karlsson J (1977)

The authors of this study examined the fatiguability characteristics of different fiber types. The authors tested this by using the fact that a high percent fast twitch fiber composition has been shown to be related to a low ability to sustain an isometric contraction. Therefore, they investigated how with repeated fast maximal isokinetic contractions, different fiber types fatigued at different rates. The main finding of this study was that there is a positive correlation between fatiguability with rapid maximal voluntary isokinetic contractions and proportion fast twitch fibers in the contracting muscle. Earlier studies found minor glycogen depletion after 50 contractions and no apparent difference between fiber types. The authors examined earlier studies that found that with repeated stimulation fast twitch motor units saw rapid decline in tension, but slow twitch muscles and motor units showed no or only minor fatigue.

R.E. Burke, D.N. Levine, P. Tsairis, F.E. Zajac III (1973)

In this study the authors examined the physiological properties of single motor units of pentobarbitone-anaesthetized cats and used a system for muscle unit classification which was developed using a combination of two physiological properties (sensitivity to fatigue and shape of the tension envelope). The authors also ran histochemical profiles of muscle units representative of each of the physiological classes using a method of glycogen depletion for muscle unit identification. They found that within each physiological type all of the units examined had the same histochemical profile. The authors found strong support for the hypothesis that all of the muscle fibers innervated by a single alpha motoneuron are histochemically identical. During this study muscle units were broken in to three populations, type FF-fatigue sensitive with relatively fast twitch contraction; type FR-fatigue resistant units with fast twitch contraction; type S- very fatigue resistant with relatively slow twitch contraction.

Wim Linssen, Dick Stegeman, Ed Joosten, Rob Binkhorst, Mieke Merks, Henk Laak, Servaas Notermans (1991)

It is known that the metabolism of type I fibers is mainly aerobic, and that these fibers show a lower energy cost for calcium cross-bridging cycling than type II fibers, which is what makes the type I muscle fibers more resistant to fatigue. During this study the authors found that in the muscles tested, patients with 95-100% type I fibers showed less fatigability than those with type II fibers, which was reflected by a nearly absent decrease of the muscle membrane excitability as measured by the muscle fiber membrane conduction velocity and only a slight increase of the surface EMG amplitude when compared with patients having 80% type I fibers and controls.

Chapter III

Methods

2.1 Participants

Seventeen male and twenty-three female healthy subjects (male: age = 21 ± 2 yrs., weight = 81.9 ± 13.6 kg, height = 1.8 ± 0.09 m; female: age = 21 ± 2 yrs., weight = 67.3 ± 8.9 kg, height = 1.69 ± 0.07 m) volunteered to participate in this study. All of them were screened for any current or ongoing neuromuscular diseases or musculoskeletal injuries that involve the ankle, knee or hip joints. This study was submitted for approval by the University Institutional Review Board for the protection of human subjects, and all participants were required to complete a health history questionnaire and sign a written informed consent document.

2.2 Research Design

Subjects were asked to visit the lab on one occasion for testing. Isometric maximal voluntary contractions (MVC), isometric ramp contractions, resting twitches and a fatigue protocol of the leg extensors were performed on the same day. Isometric strength for the right leg extensor muscles was measured using the force signal from a load cell (LC402, Omegadyne, Inc., Sunbury, OH) that was fitted to a Biodex System3 isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY). The participants sat with restraining straps over the pelvis, trunk, and contralateral thigh, and the lateral condyle of the femur was aligned with the input axis of the dynamometer in accordance with the Biodex User's Guide (Biodex Pro manual, Applications/Operations. Biodex Medical Systems, Inc., Shirley, NY, 1998). All isometric leg extensor strength assessments were performed at a leg flexion angle of 90° (i.e. 90° below full leg extension).

2.2.1 Maximal Voluntary Contraction

Strong verbal encouragement was provided during each MVC trial. The highest force output between the two trials was used to represent the MVC value.

2.2.2 Isometric Ramp Contraction

After the MVC trials, each participant performed two 6-s isometric ramp muscle actions separated by 2-m. During the ramp muscle actions, participants were required to track their force production on a computer monitor placed in front of them that displayed their real-time, digitized force signal overlaid onto a programmed ramp template. The ramp template consisted of a 5-s horizontal baseline at 5% MVC and a 6-s linearly increasing ramp line from 5% to 100% MVC. Of the two attempts, the ramp trial that best satisfied the following criteria was used for analysis: (a) force reaching at least 90% of the MVC and (b) a tracking error less than 3% around the ramp template as visually inspected by an experienced investigator. All software programs were custom-written with LabVIEW v 8.5 (National Instruments, Austin, TX).

2.2.3 Resting Stimulus

Transcutaneous electrical stimuli was delivered to the femoral nerve using a high-voltage constant-current stimulator (Digitimer DS7AH-1727, Herthfordshire, UK). The stimuli was applied via a bipolar surface electrode that was placed over the inguinal space, superficial to the femoral nerve as well as the distal portion of the quadriceps. Single stimuli will be used to determine the optimal stimulation electrode location (20mA) and the maximal compound muscle action potential (EMG M-wave) with incremental amperage increases (2-100 mA).

2.2.4 Fatigue Protocol

For the fatiguing protocol, subjects performed 50 consecutive maximal concentric isokinetic leg extension muscle actions at 180°/s with the right leg as described by Thorstensson et al. 1976. The active range of motion was standardized from 90° to 180° of knee flexion and extension. Subjects were instructed to perform consecutive leg extensions with maximal effort and to resume the starting position passively between each contraction. Every contraction lasted 0.5-s and the passive phase approximately 0.7-s. The fatigue index (FI) was calculated with the following equation:

$$FI = \left(\frac{Initial\ Peak\ Force - Final\ Peak\ Force}{Initial\ Peak\ Force}\right) \times 100$$

Peak force (PF) was determined for each of the 50 repetitions during the extension muscle actions as the highest 10-ms average force value that occurred during each force curve acquired from a load cell (LC402, Omegadyne, Inc., Sunbury, OH) that was fitted to a Biodex System3 isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY). The initial PF was calculated as the average of the 3 highest PF values that occurred during the first 10 repetitions, whereas the final PF will represent the average of the 3 lowest PF values that occurred during the final 10 repetitions.

2.2.5 Skinfold Measurement

In addition, skinfold measurements were taken prior to the isometric force assessments in the location of mechanomyographic and electromyographic electrode placement for the vastus lateralis (VL) and rectus femoris (RF). Measurements were taken according to the recommendations of Jackson and Pollock (1985) and were performed by an experienced investigator using a calibrated Harpenden caliper (John Bull, England). The investigator's reliability was tested at all four sites using an intra-class correlation statistic (ICC), its corresponding p-value and standard error of the measurement (SEM) (VL EMG p = <0.001, ICC = 0.993, SEM = 1.15; VL MMG p = <0.001, ICC = 0.998, SEM = 0.908; RF EMG p = <0.001, ICC = 0.995, SEM = 1.23; RF MMG p = <0.001, ICC = 0.997, SEM = 0.967). Three skinfold measurements were taken, and the average of the three measurements were used as the representative skinfold thickness for each participant.

2.3 Mechanomyography (MMG)

An active miniature accelerometer (EGAS-FS-10-/V05, Measurement Specialties, Inc., Hampton, VA) that was preamplified with a gain of 200, frequency response of 20-200 Hz, sensitivity of 68.5 $mV/m \cdot s^{-2}$ and range of ± 98.1 $m \cdot s^{-2}$ was used to detect the MMG signal. Accelerometers were placed on the VL and RF on the lateral/anterior portion of the muscle at 50% of the distance between the greater trochanter and lateral condyle of the femur. Double-sided adhesive tape was used to attach the accelerometer to the skin.

2.4 Electromyography (EMG)

Pre-amplified, bipolar surface EMG electrodes (TSD150B, Biopac Systems Inc.; Santa Barbara, CA, USA, gain = 330) with a fixed center-to-center inter-electrode distance of 20 mm, input impedance of 100 M**Ω**, and common mode rejection ratio of 95 dB (nominal) were taped over the VL and RF muscle of the right leg. A single pre-gelled, disposable electrode (Ag–AgCl, Quinton Quick Prep, Quinton Instruments Co., Botmhell, WA, USA) was placed on the spinous process of the 7th cervical vertebrae to serve as a reference electrode. To reduce inter-electrode impedance and increase the signal-to-noise ratio, local areas of the skin were shaved and cleaned with isopropyl alcohol prior to placement of the electrodes.

2.5 Signal Processing

The MMG (m/s^2), EMG (μV) and force (N) signals were simultaneously sampled at 2 kHz with a Biopac data acquisition system (MP150, Biopac systems, Inc., Santa Barbara, CA) during each voluntary and non-voluntary muscle action. All subsequent signals were then stored and processed off-line with custom written LabView 8.5 software (National Instruments, Austin, TX). The MMG signals was bandpass filtered (fourth-order Butterworth) at 5-100 Hz, while the EMG signals was bandpass filtered (fourth-order Butterworth) at 100-500 Hz. During the 6-s isometric ramp contraction consecutive, non-overlapping 0.25-s epochs were analyzed for the force and MMG and EMG signals. The amplitude of the MMG (MMG_{RMS}) and EMG (EMG_{RMS}) signal were quantified by calculating the root-mean-square (RMS) values for each signal epoch. The subsequent EMG M-waves and MMG gross lateral movement (GLM) from the VL and RF during the stimulation at rest were expressed as peak-to-peak amplitude values (mV).

