MUSCULAR DIFFERENCES BETWEEN FEMALE POWER AND ENDURANCE ATHLETES

THESIS

Presented to the Graduate Council of the University of North Texas in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

By

Allen Akers, B.S.

Denton, Texas

August, 1997
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The purpose of this study was to compare the torque generating capabilities and fatigue responses of female power athletes, female endurance athletes, and age-matched female non-athletic controls. There were six participants in each group. Participants completed isokinetic leg extensions at five different testing speeds and one 60 second isometric fatigue test at 90 degrees of knee flexion. sEMG measurements were collected from the m.vastus medialis. Peak torque, median frequency, and E/T were obtained for all tests and slopes were determined. PT slope and E/T slope showed a significant group effect in the isometric test. PT had significant group and speed effects in the isokinetic tests. All other variables, except MF slope, showed significant speed effects. Research supported previous findings and established similar fatigue responses for females compared to earlier research on males. Further research in this area may help determine muscular level training effects not directly reflected in athletic performance.
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CHAPTER I

INTRODUCTION

Athletic performance is affected by many factors in the physiological, biomechanical, and psychological domains. While biomechanical factors are generally well-established in defining proper techniques and body type advantages in sport specific settings, physiological and psychological factors are less understood. Physiological factors relating to muscle fatigue are particularly confounding as studies find apparently contradicting results with similar testing protocols (Ament, Bonga, Hof, & Verkerke, 1996; Horita & Ishiko, 1987; Jansen, Ament, Verkerke, & Hof, 1997; Mannion & Dolan, 1996).

Several methods and parameters have been used in studying muscular fatigue, which leads to some of the apparent contradictions in the research conclusions. Submaximal workloads and aerobic exercise mode have been used in some studies (Ament et al., 1996; Jansen et al., 1997) while maximal and supramaximal workloads and/or isokinetic and isometric testing have been used in others (Horita & Ishiko, 1987; Mannion & Dolan, 1996; Tesch, Komi, Jacobs, Karlsson, & Viitasalo, 1983).

Furthermore, the measures used to signify muscular fatigue include mean power frequency, median power frequency, electromechanical delay, force output reduction, and various slopes and ratios of various electromyographic and force parameters.

Little work has examined the electromyographic differences between athletes of
different types (e.g., endurance vs. power). Most EMG studies have either been of a clinical nature or used homogeneous samples of untrained or similarly trained individuals. The studies comparing different types of athletes have yielded interesting results in terms of intrinsic physiological differences in the differently trained muscles (Lorentzon, Johansson, Sjöström, Fagerlund, & Fugl-Meyer, 1988; Sleivert, Backus, & Wenger, 1995). As expected, power trained athletes and sprinters have greater absolute torque producing ability, but tend to fatigue more quickly in endurance testing protocols when compared to endurance trained athletes.

The purpose of this research was to determine the force and electromyographic differences between female power and endurance athletes and non-athletic controls. The non-athletic controls were included to serve as a baseline by which muscular differences of athlete groups could be compared. Increased ability to determine whether muscular level adaptations to training have taken place will provide a picture of training response that is not clouded by other factors such as biomechanical considerations and psychological effects. If refined to a greater level, this may provide coaches the ability to determine the optimal running distance for an athlete’s given strength and fatigue response. It may also indicate that optimal performance is being hampered by factors other than muscular, such as cardiovascular, biomechanical, or psychological. Force production in this study was measured by torque output and electromyographic parameters analyzed were median frequency of the power spectrum, electromechanical delay, and the integrated EMG values.

The following terms are related to research on this topic as well as being used
throughout the paper and are included to aid reader comprehension. Terms that are only applicable to this particular study are qualified within the definition.

**Power athlete**- an athlete that trains primarily in an explosive, short duration, highly anaerobic manner. Collegiate Division I female volleyball players represent the power athlete group in this study.

**Endurance athlete**- an athlete that trains primarily in a long duration, highly aerobic manner. Collegiate Division I female track athletes running distances of 800 meters and greater represent the endurance athletes in this study. Although the 800 meter event itself is not considered highly aerobic, much of the training in preparation for the event is of longer duration.

**Torque (T)**- angular representation of force usually expressed in newton-meters (Nm).

**Peak Torque (Tpeak)**- the greatest torque value for a given repetition or time interval as determined by an isokinetic dynamometer.

**Electromyogram (EMG)**- a representation of the electrical activity within a muscle that is determined by either surface (sEMG) or inserted needle electrodes.

**Electromechanical Delay (EMD)**- the time interval between the start of electrical activity in a muscle and the start of the resulting torque production as determined by EMG and an isokinetic dynamometer.

**Fast Fourier Transform (FFT)**- an algorithm which converts signal data from the time domain to the frequency domain by decomposing the signal into its frequency components and respective power in the signal. It is necessary to
perform an FFT on signal data to determine the mean power frequency or median power frequency.