2.6 Statistical Analyses

Simple linear regression models were fit to the natural log-transformed EMG_{RMS} and MMG_{RMS}-force relationships. The equations were represented as:

$$\ln(Y) = b(\ln[X]) + \ln(a) \quad \text{Eq. 1}$$

where ln(Y) = the natural log of the MMG_{RMS} and EMG_{RMS} values, ln(X) = the natural log of the force values, b = slope, and ln(a) = the natural log of the Y-intercept. This can also be expressed as an exponential equation after antilog transformation of both sides of the equation

$$Y = aX^b \quad \text{Eq. 2}$$

where Y = the predicted MMG_{RMS} and EMG_{RMS} values, X = force, b = slope of Eq. (1), and a = the antilog of the Y-intercept from Eq. (1). Slopes (b) and Y-intercepts (a) were calculated using Microsoft Excel version 2003 (Microsoft, Inc., Redmond, WA).

Pearson’s product moment correlation coefficients were calculated comparing the VL and RF skinfold measurements to: a) EMG_{RMS} a term, b) MMG_{RMS} a term, c) EMG M-wave and d) MMG GLM for each muscle.. In addition, Pearson’s product moment correlations were calculated comparing the EMG_{RMS} and MMG_{RMS} b terms for the VL and RF to the fatigue index calculate from the 50 maximal concentric isokinetic leg extension muscle actions.

Chapter IV

Results

3.1 a Terms, EMG M-waves, and MMG GLM

Pearson's product moment correlations were not significant when comparing skinfold thicknesses to the *a* terms from the EMG_{RMS}-force relationships for the RF (p = 0.614, r = -0.082) (Figure 1a) and VL (p = 0.518, r = -0.105) (Figure 1b) and *a* terms from the MMG_{RMS}-force relationships for the RF (p = 0.507, r = 0.108) (Figure 1c) and VL (p = 0.546, r = 0.098) (Figure 1d). Whereas, Pearson's product moment correlations were significant among skinfold thicknesses and EMG M-waves for the RF (p = 0.002, r = -0.521) (Figure 2a) and VL (p = 0.005, r = -0.479) (Figure 2b) and among skinfold thicknesses and the MMG GLM for the RF (p = 0.031, r = -0.376) (Figure 2c) and VL (p = 0.004, r = -0.484) (Figure 2d).

3.2 b Terms and Fatigue Indexes

Correlations among the fatigue index and the *b* terms from the MMG_{RMS}-force relationships were significant for the RF (p = 0.014, r = 0.386) (Figure 3a) and VL (p = 0.007, r = 0.417) (Figure 3b). In contrast, only the *b* terms from the EMG_{RMS}-force relationships for the RF (p = 0.017, r = 0.375) (Figure 3c), but not for the VL (p = 0.733, r = 0.056) (Figure 3d), were correlated with the fatigue index.

Chapter V

Discussion

The findings of the present study were: (a) the *a* terms from the EMG_{RMS} and MMG_{RMS}-force relationship were not correlated with the skinfold measurements taken from the electrode sites, (b) the EMG M-wave and MMG GLM of the VL and RF were found to be significantly correlated with the skinfold measurements, and (c) there were significant correlations between the fatigue index from the Thorstensson test and the *b* terms from the MMG_{RMS}-force relationships for the RF and VL, while the *b* terms for the RF, and not the VL, from the EMG_{RMS}-force relationships were correlated with the fatigue index.

The *a* term represents the gain coefficient which reflects an upward or downward shift in the exponential relationship without changing the shape of the relationship. Therefore, if the MMG_{RMS} or EMG_{RMS} values are greater or lesser across the force spectrum, in theory, the *a* term would reflect those differences. In the present study, the *a* terms from the MMG_{RMS}- and EMG_{RMS}-force relationships were not correlated with skinfold thicknesses at the corresponding sensor sites. This is contrary to a previous hypothesis (Cooper, 2012; Herda et al., 2010), which proposed that the *a* term may be influenced by the amount of subcutaneous fat that lies between the sensor and the muscle. Herda et al. (2010) reported that the *a* terms from the EMG_{RMS}- and MMG_{RMS}-torque relationships were greater for aerobically-trained (mean *a* term = 1.661) compared to resistance-trained (mean *a* term = 0.197) individuals with the resistance-trained individuals (mean SF = 15.4) having greater skinfold thicknesses than the aerobically-trained individuals (mean SF = 8.7). Furthermore, Cooper and Herda (2012) reported that the *a* terms for the MMG_{RMS}-force relationships were larger for the FDI (mean *a* term = 20.8) in comparison to the VL (mean *a* term = 1.57) and RF (mean *a* term = 2.76) with the VL (mean SF = 9.68) and

RF (mean SF = 11.33) having greater skinfold thicknesses than the FDI (mean SF = 4.00). Thus, in the present study, an inverse relationship would be expected between the *a* terms from the EMG_{RMS}- and MMG_{RMS}-force relationships and skinfold thicknesses, however, the correlations were not significant. Similarly, Jaskolaska et al. (2004) reported evidence that skinfold thickness influenced MMG frequency recorded during voluntary muscle actions, however, the authors also report nonexistent to low correlations between the skinfold thicknesses and MMG parameters. Although it is evident from previous studies that subcutaneous fats influences the EMG and MMG signals recorded during voluntary muscle actions, correlations among skinfold thickness and EMG and MMG signal parameters remain elusive. Future studies are encouraged to examine the effects of subcutaneous fat on the EMG and MMG signals collected during voluntary muscle actions.

In the present study, EMG M-waves and MMG GLM of the VL (r = -0.479, -0.484) and RF (r = -0.521, -0.376) had significant correlations with skinfold thicknesses. Under non-voluntary conditions (i.e., evoked potentials), previous studies (Evetovich et al., 1998; Herda et al., 2010; Herda et al., 2011; Petrofsky, 2008) have reported differences in EMG M-waves as a result of differences in the amount of subcutaneous fat that overlies the muscle. Herda et al. (2011) reported differences between the EMG M-wave for the medial gastrocnemius (MG) and soleus (SOL) and attributed the differences to the anatomical location of the MG being more superficial than the SOL. In addition, Petrofsky et al. (2008) inserted needle electrodes into the muscle belly to stimulate current within the muscle while simultaneously using bipolar surface EMG to measure the electrical activity above the fascia. The results suggested that with a signal generated in muscle, such as the EMG, the signal is altered by subcutaneous fat layers before it is recorded on the surface of the skin. To our knowledge, this is the first study to report significant correlations between MMG GLM and subcutaneous fat. Previously, Stokes and Dalton (1991, JAP) and Bolton et al. (1989) suggested that the tissue layer between the muscle and the skin might act as a low pass filter for the mechanical waves traveling from the muscle to the skin's surface. These authors observed differences between MMG GLM amplitudes at the muscle belly and the fascia, however, no statistical procedures were performed on these observations. The results from the present study demonstrated, that similar to EMG M-waves, the MMG GLM is influenced by subcutaneous fat.

In the present study, there were significant correlations between the fatigue index from the Thorstensson test and the *b* terms from the MMG_{RMS}-force relationships for the RF (r = 0.386) and VL (r = 0.417). Previously, Herda et al. (2010) reported that the *b* terms reflected the MHC expression of the VL. Individuals with a greater percentage of type I MHC (mean type I MHC = 72.6) had lower *b* terms (mean *b* term = 0.325) than individuals with a greater percentage of type II MHC (mean type II MHC = 59.0, mean *b* term = 0.856) of the VL. In addition, Cooper and Herda reported a significant difference between muscles of known fiber type differences. For example, the *b* terms for the MMG_{RMS}-force relationships were found to be lower for muscles composed of primarily type I muscle fibers (first dorsal interosseous, mean *b* term = 0.17) than a more mixed fiber type muscle (mean VL and RF, mean *b* terms = 0.78, 0.82), indicating that the *b* term may reflect the approximate location of when the muscle begins relying primarily on rate coding to increase force. Thorstensson et al. (1976) correlated the fatigue index with the type I fiber composition of the individual and reported a positive correlation coefficient of 0.86. Thus, individuals with a greater percentage of fast-twitch fibers had a greater fatigue index than the individuals with a greater percentage of slow-twitch fibers. In theory, since the *b* terms from the MMG_{RMS}-force relationships has been able to distinguish between fiber type compositions, it is not surprising that the correlations between the fatigue index and *b* terms were found to be statistically significant. Although, the correlations were smaller than previously expected, which may be attributed to extraneous factors such as subject effort level during the fatiguing and maximal voluntary contractions.

The *b* terms from EMG_{RMS}-force relationships for the RF (r = 0.375) were correlated with the fatigue index, however, the *b* terms from the VL were not correlated with the fatigue index. Previous studies have reported that the *b* terms from the EMG_{RMS}-torque relationships were unable to distinguish between muscle MHC of the VL (Herda et al., 2010). For example, Herda et al. (2010) reported that there were no differences in the *b* terms from the EMG_{RMS}-torque relationships for the VL between the resistance-trained (mean type I MHC = 40.9) and aerobically-trained (mean type I MHC = 72.6) individuals. Although the EMG_{RMS} patterns of response have not reflected MHC, Herda et al. (2011) and Herda and Cooper (2013) have reported that the *b* terms from the EMG_{RMS}-force relationship may reflect the activation capabilities of the individual. For example, Herda et al. (2011) reported the *b* terms from the MG EMG_{RMS}-force relationships were greater (mean *b* term = 1.27) for the high- (mean voluntary activation = 97.44%) than the moderate (mean voluntary activation = 73.11%)-activated (mean *b* term = 0.88) individuals. In addition, Herda and Cooper (2013) reported similar findings for the leg extensors (VL and RF), with the *b* terms being greater for the high (mean VL and RF *b* terms = 1.10, 1.47)- than the moderate (mean VL and RF *b* terms = 1.03, 1.18)-activated individuals. The authors suggested that the greater *b* terms for the high-activated individuals may have reflected the higher firing rates achieved during the higher contraction intensities in the high-activated subjects, which Herda and Cooper (2013) suggested could result in a greater acceleration in EMG_{RMS} towards the end of the force spectrum. It is unclear, however, why the *b* terms from the EMG_{RMS}-force relationships for the RF had a correlation with the fatigue index, but not the VL. Previous studies have reported fatigue related differences in the EMG signal between the VL and RF. For example, Housh et al. (1995) demonstrated that the fatigue response was different for the RF compared to the VL when examining the EMG fatigue threshold. The authors reported that the RF fatigue threshold was significantly lower than that of the VL, therefore, suggesting that the RF may have fatigued more so than the VL. The differences in the fatigue characteristics of the VL and RF may be the result of a greater percentage of fast-twitch fibers and/or the RF is a biarticular muscle. In addition, Herda and Cooper (2013) reported that the *b* terms from the EMG_{RMS}-force relationships were greater for the RF than the VL, which further suggests there may be underlying differences in motor unit activation strategies between the VL and RF. Future research is needed to make clearer the mechanisms that result in a correlation between the fatigue index and the *b* terms from the EMG_{RMS}-force relationships for the RF, but not the VL.