**Mean Power Frequency (MPF)** - the mean frequency by power within the power spectrum density function as determined by the FFT.

**Median Power Frequency (MF, f_{med})** - the median frequency by power within the power spectrum density function as determined by the FFT.

**Filter** - removes certain frequencies from sample waveform data. This can be a low pass filter (which removes frequencies below a certain frequency), a high pass filter (which removes frequencies above a certain frequency), a band pass filter (which removes frequencies outside a certain frequency range), or a band stop filter (which removes frequencies within a certain frequency range).

**Rectification** - removes the negative portions of a waveform. This can be half wave rectification, which cuts out the negative portion of the waveform, or full wave rectification, which converts the negative portion of the wave to its absolute value.

**Maximum Voluntary Contraction (MVC)** - the greatest muscular contraction that can be voluntarily elicited. This may be represented by the associated torque or EMG values.

Delimitations for this research were:

1. The subjects consisted of 6 female volleyball players, 6 female track distance runners, and 6 apparently healthy female non-athletes from an NCAA Division I university.

2. The subjects had not engaged in strenuous activity for at least 24 hours prior to
testing.

(3) The independent variables were (a) group (power, endurance, control) and (b) test type (isokinetic speeds of 60, 120, 180, 240, 300, and isometric at 90 degrees knee flexion).

(4) The dependent variables are (a) mean median frequency; (b) mean electromechanical delay; (c) mean RMS EMG to mean torque ratio; (d) peak torque; (e) median frequency slope; (f) electromechanical delay slope; (g) RMS EMG to mean torque slope; and (h) peak torque slope.

Limitations for this research were:

(1) Results may not generalize to male populations, because only females were tested.

(2) Most conclusions were based on the athletic populations and, therefore, may not generalize to non-athletic populations.

(3) Testing was conducted in one lab visit and between day variability may affect results.

Research Hypotheses

(1) Power athletes were expected to demonstrate greater fatigue than endurance athletes as indicated by greater and more rapid median frequency decrease, electromechanical delay increase, and a decrease in peak torque during testing.

(2) Power athletes were expected to possess greater force generating capability in absolute terms than endurance athletes as indicated by peak torque.

(3) Power athletes were expected to generate greater torques than endurance athletes with anthropometric variables (body weight, body composition, lever arm length, thigh cross sectional area) accounted for at increasing isokinetic testing speeds.
(4) Power athletes were expected to exhibit greater synchronization than endurance athletes under low repetition, high torque conditions, as indicated by low EMG values per unit torque.
CHAPTER II

REVIEW OF LITERATURE

The purpose of this research was to determine the electromyographic and force production differences between female power and endurance athletes and non-athletic controls. This review of literature consists of (1) fatigue related electromyographic indices, (2) reliability of power spectral density measures and torque measurements, and (3) effect of fiber type on force production and EMG parameters.

Fatigue Related Electromyographic Indices

Various parameters of electromyographic data have been used to represent fatigue in muscle fibers. Among these are mean power frequency, median power frequency, and electromechanical delay (when collected with force/torque data). Research on the correlation of changes in these measures and neuromuscular fatigue has been somewhat equivocal due to protocol and definition differences causing direct comparisons to be difficult.

The same researchers have found conflicting research when testing with differing protocols. Ament, Bonga, Hof, and Verkerke (1993) found a significant decrease in median frequency of the soleus and gastrocnemius muscles during an exhausting treadmill run at a 33% grade and a speed of 5 km·hr⁻¹. In a study published three years later, they report no significant decrease in median power frequency during an exhausting treadmill run at 20% grade and a speed of 5 km·hr⁻¹ (Ament et al., 1996). The disparity
was explained as two different types of exhaustion occurring at low intensities and higher intensities. Incremental cycle ergometry testing one year later showed no systematic decrease in median power frequency and no relation between lactate accumulation and median power frequency shift (Jansen et al., 1997). It was suggested that the protocol used (generally lasting over 15 minutes) may not have been of a high enough intensity to effect a decrease in median power frequency.

Most other research on electromyographic fatigue correlates involves the use of electronic dynamometers of an isokinetic or isometric nature. These studies generally agree on the decrease in median frequency with neuromuscular fatigue. Mannion and Dolan (1996) required 10 subjects to hold submaximal isometric contractions of 20, 30, 40, 50, and 60% MVC until exhaustion, while intermittently having them evoke an attempted MVC. Peak torque on the attempted MVCs was found to decrease linearly and correlated highly with a decrease in median frequency, as well as time to exhaustion (p<0.0001).

Lactate accumulation within the working muscle has been shown to be related to the decrease in median frequency during short term intense exercise (Horita & Ishiko, 1987). Eleven males performed isokinetic knee extensions at 180 deg·sec⁻¹ for 30 and 60 seconds. Both median frequency decrease and electromechanical delay increase were related to lactate accumulation in the muscle and neuromuscular fatigue. The increased muscular pH is hypothesized to decrease the muscle fiber conduction velocity. There was also an increase in the integrated EMG/peak torque ratio, suggesting decreased efficiency of electrical activity in the working muscle.
Reliability of Power Spectral Density Measures and Torque Measurements

Mean frequency of the power spectral density function has been shown to be extremely reliable between trials and from day-to-day (Daanen, Mazure, Holewijn, & Van der Velde, 1990). During the study, EMG data were collected twice a day for five consecutive days at 40% MVC. The five day/two trial intraclass correlation coefficient was 0.99, stating that less than 1% of the error associated with the mean power frequency could not be accounted for by interindividual differences, making it a highly reliable measure for test-retest or longitudinal studies. The intraclass correlation coefficient for one day/one trial, such as the protocol of the current study, was 0.93. Other studies have shown that both median power frequency and mean power frequency provide a good representation of the power spectrum shift (De Luca, 1984), but it is also shown that median power frequency is less affected by high frequency noise (Hof, 1991).

Peak torque during a movement, defined as “the single highest torque output of the joint produced by muscular contraction as the limb moves through the range of motion,” has been shown to be a highly accurate and reliable measure (Kannus, 1994). Peak torque is the “gold standard” in isokinetic testing to which all other force parameters should be compared.

Effect of Fiber Type on Force Production and EMG Parameters

Different amounts of type I and type II fibers have been shown to affect the shifting of EMG parameters in studies of exhaustive exercise. Higher proportions of fast twitch (type II) muscle fibers correlate to more marked and rapid decreases in the median power frequency and mean power frequency in cycle ergometry (Taylor, Bronks, Smith,
& Humphries, 1997) and isokinetic leg extension (Tesch et al., 1983). In the cycle ergometry study, a predominance of type II fibers was also correlated to an increase in the electromechanical delay and integrated EMG/force ratio and a decrease in muscle fiber conduction velocity, while in the leg extension study, it showed no relationship to integrated EMG/force ratio.

Other studies relating the force production/fatigue characteristics of power athletes versus endurance athletes have shown that fiber type composition is important for absolute strength measures and fatigue response to exhaustive exercise. Volleyball players were shown to have higher cycle ergometry power and isokinetic leg extension torque than middle distance runners, but the cycle ergometry differences disappeared when scores were corrected for body mass or thigh volume (Sleivert et al., 1995). There appeared to be no differences in type I or type II cross sectional area, but there was a significant difference in the type II/type I cross sectional area ratio.

Another study contrasting sprinters with marathoners showed a much greater difference between the anaerobic and aerobic athletes and differing muscle types (Lorentzon et al., 1988). Sprinters had a 76% type II muscle fiber composition in their m. vastus lateralis as compared to slightly over 40% for the marathoners. Sprinters fatigued within the first 25 of the 200 repetition testing protocol and three out of five completed less than 50 repetitions due to subjective discomfort in the tested thigh, while all marathoners completed the full number of repetitions with the same initial decline but a steady work output thereafter.
Current Study

Most of the research cited has been conducted with male participants, especially when athletes were used. This lack of data for female athletes is one of the reasons that this group was the focus of the current study. Another reason females were chosen is that there is less anthropometric disparity between the power and endurance athletes in female populations than in male populations, due to a lesser ability for females to increase lean tissue. This may lead to an increased need to maximize the neural efficiency to the sporting task and therefore a greater electromyographic difference with regard to synchronization and fatigue measures.

The majority of the literature is also of a clinical or in vitro nature, with very few studies with an athletic performance focus. Research in this area may lay groundwork for more research into training mode as a factor in electromyographic fatigue indices and the use of such indices as tools for evaluating neuromuscular effects of training.
CHAPTER III

METHOD

The purpose of this research was to determine the electromyographic differences between female endurance and power athletes, as previously defined, and non-athletic controls by measuring EMG and torque under varying testing conditions. The testing consisted of two different testing protocols and results for each athlete group were also compared to a gender and age-matched non-athletic group. This chapter discusses specifics of subjects, instrumentation, procedures, data reduction, and statistical analyses.

Participants

Six female volleyball players and six female track distance athletes, aged 18 to 24 years, were recruited for testing from their respective teams at an NCAA Division I university. Six non-athletic female college students were recruited from non-sport related physical activity classes to serve as controls. All participants completed a notice of informed consent, indicating their willingness to participate in the study (see Appendix A). All participants provided demographic information including age, aerobic training frequency (hours/week), aerobic training history (weeks), anaerobic training frequency (hours/week), and anaerobic training history (weeks) (see Appendix B).