In the current study, the *a* terms from the log-transformed MMG_{RMS}- and EMG_{RMS}-force relationships had no relationships with skinfold thicknesses. In contrast, under non-voluntary conditions (i.e., evoked potentials), the EMG M-waves and MMG GLM were correlated with skinfold thicknesses. Finally, the *b* terms from the VL and RF MMG_{RMS}-force relationships were correlated with the fatigue index from the Thorstensson test and, thus, adding further support that the *b* terms from the MMG_{RMS}-force relationships may reflect muscle fiber type composition. In contrast, only the *b* terms from the RF for the EMG_{RMS}-force relationships were correlated with the fatigue index. Future research is needed to fully understand the muscle-related characteristic differences between the VL and RF.

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Figure Legend

Figure 1a: Skinfold thickness (mm) values for the rectus femoris electromyography site versus *a* terms from the log transformed EMG_{RMS}-force equation.

Figure 1b: Skinfold thickness (mm) values for the vastus lateralis electromyography site versus *a* terms from the log transformed EMG_{RMS}-force equation.

Figure 1c: Skinfold thickness (mm) values for the rectus femoris mechanomyography site versus *a* terms from the log transformed MMG_{RMS}-force equation.

Figure 1d: Skinfold thickness (mm) values for the vastus lateralis mechanomyography site versus *a* terms from the log transformed MMG_{RMS}-force equation.

Figure 2a: Rectus femoris electromyography peak-to-peak M-wave values versus skinfold thickness (mm) values for the rectus femoris.

Figure 2b: Vastus lateralis electromyography peak-to-peak M-wave values versus skinfold thickness (mm) values for the vastus lateralis.

Figure 2c: Rectus femoris mechanomyography peak-to-peak gross lateral movement values versus skinfold thickness (mm) values for the rectus femoris.

Figure 2d: Vastus lateralis electromyography peak-to-peak gross lateral movement values versus skinfold thickness (mm) values for the vastus lateralis.

Figure 3a: Fatigue index for the rectus femoris versus the *b* terms from the log transformed MMG_{RMS}-force equation for the rectus femoris.

Figure 3b: Fatigue index for the vastus lateralis versus the *b* terms from the log transformed MMG_{RMS}-force equation for the vastus lateralis.

Figure 3c: Fatigue index for the rectus femoris versus the *b* terms from the log transformed EMG_{RMS}-force equation for the rectus femoris.

Figure 3d: Fatigue index for the vastus lateralis versus the *b* terms from the log transformed EMG_{RMS}-force equation for the vastus lateralis.

Figures

Figure 1

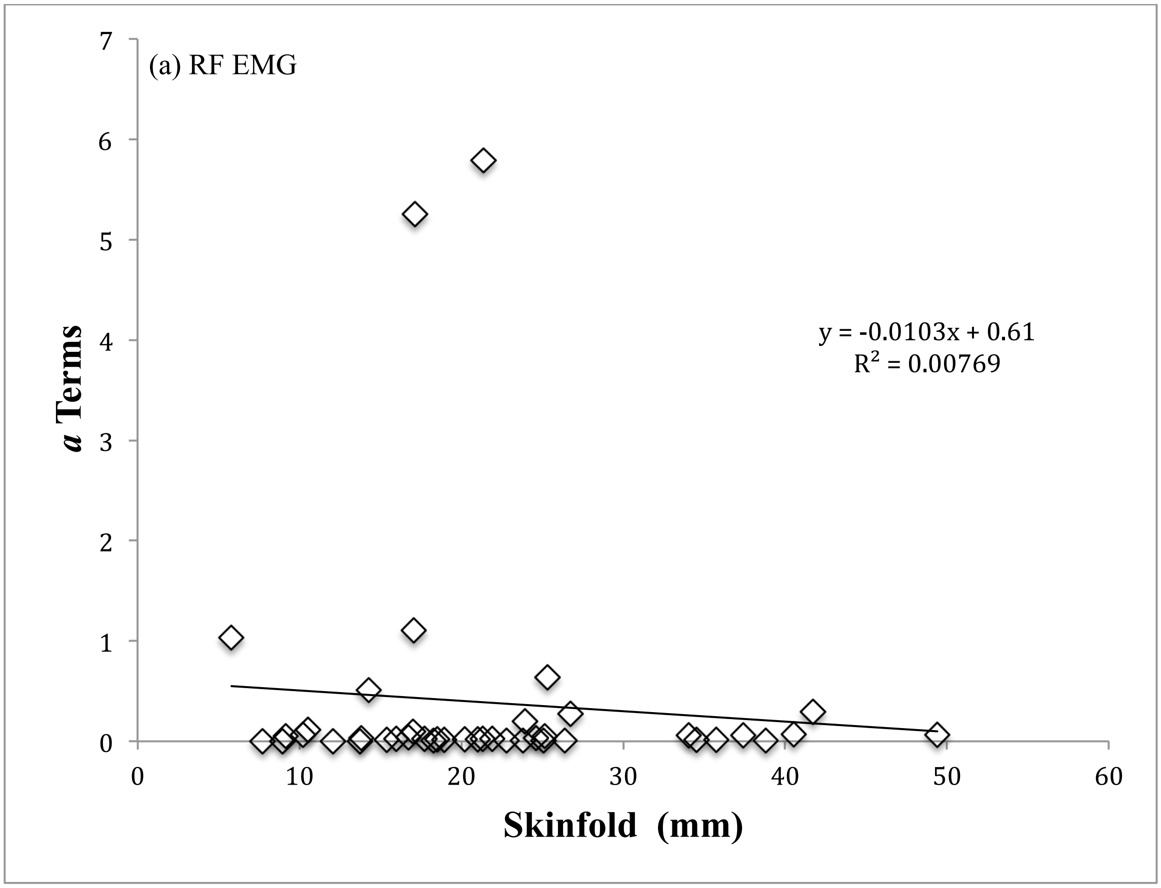

Figure 1a: Skinfold thickness (mm) values for the rectus femoris electromyography site versus *a* terms from the log transformed EMG_{RMS}-force equation.

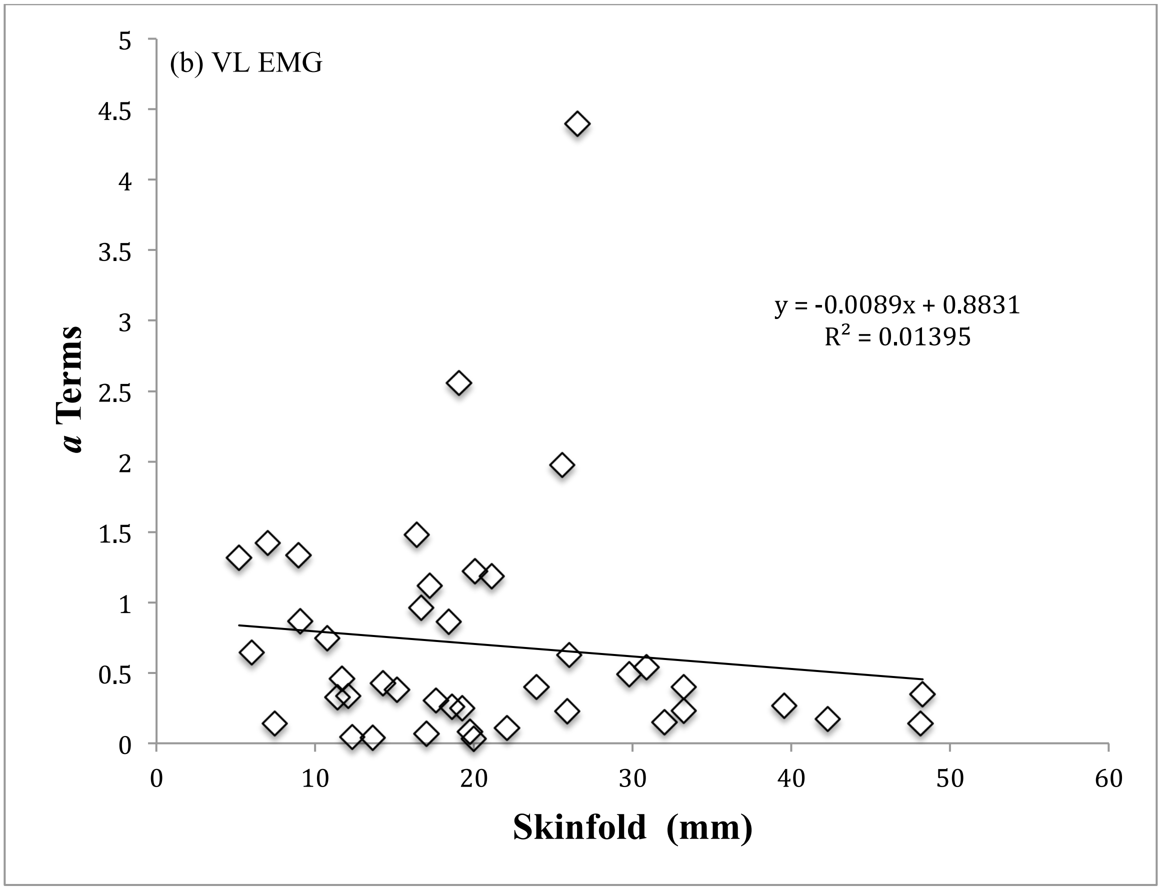

Figure 1b: Skinfold thickness (mm) values for the vastus lateralis electromyography site versus *a* terms from the log transformed EMG_{RMS}-force equation.

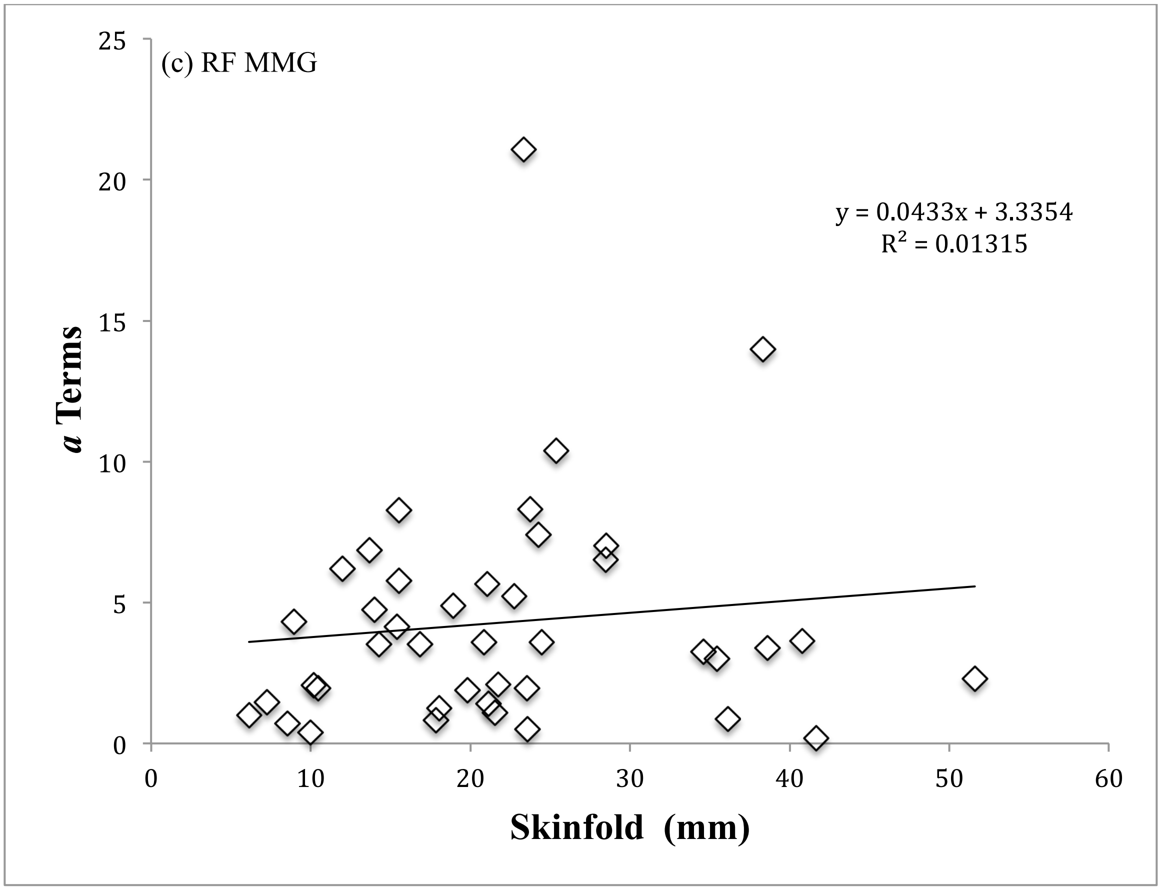

Figure 1c: Skinfold thickness (mm) values for the rectus femoris mechanomyography site versus *a* terms from the log transformed MMG_{RMS}-force equation.

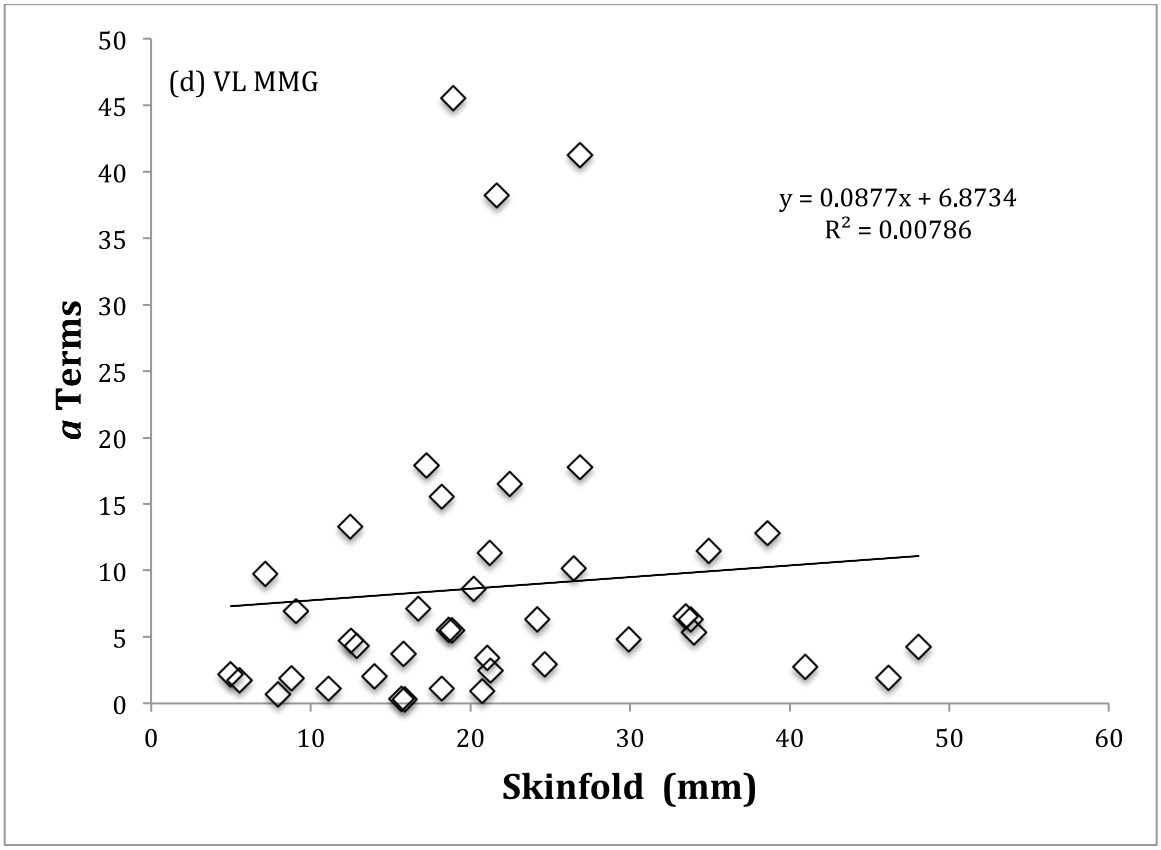

Figure 1d: Skinfold thickness (mm) values for the vastus lateralis mechanomyography site versus *a* terms from the log transformed MMG_{RMS}-force equation.

Figure 2

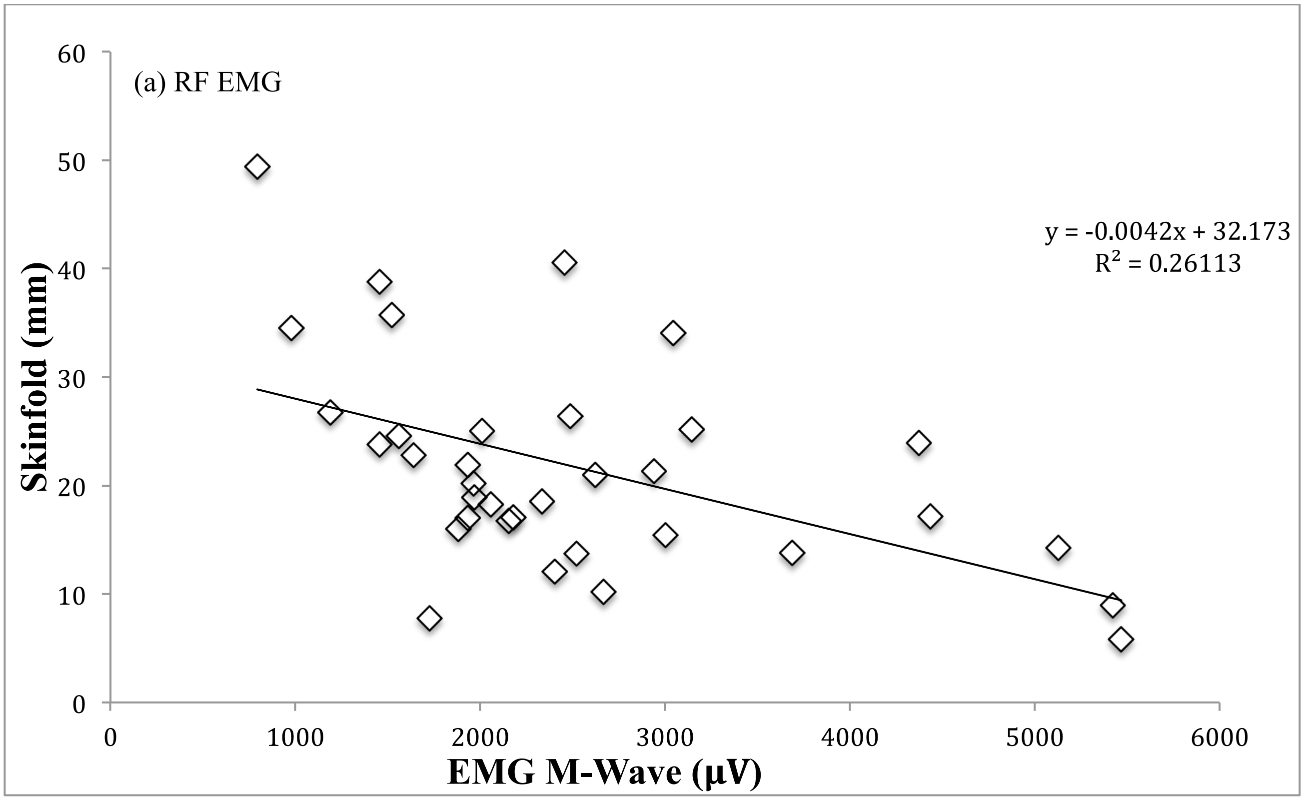

Figure 2a: Rectus femoris electromyography peak-to-peak M-wave values versus skinfold thickness (mm) values for the rectus femoris.