Instrumentation

A Biopac (Biopac Systems, Inc., Goleta, CA) MP100 data acquisition unit equipped with a UIM100 (Universal Interface Module) and two EMG100A electromyographic amplifier modules was used for all end data collection. This hardware
was connected to a Pentium 90 computer with which the data were obtained using
AcqKnowledge III data acquisition software (Biopac Systems, Inc.). The data reduction
and data analysis were performed with LabView software (National Instruments, Austin,
TX) and in-house software designed specifically for the study. EMG electrodes
consisted of pre-gelled self-adhesive Ag/AgCl electrodes with a 10 mm diameter contact
surface and metal snaps to which pinch leads from the EMG100A were attached. Torque
and EMG were both sampled at 1000 Hz to allow spectral analysis of the EMG up to 500
Hz and also a temporal comparison of the separate measures.

The EMG100A module served as the interface for all electromyographic data
acquisition. This unit has an input voltage range of -10 to +10 volts and was set for a gain
of 5000. When the filter option is off, the frequency response is 10 to 4000 Hz. With the
filter option selected, the frequency response is 100 to 4000 Hz, which eliminates the 50
to 60 Hz electrical noise that may be generated by electrical appliances and equipment.
The integration switch, when activated, results in a full-wave rectifying of the EMG
signal as well as applying a 10 Hz, two pole, low pass filter, which produces a smoothed
wave of electromyographic activity with peaks indicating points of highest activity.
These options were not activated, as they would interfere with the spectral analysis by
pre-conditioning the data. Post processing filters, full-wave rectification, and integration
were performed with LabView and in-house software.

A Biodex isokinetic dynamometer (Biodex Medical Systems, Shirley, NY) was
attached to the UIM100 module via a custom cable connecting the secondary 37-pin
output port of the Biodex and the 3.5 mm mini phono jacks of the UIM100 at channels 3,
4, and 5 (corresponding to velocity, torque, and position). This enabled a greater sampling frequency than the native Biodex software as well as allowing for use of the AcqKnowledge III software for data acquisition side-by-side, and temporally synchronized, with the EMG data.

Lange skinfold calipers (Cambridge Scientific Industries, Cambridge, MD) were used for body composition measures using the sites and calculations of the Jackson-Pollock method (Jackson, Pollock, & Ward, 1980) for determining body density and a mean of the Siri (Siri, 1961) and Brožek (Brožek, Grande, Anderson, & Keys, 1963) formulas for body fat percentage. Circumference and limb length measures were obtained using a flexible, retractable 60 inch tape measure. These measures were necessary to eliminate possible mechanical advantages of the different body types when comparing the groups.

Procedures

All participants provided demographic information and were measured for weight in shoes using a physician's scale and height by comparison to a measured scale placed on the wall. In addition, the length of the femur (from inguinal fold to mid patella) and the length of the tibia (from mid patella to lateral malleolus) were measured, as were the midthigh circumference (midpoint between inguinal fold and mid patella) and suprapatellar circumference (approximately 2 cm above the superior patellar border) and the knee joint breadth was taken at mid patellar height.

Body composition was taken using the three site formula and sites for the Jackson-Pollock method (i.e., triceps, supra iliac, and mid-thigh for females). Each
skinfold measure was taken three times and the median score recorded. Lean cross-
sectional area of the thigh was estimated from the thigh skinfold and mid-thigh
circumference, using the formula developed by Housh, Housh, Weir, Weir, Johnson, and
Stout (1995). This total thigh musculature was previously shown to have a 0.86
correlation with a standard error of estimation of 9.5 cm$^2$ when compared to values
obtained from MRI.

After these anthropometric measures were completed, the participant was prepped
for the testing portion of the study. The participant was informed that the preparatory
procedure for electrode placement involves discomfort similar to that of a moderate
sunburn, which is associated with bringing new skin to the surface. The skin of the
participant's right thigh was cleaned with an alcohol cleansing solution to remove oils
and dead skin from the area where the electrodes were to be placed, as well as the skin on
the left shin covering the tibia. These areas were then abraded with a fine sandpaper to
further remove nonconductive epidermal tissue and again the debris was cleaned with an
alcohol rub. Interelectrode resistance was kept below 5 kΩ (kiloohms) for testing
purposes, as measured by a battery operated multi meter. Electrode gel was added to the
pre-gelled foam of the electrode pads to increase conductivity. The participant was
instructed to contract the right quadriceps and the pad for the negative electrode was
placed on the inferior edge of the belly of the m. vastus medialis and the center of the pad
for the positive electrode was placed five centimeters superior to the center of that
electrode. The ground electrode was placed over the tibia of the left leg.