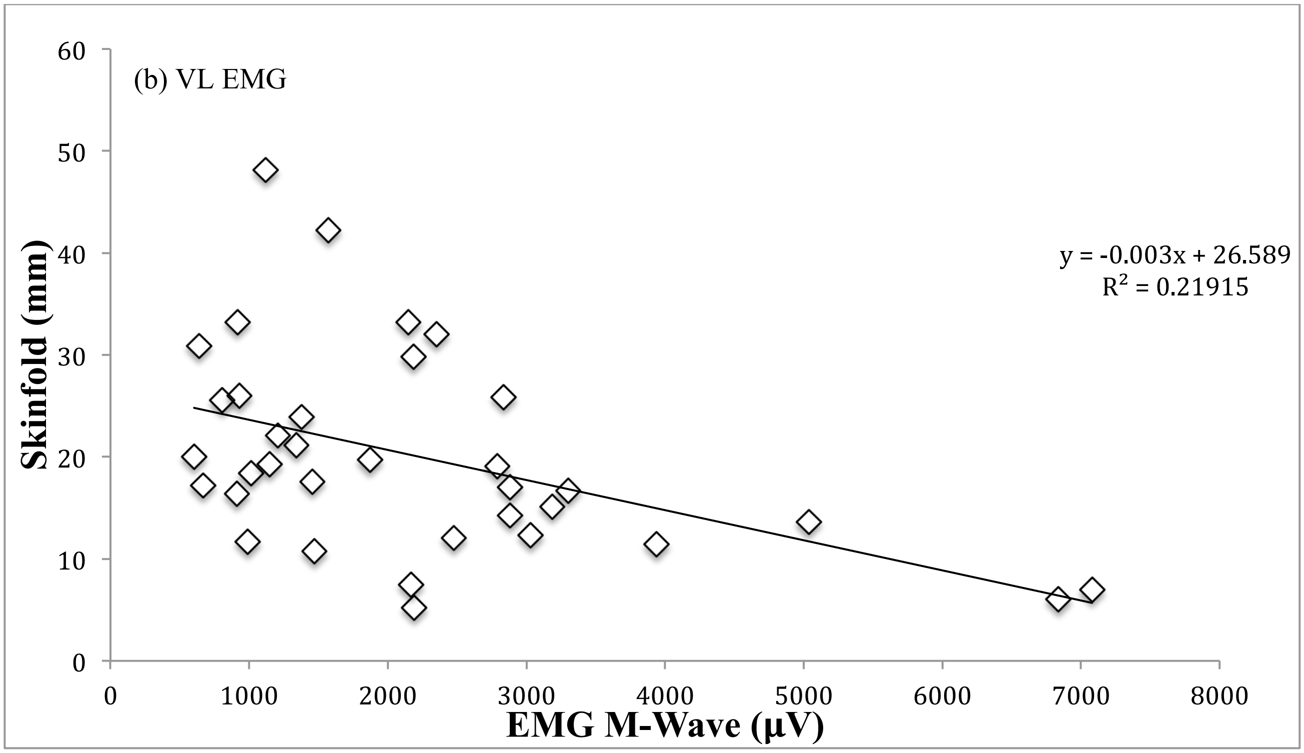

Figure 2b: Vastus lateralis electromyography peak-to-peak M-wave values versus skinfold thickness (mm) values for the vastus lateralis.

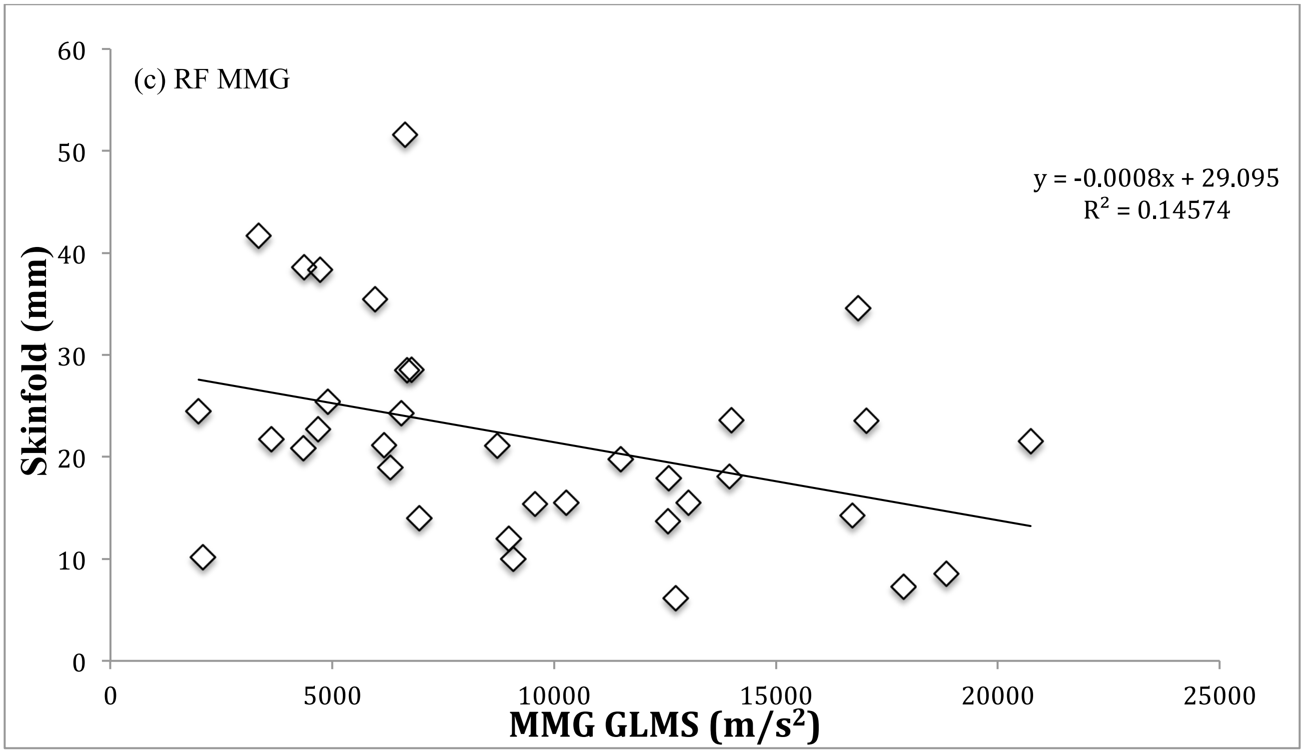

Figure 2c: Rectus femoris mechanomyography peak-to-peak gross lateral movement values versus skinfold thickness (mm) values for the rectus femoris.

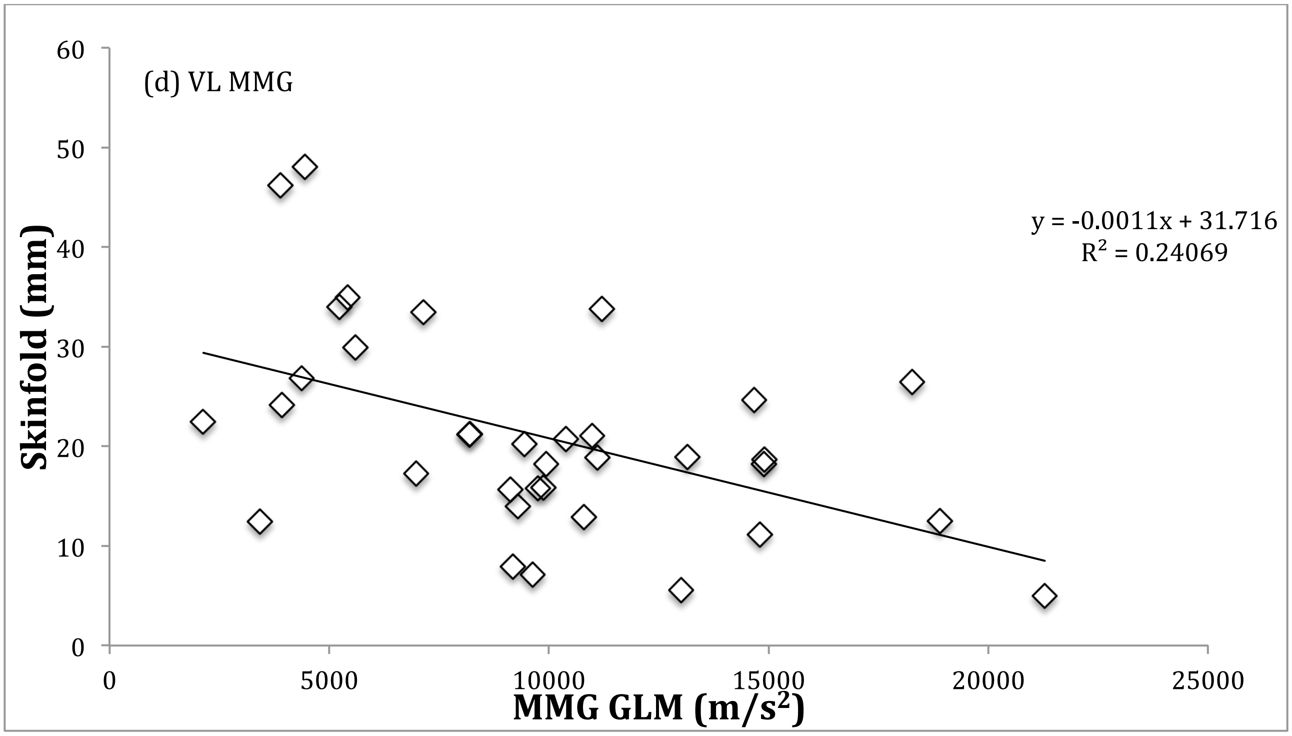

Figure 2d: Vastus lateralis electromyography peak-to-peak gross lateral movement values versus skinfold thickness (mm) values for the vastus lateralis.

Figure 3

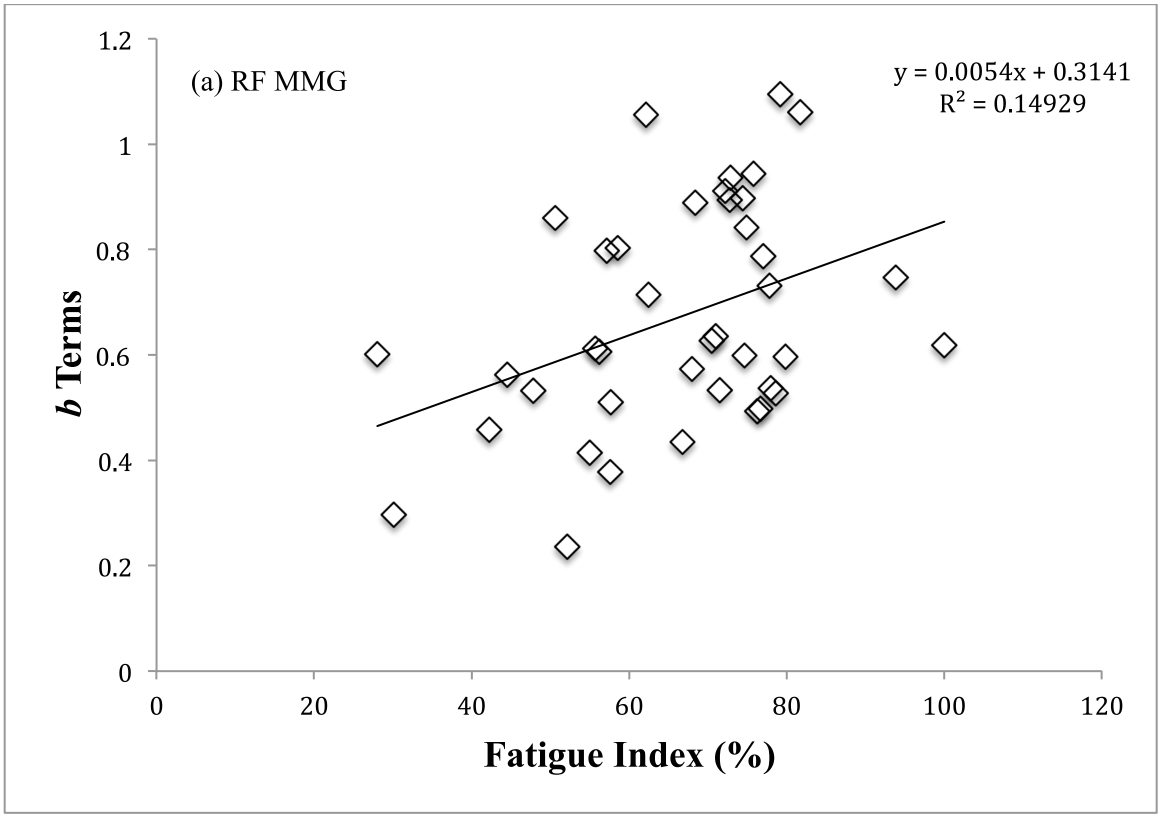

Figure 3a: Fatigue index for the rectus femoris versus the *b* terms from the log transformed MMG_{RMS}-force equation for the rectus femoris.

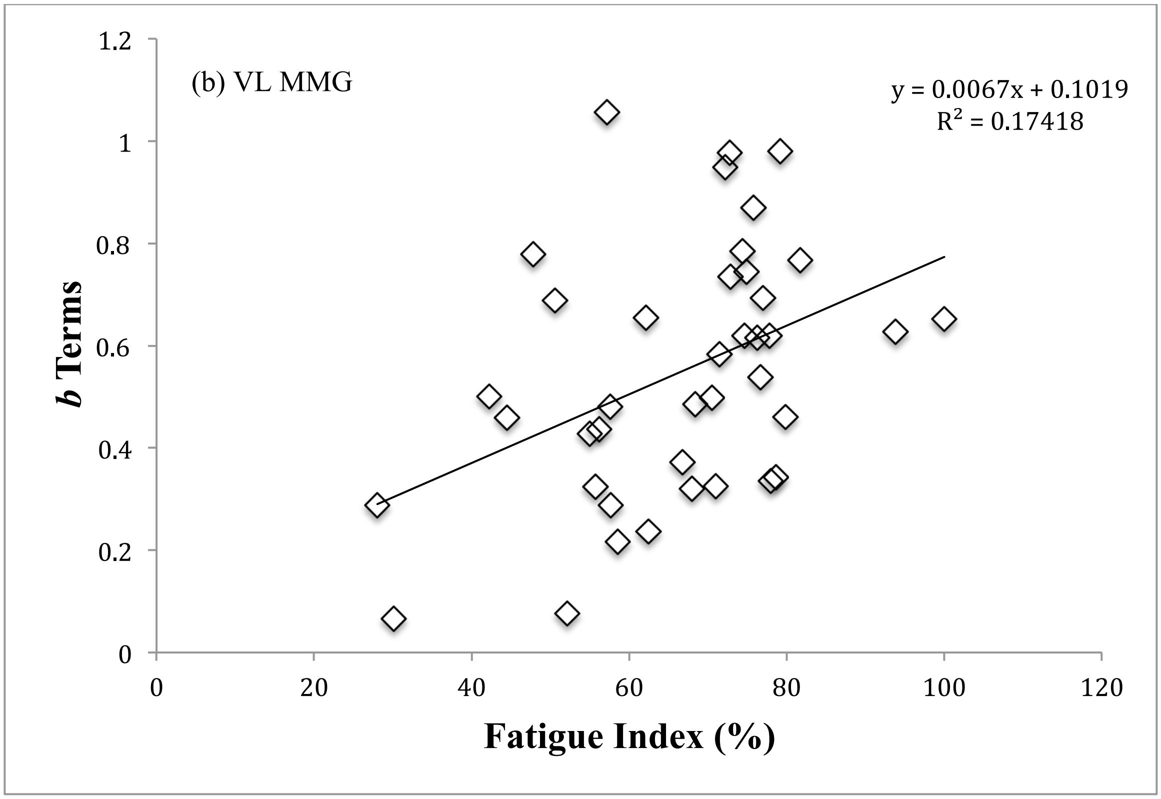

Figure 3b: Fatigue index for the vastus lateralis versus the *b* terms from the log transformed MMG_{RMS}-force equation for the vastus lateralis.

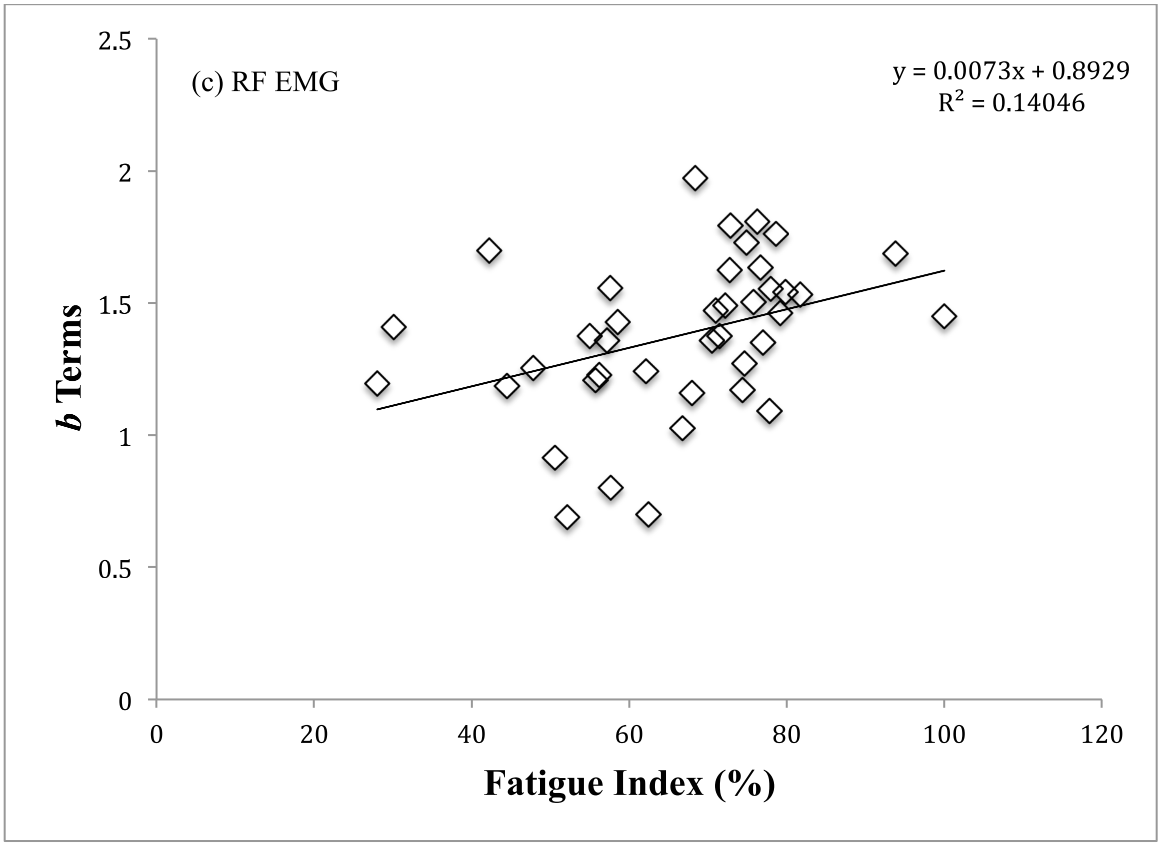

Figure 3c: Fatigue index for the rectus femoris versus the *b* terms from the log transformed EMG_{RMS}-force equation for the rectus femoris.