Next the participant assumed a seated position in the Biodex and the lever arm
was adjusted so that the pad was secured midway between the knee and the ankle and the
seat height adjusted so that the center of the knee joint was approximately center over the
lever arm axis of rotation. A few unresisted repetitions of knee extension were performed
to assure proper alignment of the Biodex to the participant before she was restrained
using the thigh, waist, and shoulder harnesses attached to the seat. After the Biodex
software was configured for the testing protocol, the EMG leads were attached to the
electrodes and testing began.

Before the primary testing trials were begun, maximal isometric knee extensions
were performed at 90 degrees of knee flexion to determine MVC values for torque and
EMG. Three maximal efforts of 5 seconds each with a 30 second rest interval were used
to determine the maximal EMG and peak torque for later scaling of data, with the greatest
value of the three being recorded.

The first phase of testing consisted of isokinetic leg extension tests of 10, 20, 30,
40, and 50 repetitions at 60 deg/sec, 120 deg/sec, 180 deg/sec, 240 deg/sec, and 300
deg/sec, respectively. The participant was instructed to extend the knee as forcefully as
possible on each repetition and relax on the flexion portion of the movement. There was
a 5 minute rest between testing speeds to assure proper recovery. The order of test speeds
was randomly assigned before the subject arrived for testing.

The second phase of testing consisted of a 60 second isometric contraction at 90
degrees of knee flexion. This angle was chosen as it is generally indicative of muscular
strength at any lesser angles, whereas lesser knee flexion angles do not necessarily
indicate strength at greater knee flexion angles during maximal knee extensions (Bandy &
The participant was instructed to extend as forcefully as possible for the entire 60 seconds and informed that the lever arm would not move, no matter how hard she extended.

Data Reduction

Data were reduced to obtain the desired variables for each test. For the isokinetic tests, measures were taken starting with repetition number three, as pilot work indicated that it takes two repetitions for the participant to accommodate to the testing speed. One of the measures that was directly taken from the data was the mean electromechanical delay (EMD), which is the time between the initiation of muscle activity and the start of torque production. The values for EMD were found to be inconsistent in many participants due to the inability to follow the contract-relax protocol for the knee extensions and, therefore, this variable was omitted from statistical analysis. Mean median frequency of the power spectrum (MF) was obtained after converting the data to the frequency domain by way of fast Fourier transform using LabView software. RMS EMG (E) and mean torque (T) were calculated over a 250 ms window prior to the recorded peak torque of each repetition and combined into an E/T ratio. The peak torque (Tpeak) for each test speed was also recorded. Along with these direct values, slopes indicating the change in the EMG and force production parameters were calculated for each of the five isokinetic trials. These include MFslope, EMDslope (omitted due to problems with determination of EMD), E/Tslope, and Tpeak-slope, and were obtained by fitting a line to the values of each measure at each repetition. For the isometric fatigue test, the data were divided into one second intervals (starting with second number one).
for which MF, E/T, and Tpeak were obtained. These values were then used to calculate slopes for each variable across the timespan of the test. These slopes were the dependent variables for the isometric fatigue test.

**Statistical Analysis**

Descriptive statistics of the variables of interest were computed. These dependent variables were MF, E/T, and Tpeak for the isokinetic tests, as well as MFslope, E/Tslope, and Tpeak-slope for all test conditions. Five variables for the isokinetic test conditions (MF, E/T, MFslope, E/Tslope, Tpeak-slope) were analyzed with a repeated measures ANOVA with five levels representing the different isokinetic speeds (see Table 1). A repeated measures ANCOVA was used to analyze Tpeak so that it could be covaried by the lean cross-sectional area of the thigh musculature to reduce the differences due to body type between groups. Separate one-way ANOVAs were performed for the three dependent variables which applied only to the isometric fatigue test. These were MF, E/T, and Tpeak. The Tukey post hoc test was used to investigate main effects in the ANOVAs. Statistical significance was set at .05 for all tests.

Table 1.

| Repeated Measures ANOVA Design for Isokinetic Tests |
|-----------------------------------------|-----|-----|-----|-----|-----|
|                                        | 60  | 120 | 180 | 240 | 300 |
| Power                                  | 5 DV| "   | "   | "   | "   |
| Endurance                              | "   | "   | "   | "   | "   |
| Control                                | "   | "   | "   | "   | "   |

Note: 5DV = Tpeak-slope, E/T, E/Tslope, MF, Mfslope
CHAPTER IV

RESULTS

The purpose of this research was to determine the electromyographic and force production differences between female power and endurance athletes. This chapter includes the results from (1) participant demographics and anthropometric measures, (2) isokinetic EMG and force variables, and (3) isometric EMG and force variables.