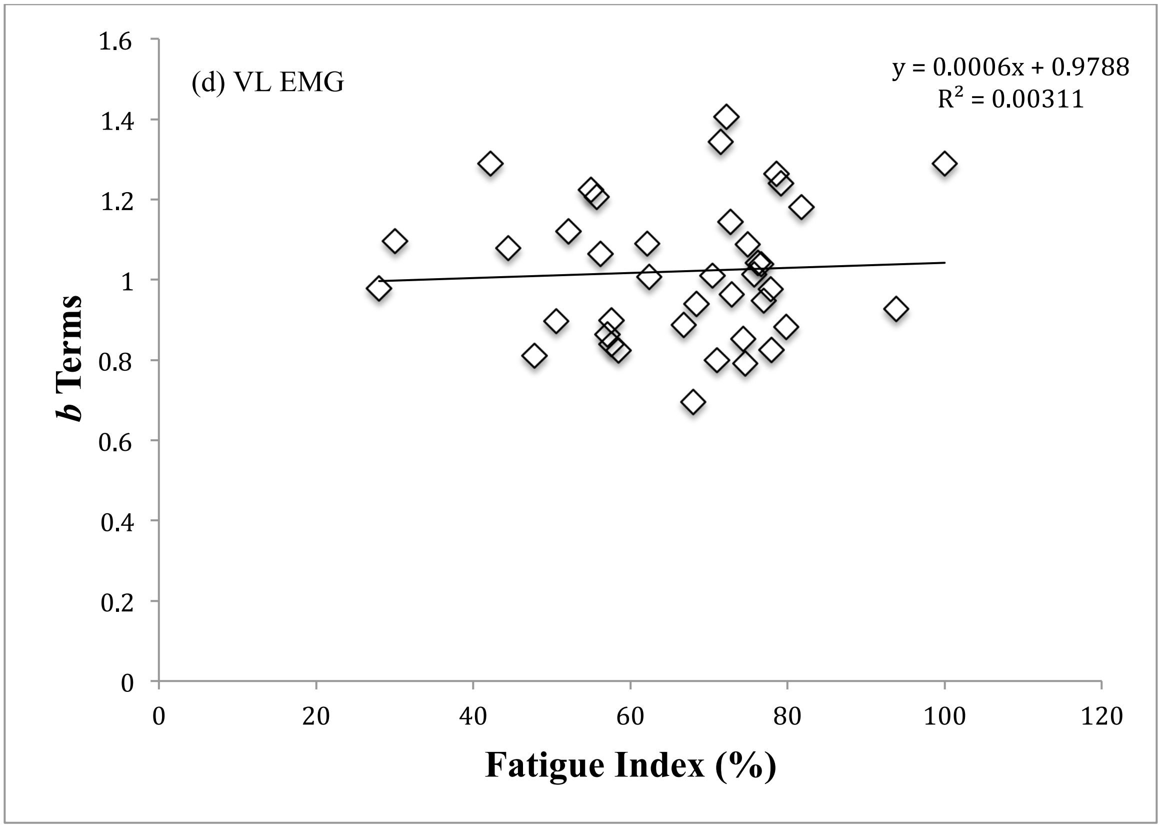

Figure 3d: Fatigue index for the vastus lateralis versus the *b* terms from the log transformed EMG_{RMS}-force equation for the vastus lateralis.

Table 1

Column1	VLEMGSF	VLMMGSF	RFEMGSF	RFMMGSF	VLMMGATERM	RFMMGATERM	VLEMGATERM	RFEMGATERM	RFMMGPTOP	RFEMGPTOP	VLMMGPTOP	VLEMGPTOP	RFMMGRMSPTOP	RFEMGRMSPTOP	VLMMGRMSPTOP	VLEMGRMSPTOP
VLEMGSF		0.982	0.955	0.948					-0.457	-0.422	-0.472	-0.479	-0.469		-0.536	-0.523
VLMMGSF			0.959	0.961				0.371	-0.354		-0.46	-0.468	-0.47	-0.38	-0.540	-0.529
RFEMGSF				0.986					-0.373	-0.521	-0.501	-0.422	-0.396	-0.452	-0.574	-0.495
RFMMGSF									-0.376	-0.515	-0.491	-0.423	-0.397	-0.447	-0.572	-0.491
VLMMGATERM						0.524		0.443								
RFMMGATERM								0.506					-0.361			
VLEMGATERM										0.586				0.739		
RFEMGATERM										0.379				0.493		
RFMMGPTOP											0.445	0.559	0.991		0.506	0.500
RFEMGPTOP														0.897	0.391	
VLMGPTOP													0.464		0.907	
VLEMGPTOP													0.576			0.967
RFMMGRMSPTOP															0.532	0.526
RFEMGRMSPTOP																
VLMMGRMSPTOP																
VLEMGRMSPTOP																
	$p < 0.05$															
	$p < 0.01$															

Table 1. The pearson's product moment correlations (r) for the vastus lateralis (VL) and rectus femoris (RF) for the: EMG M-wave, MMG gross lateral movement (GLM), EMG M-wave root mean square (RMS), MMG GLM_{RMS}, EMG_{RMS} *a* terms, MMG_{RMS} *a* terms, EMG skinfold, and MMG skinfold

The Relationships Between Skinfold, Fatigue and the Traditional and Log-Transformed Electromyographic and Mechanomyographic Signal in the Vastus Lateralis and Rectus Femoris

Informed Consent

INTRODUCTION
The Department of Health Sport and Exercise Sciences at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. You may refuse to sign this form and not participate in this study. You should be aware that even if you agree to participate, you are free to withdraw at any time. If you do withdraw from this study, it will not affect your relationship with this unit, the services it may provide to you, or the University of Kansas.

PURPOSE OF THE STUDY
The purpose of the present study is to examine possible correlations between skinfold thickness and various parameters of the EMG and MMG signal. Specifically, correlations will be performed among the y-intercepts from the log-transformed EMG and MMG amplitude-force relationships and the EMG amplitudes and the MMG amplitudes produced from an evoked stimulus. In addition, correlations will be performed among the slopes from the EMG and MMG amplitude-force relationships and the fatigue index from the Thorstensson test.

ELGIBILITY
You are eligible to participate in this study if you meet certain criteria. This criteria includes, being male or female between the ages of 18-30, healthy and free of any current or ongoing neuromuscular disease or musculoskeletal injuries specific to the ankle, knee, or hip joints. The total time commitment, if you choose to participate, will be approximately 1.5 hours.

PROCEDURES
A time-line of the testing procedures and an overview of the testing sequence for the test day are presented below. All procedures will be conducted in the Biomechanics Laboratory at the University of Kansas and will be supervised by trained personnel.

Visit 1: Consent Form
Pre-Exercise Testing Health & Exercise Status Questionnaire
Familiarized to the equipment and testing protocol
Perform isometric strength testing of the leg extensors (thigh muscles)
Evoked stimulus to the leg extensors (thigh muscles)
Isokinetic Fatigue Test

Isometric Strength Testing – You will be positioned in the isokinetic dynamometer for leg extensor (thigh muscles) strength testing. After the positioning and prior to the strength tests, electromyographic (EMG) and mechanomyographic (MMG) electrodes will be placed on the skins surface of your right thigh. Following 2-4 warm-ups, you will perform 2 maximal strength tests with 2 minutes rest between each one. Then in random order you will perform nine submaximal strength tests at 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% of your maximal strength. Then you will perform two to four ramp muscle actions that consist of you gradually increasing your force from 5% to 100% of your maximal strength. You will have 2 minutes rest between each strength test.

Evoked Twitch Test – When we test your leg extensors (thigh muscles), we will perform electrical stimulation to your femoral nerve (thigh muscles) at rest. The electrical stimulation feels like a slight pinch and will last approximately 1-ms.

Fatigue Test- After all other tests have been performed you will perform a fatiguing contraction where you will perform 50 isokinetic leg extensions at 180 °/s on the isokinetic dynamometer.

RISKS
As a participant there is the potential to experience some physical stress and muscle soreness while performing the maximal voluntary contractions, the isometric ramp contractions, isometric step contractions, and fatiguing contractions performed. In addition, you may have skin abrasions due to shaving and cleansing the skin with alcohol prior to electrode placement.

BENEFITS
You will not directly benefit from participating in this study. However, you will gain an increased understanding of your skeletal muscle function. Specifically, you will learn about your level of muscular strength and about the fatigue traits of your leg extensors. A copy of all personal data from the tests will be provided to you and your data will be completely explained to you by a member of the investigation team.