Participant Demographics and Anthropometric Measures

Descriptive statistics for the demographics and anthropometric measures for each group were computed and one-way ANOVAs were performed to determine if significant differences appeared among the groups. The Tukey post-hoc procedure was used to investigate significant differences. Means and standard deviations for each group on all of the measures are summarized in Table 2, along with significance values for the omnibus tests. Significant differences were found in body fat measures between the endurance group and control group, $p < .05$, with the endurance group being approximately 8 percent leaner. The power group was significantly taller than both the endurance, $p < .05$, and control groups, $p < .05$, by an average of 11.8 cm and 11.2 cm, respectively. The power group also had a significantly greater mid-patella to lateral malleolus length than both other groups, $p < .001$ for endurance and $p < .01$ for control, while the mid-patella to inguinal fold length difference was not significant. Midthigh circumference, $p < .05$, and suprapatellar circumference, $p < .05$, measures were
significantly higher in the power group than in the endurance group with mean differences of 5.8 cm and 5.5 cm, respectively. The power group was also significantly heavier than the endurance group, $p < .005$, with a mean difference of 19.7 kg, although there were no significant differences in BMI or lean BMI among the groups. The lean cross-sectional area (CSA) of the thigh was significantly greater in the power group than the control group, $p < .01$, with a mean difference of 36.3 cm$^2$. 
Table 2.

**Demographic and Anthropometric Measures By Group (N = 18)**

<table>
<thead>
<tr>
<th></th>
<th>Power (n=6)</th>
<th>Endurance (n=6)</th>
<th>Control (n=6)</th>
<th>p&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE (yrs)</td>
<td>19.83 (.98)</td>
<td>20.50 (.55)</td>
<td>21.50 (1.97)</td>
<td>&lt;.120</td>
</tr>
<tr>
<td>BMI (kg·m&lt;sup&gt;-2&lt;/sup&gt;)</td>
<td>23.46 (1.90)</td>
<td>19.91 (1.16)</td>
<td>22.58 (4.80)</td>
<td>&lt;.147</td>
</tr>
<tr>
<td>BODYFAT (%)</td>
<td>23.29 (4.32)</td>
<td>19.02 (2.81)</td>
<td>27.10 (6.15)</td>
<td>&lt;.028</td>
</tr>
<tr>
<td>HEIGHT (cm)</td>
<td>181.40 (5.13)</td>
<td>169.57 (5.99)</td>
<td>170.17 (7.64)</td>
<td>&lt;.009</td>
</tr>
<tr>
<td>WEIGHT (kg)</td>
<td>77.15 (6.47)</td>
<td>57.50 (7.29)</td>
<td>64.88 (10.71)</td>
<td>&lt;.003</td>
</tr>
<tr>
<td>KJB (cm)</td>
<td>10.91 (.48)</td>
<td>9.85 (1.01)</td>
<td>10.38 (1.26)</td>
<td>&lt;.199</td>
</tr>
<tr>
<td>LEANBMI (kg·m&lt;sup&gt;-2&lt;/sup&gt;)</td>
<td>18.01 (1.90)</td>
<td>16.12 (.90)</td>
<td>16.24 (2.10)</td>
<td>&lt;.138</td>
</tr>
<tr>
<td>MPIL (cm)</td>
<td>43.67 (2.84)</td>
<td>42.25 (2.62)</td>
<td>41.50 (1.70)</td>
<td>&lt;.323</td>
</tr>
<tr>
<td>MPML (cm)</td>
<td>45.25 (.76)</td>
<td>40.33 (2.07)</td>
<td>41.25 (2.49)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>MTC (cm)</td>
<td>54.08 (2.48)</td>
<td>48.33 (2.58)</td>
<td>48.72 (5.43)</td>
<td>&lt;.031</td>
</tr>
<tr>
<td>SPC (cm)</td>
<td>42.33 (1.66)</td>
<td>36.83 (2.40)</td>
<td>38.83 (4.59)</td>
<td>&lt;.026</td>
</tr>
<tr>
<td>THIGHCSA (cm&lt;sup&gt;3&lt;/sup&gt;) *</td>
<td>121.61 (16.64)</td>
<td>100.28 (15.72)</td>
<td>85.35 (20.54)</td>
<td>&lt;.010</td>
</tr>
</tbody>
</table>

Note: Values listed m (SD); KJB = knee joint breadth; LEANBMI = lean mass in kg divided by height in meters squared; MPIL = mid-patella to inguinal fold length, MPML = mid-patella to lateral malleolus length; MTC = mid-thigh circumference; SPC = suprapatellar circumference; THIGHCSA = estimated cross-sectional area of the thigh muscles

<sup>a</sup> df = 2, 15
Isokinetic EMG and Force Variables

Repeated measures ANOVAs (group x speed) were performed on the data from the isokinetic tests, except for the peak torque which required an ANCOVA, and statistical significance was determined at the .05 level. Any main effects for speed that do not show (4, 60) degrees of freedom were adjusted by the Huynh-Feldt epsilon for violations of the sphericity assumption.