PAYMENT TO PARTICIPANTS
As a participant you will receive no payment for your participation in this study.

PARTICIPANT CONFIDENTIALITY
Your name will not be associated in any publication or presentation with the information collected about you or with the research findings from this study. Instead, the researcher(s) will use a study number or a pseudonym rather than your name. Your identifiable information will not be shared unless required by law or you give written permission.

Permission granted on this date to use and disclose your information remains in effect indefinitely. By signing this form you give permission for the use and disclosure of your information for purposes of this study at any time in the future.

REFUSAL TO SIGN CONSENT AND AUTHORIZATION
You are not required to sign this Consent and Authorization form and you may refuse to do so without affecting your right to any services you are receiving or may receive from the University of Kansas or to participate in any programs or events of the University of Kansas. However, if you refuse to sign, you cannot participate in this study.

CANCELLING THIS CONSENT AND AUTHORIZATION
You may withdraw your consent to participate in this study at any time. You also have the right to cancel your permission to use and disclose further information collected about you, in writing, at any time, by sending your written request to: Trent J Herda, 1301 Sunnyside Avenue 101BE Robinson Center, Lawrence KS 66045

If you cancel permission to use your information, the researchers will stop collecting additional information about you. However, the research team may use and disclose information that was gathered before they received your cancellation, as described above.

QUESTIONS ABOUT PARTICIPATION
Questions about procedures should be directed to the researcher(s) listed at the end of this consent form.

PARTICIPANT CERTIFICATION:
I have read this Consent and Authorization form. I have had the opportunity to ask, and I have received answers to, any questions I had regarding the study. I understand that if I have any additional questions about my rights as a research participant, I may call (785) 864-7429 or (785) 864-7385, write the Human Subjects Committee Lawrence Campus (HSCL), University of Kansas, 2385 Irving Hill Road, Lawrence, Kansas 66045-7568, or email irb@ku.edu.

I agree to take part in this study as a research participant. By my signature I affirm that I am at least 18 years old and that I have received a copy of this Consent and Authorization form.

_______________________________ ____________________
Type/Print Participant's Name Date

____
Participant's Signature

Researcher Contact Information

Michael Cooper	Trent J Herda, PhD
Secondary Investigator	Faculty Supervisor/Principal Investigator
Health Sport and Exercise Sciences	Health Sport and Exercise Sciences
101 B Robinson Center	101 BE Robinson Center

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PRE-EXERCISE TESTING
HEALTH & EXERCISE
STATUS QUESTIONNAIRE

DECISION-MAKING CRITERIA

Name ____ Date____________

Home Address ____

Work Phone ___________________ Home Phone ____________________

Person to contact in case of emergency ___________________________________

Emergency Contact Phone __________________ Birthday (mm/dd/yy)____/____/____

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)

DECISION-MAKING CRITERIA:

This question is intended to heighten the awareness for a potential metabolic (or other) disorder that may affect the subject's body weight and subsequently affect the results of the present study. Therefore, if an individual indicates that there has been a gain or loss of weight in excess of 10 lbs (4.5 kg) in the past year, this does not by itself preclude the subject from participation. It should, however, increase the awareness of a potential disorder that may be indicated in sections A – F in the remaining questionnaire.

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

Joint Areas	Muscle Areas
( ) Wrists	( ) Arms
( ) Elbows	( ) Shoulders
( ) Shoulders	( ) Chest
( ) Upper Spine & Neck	( ) Upper Back & Neck
( ) Lower Spine	( ) Abdominal Regions
( ) Hips	( ) Lower Back
( ) Knees	( ) Buttocks
( ) Ankles	( ) Thighs
( ) Feet	( ) Lower Leg
( ) Other______________________	( ) Feet
	( ) Other____________________

DECISION-MAKING CRITERIA:

1. If an individual checks ***one*** of the Joint Areas and/or Muscle Areas above that is involved in the exercise tests and/or the disposition of the subject during the exercise tests, this response by itself would preclude the subject from participation in this study.

2. If an individual checks ***one or more*** of the Joint Areas and/or Muscle Areas above that is ***not*** involved in the exercise tests and/or the disposition of the subject during the exercise tests, and the potential subject feels comfortable participating in the exercise tests despite their current problem(s) denoted above, the subject can be included in this study.

3. If an individual checks ***other*** for either the Joint Areas and/or Muscle Areas above and the other description cannot be classified into one of the above categories, this response by itself would preclude the subject from participation in this study.

   Areas that are involved during maximal leg extension/flexion exercises on the Biodex System 3 isokinetic dynamometer include:

   Joint Areas: Lower Spine, Hips, and Knees
   Muscle Areas: Lower Back, Buttocks, Thighs, and Lower Leg

   Areas that are involved during maximal arm extension/flexion exercises on the Biodex System 3 isokinetic dynamometer include:

   Joint Areas: Wrists, Elbows, and Shoulders
   Muscle Areas: Arms and Shoulders

   Areas that are involved during maximal or submaximal exercise on a stationary cycle ergometer include:

   Joint Areas: Lower Spine, Hips, Knees, Ankles, and Feet
   Muscle Areas: Lower Back, Buttocks, Thighs, Lower Leg, and Feet

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

( ) High Blood Pressure
( ) Heart Disease or Dysfunction
( ) Peripheral Circulatory Disorder
( ) Lung Disease or Dysfunction
( ) Arthritis or Gout
( ) Edema
( ) Epilepsy
( ) Multiple Sclerosis
( ) High Blood Cholesterol or Triglyceride Levels
( ) Allergic reactions to rubbing alcohol
( ) Acute Infection
( ) Diabetes or Blood Sugar Level Abnormality
( ) Anemia
( ) Hernias
( ) Thyroid Dysfunction
( ) Pancreas Dysfunction
( ) Liver Dysfunction
( ) Kidney Dysfunction
( ) Phenylketonuria (PKU)
( ) Loss of Consciousness

* *NOTE: If any of these conditions are checked, then a physician's health clearance will be required.*

DECISION-MAKING CRITERIA:

1. If an individual checks ***two or more*** of the Health Status Conditions above, this response by itself would preclude the subject from participation in this study.

2. If an individual checks ***one*** of the Health Status Conditions above, then a physician's health clearance will be required for them to participate in this study.

   NOTE: If this symptom is exhibited immediately prior to or during the exercise tests of this study, the tests will be immediately discontinued.

3. If ***none*** of these conditions are checked, the participant can be included in this study if all other inclusion criteria have been met.

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?___________________________________

____

DECISION-MAKING CRITERIA:

1. If an individual indicates that he/she has had a physical examination *and* the physician has recommended a limitation on his/her physical activity, this response by itself would preclude the subject from participation in this study.

2. If an individual indicates that he/she has had a physical examination *and* the physician has not recommended a limitation on his/her physical activity, the subject can be included in this study.

3. If an individual indicates that he/she has had a physical examination *and* the physical problems noted at the time of the physical examination align with two or more conditions listed in sections A, B, and/or E, this response by itself would preclude the subject from participation in this study.

4. If an individual indicates that he/she has never had a physical examination, the subject can be included in this study.

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

MEDICATION	CONDITION
____________________	____________________________
____________________	____________________________
____________________	____________________________

DECISION-MAKING CRITERIA:

1. Taking certain medications ***does not*** preclude a subject from participating in this study.

2. However, if an individual indicates that he/she is currently taking medications that treat a condition that aligns with ***two or more*** of the conditions listed in sections A, B, C, and/or E, this response by itself would preclude the subject from participation in this study.

3. If no medications are listed, the subject can be included in this study.

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))

PA	SED		PA	SED	
( )	( )	Chest Pain	( )	( )	Nausea
( )	( )	Heart Palpitations	( )	( )	Light Headedness
( )	( )	Unusually Rapid Breathing	( )	( )	Loss of Consciousness
( )	( )	Overheating	( )	( )	Loss of Balance
( )	( )	Muscle Cramping	( )	( )	Loss of Coordination
( )	( )	Muscle Pain	( )	( )	Extreme Weakness
( )	( )	Joint Pain	( )	( )	Numbness
( )	( )	Other______________________	( )	( )	Mental Confusion

DECISION-MAKING CRITERIA:

1. If an individual checks ***two or more*** of the Physical Perception Conditions listed above (PA and/or SED), this response by itself would preclude the subject from participation in this study.

2. If an individual checks only ***one*** of the Physical Perception Conditions above and the potential subject feels comfortable participating in the exercise tests despite their problem denoted above, the subject can be included in this study.

   NOTE: If this symptom is exhibited immediately prior to or during the exercise tests of this study, the tests will be immediately discontinued.

3. If an individual checks ***other*** and the other description cannot be classified into one of the above categories, this response by itself would preclude the subject from participation in this study.

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)

DECISION-MAKING CRITERIA:

1. If an individual checks ***one or more*** of the Family History items listed above, the subject can be included in this study.

However, if the potential subject checks ***one or more*** of the Family History items listed above *and* checks ***one*** of the items in sections B or E, this combination of responses would preclude the subject from participation in this study.

G. EXERCISE STATUS

Do you regularly engage in aerobic forms of exercise (i.e., jogging, cycling, walking, etc.)?
YES NO

How long have you engaged in this form of exercise? ______ years ______ months

How many hours per week do you spend for this type of exercise? _______ hours

Do you regularly lift weights? YES NO

How long have you engaged in this form of exercise? ______ years ______ months

How many hours per week do you spend for this type of exercise? _______ hours

Do you regularly play recreational sports (i.e., basketball, racquetball, volleyball, etc.)?
YES NO

How long have you engaged in this form of exercise? ______ years ______ months

How many hours per week do you spend for this type of exercise? _______ hours

DECISION-MAKING CRITERIA:

1. The items under section G. Exercise Status above are not to be used to preclude subjects based upon their risk factors. The responses to section G will provide insight regarding the exercise tolerance for individual subjects.