Peak Torque. Peak torque was found to have significant main effects for speed, $F(2, 35) = 99.88, p < .01$. Peak torque showed an inverse relationship to isokinetic testing speed (see Figure 1). There was also a main effect for group as the power group had significantly higher torque values, $F(2, 14) = 8.63, p < .005$, than both the endurance and control groups, even after covariance by lean cross-sectional area of the thigh musculature. There were no significant group by speed interactions for peak torque. There was a significant speed, $F(1, 26) = 4.68, p < .05$, effect for peak torque slope, but no significant group effects or interactions. The greatest group differences existed at 60 deg-sec$^{-1}$ with differences narrowing at 120 and 180, but remaining stable at higher speeds (see Figure 2).

E/T. Mean E/T ratio also showed a significant speed, $F(3, 44) = 144.12, p < .01$, effect, but no group effects or interactions. All groups had increased EMG activity compared to torque production at increasing speeds (see Figure 3). Speed, $F(3, 48) = 4.48, p < .01$, was the only significant effect for E/T slope with the endurance group having a different trend than both of the other groups across the speeds. All groups increased E/T slope from speeds 60 to 120, but the endurance group also increased from
120 to 180 and 180 to 240, whereas the power and control groups both decreased during those intervals. From 240 to 300, the power and control groups reversed trend and increased while the endurance group markedly decreased (see Figure 4).

Figure 1.

Median Frequency. The only significant effect for any of the isokinetic testing measures dealing with median frequency was a speed effect, $F(4, 60) = 4.41, p < .005$, for mean median frequency. The mean median frequency tended to decrease with increasing isokinetic testing speeds. No significant group effects or group by speed effects were found for the mean median frequency, nor were any significant effects found for median frequency slope, although the median frequency slope for the control group at the 60 deg·sec$^{-1}$ speed was markedly out of place (see Figures 5 and 6).
Figure 2.

**Peak Torque Slope by Testing Speed**

- **Group:**
  - Power
  - Enduran
  - Control

Figure 3.

**E/T Ratio by Testing Speed**

- **Group:**
  - Power
  - Enduran
  - Control
Figure 4.

E/T Slope by Testing Speed

Figure 5.

Median Frequency by Testing Speed
Isometric EMG and Force Variables

One-way ANOVAs were performed on the slopes obtained from the isometric fatigue test with the Tukey post hoc procedure used to investigate significant main effects. The tests for two subjects (one each from the power and endurance groups) were omitted due to failure to successfully complete the entire test. They were unable to sustain a muscular contraction for the full sixty seconds, which greatly affected the slopes obtained. There was a significant difference among groups for the E/T slope, \( F(2,13) = 3.89, p < .05 \), but post hoc tests were not sensitive enough to detect any significant pairwise differences. The peak torque slope was significantly different among the groups, \( F(2,13) = 5.93, p < .05 \), with post hoc tests revealing a significant difference, \( p < .05 \), between the endurance and power groups. No significant differences were found in the median frequency slope. Significant differences for all tests are summarized in Table 3.
Table 3.

Summary of Significant Differences in Testing Variables (N = 18)

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Variable</th>
<th>Effect Type</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isokinetic</td>
<td>Peak Torque</td>
<td>Group</td>
<td>( p &lt; .005 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Speed</td>
<td>( p &lt; .01 )</td>
</tr>
<tr>
<td></td>
<td>Peak Torque Slope</td>
<td>Speed</td>
<td>( p &lt; .05 )</td>
</tr>
<tr>
<td></td>
<td>E/T Ratio</td>
<td>Speed</td>
<td>( p &lt; .01 )</td>
</tr>
<tr>
<td></td>
<td>E/T Slope</td>
<td>Speed</td>
<td>( p &lt; .01 )</td>
</tr>
<tr>
<td></td>
<td>Median Frequency</td>
<td>Speed</td>
<td>( p &lt; .005 )</td>
</tr>
<tr>
<td>Isometric</td>
<td>E/T Slope</td>
<td>Group</td>
<td>( p &lt; .05 )</td>
</tr>
<tr>
<td></td>
<td>Peak Torque Slope</td>
<td>Group</td>
<td>( p &lt; .05 )</td>
</tr>
</tbody>
</table>

Note: N = 16 for the isometric tests due to the inability of two participants (one each from the power and endurance groups) to successfully complete the required test.
CHAPTER V

DISCUSSION

The purpose of this research was to determine the electromyographic and force production differences between female power and endurance athletes and non-athletic controls. This chapter includes (1) discussion of results of this research, (2) summary of conclusions, and (3) recommendations for future research.

Power athletes were expected to demonstrate greater fatigue as indicated by the various fatigue-related indices measured. These indices were established as greater and more marked median frequency decrease (more negative MF slope), electromechanical delay increase (greater EMD slope), E/T slope increase (greater E/T slope) and peak torque decrease (more negative PT slope). Differences were found between groups, but most were not significant. This may be due to the small number of subjects decreasing the power of the statistical analyses performed. Electromechanical delay could not be measured due to a large part of the participants being unable to follow the proper contract and relax protocol in the leg extension task. All fatigue measures supported previous research within tests as participants displayed negative MF and PT slopes and positive E/T slopes, in accordance with participant response to fatiguing exercise (Horita & Ishiko, 1987; Lorentzon et al., 1988; Mannion & Dolan, 1996). The unique hypotheses of this research were not conclusively supported.

In the isometric fatigue test, the power group showed a significantly more
negative PT slope than the endurance group, indicating greater fatigue and more reduced torque output as time progressed. There was also a significant difference in the E/T slopes of the three groups, with the endurance group having a lower slope than both the power and endurance groups, indicating less fatigue in the endurance group. There was no significant difference between groups for the MF slope, but the endurance group did have a less negative MF slope than both the power and control groups, indicating less fatigue.

The isokinetic tests did not discriminate between groups for these fatigue measures as well as the isometric tests. No significant group effects were found in any of the fatigue measures in these tests. There were significant speed effects for PT slope and E/T slope, showing that intensity of effort affected these measures. Although not significant, for PT slope the lowest speed (60 deg·sec$^{-1}$) produced the greatest group differences, followed by the second lowest speed (120 deg·sec$^{-1}$) with differences remaining fairly constant thereafter (see Figure 2). This apparent change from group differences to small group differences that are apparent upon visual inspection may not have been significant due to the low power of the analyses caused by the small number of subjects. For E/T slope, the greatest group differences were found at 120 deg·sec$^{-1}$ and 300 deg·sec$^{-1}$, with the former being the most pronounced (see Figure 4). Interestingly, the endurance group had an opposite trend than the other two groups for measures beyond the speed of 120 deg·sec$^{-1}$. MF slope showed no significant effects or interactions and values remained stable across speeds (see Figure 6).

Power athletes were expected to possess greater force generating capability in
absolute terms than endurance athletes as indicated by peak torque. This hypothesis was supported as the power group had significantly higher peak torques than both of the other groups across all test types and test speeds. This difference was still significant after covariance for the lean cross-sectional area of the thigh musculature. The endurance and control group were very similar after covariance for the lean CSA of the thigh, with no significant differences found.

Power athletes were expected to generate greater torques than endurance athletes with anthropometric covariances accounted for at increasing isokinetic testing speeds. The hypothesis was supported as power athletes demonstrated greater peak torques for all test speeds after covariance for lean cross-sectional area of the thigh and all other mechanical advantages, of which lean CSA was the most significant in this study, \( r = .751, p < .001 \). The unstated premise that the differences increase with increasing isokinetic speeds is not supported as percentages of power group peak torque compared to the other groups remains fairly constant across all test speeds. This may be due to the fact that the highest speed was not as fast as is normally considered a high angular speed for the knee extension task, although the beginning of the trend could be expected by the 300 deg-sec\(^{-1}\) test speed.

Power athletes were expected to exhibit greater synchronization under low repetition, high torque conditions, as indicated by low EMG values per unit torque. This hypothesis was not supported by the E/T ratio variable as all groups performed almost identically under the low repetition, high torque conditions of the 60 deg-sec\(^{-1}\) isokinetic testing speed. It is not a definite contradiction to the hypothesis, because E/T ratio is not
a direct assessment of neuromuscular synchronization. Because the EMG measures were only taken from the agonist group and no temporal analysis of the EMG signals were provided, it may be possible that increased reciprocal inhibition or more efficient firing timing did occur, but were simply not reflected in the variable as defined in this context.

Summary of Conclusions

Previous findings of general indices of fatigue were supported as individuals displayed peak torque decrease, E/T ratio increase, and median frequency decrease during each test. This indicates that females demonstrate the same responses to exercise in terms of the developed fatigue indices as males used in previous studies (Lorentzon et al., 1988; Sleivert et al., 1995). Group differences for fatigue indices across isokinetic testing speeds were not significantly demonstrated. Significant group differences were found for the increase in E/T ratio and the decrease in peak torque during the isometric fatigue test. Power athletes were shown to have significantly higher peak torque values across all speeds with covariance for thigh muscle cross-sectional area. Power athletes were not shown to exhibit greater synchronization under low repetition, high torque conditions as reflected by the E/T ratio variable used in this research.

It appears from these results that isometric testing is the better method for determining group differences in terms of the fatigue indices. This may be due to the decreased blood flow to the working muscle during isometric contraction. Previous investigators have hypothesized that differences in some fatigue parameters were due to the accumulations of metabolites, primarily lactate, which decrease the local pH and may cause decreased action potential conduction velocity along the muscle fiber (Horita &
Ishiko, 1987). The decreased blood flow through the working muscle would allow greater accumulation of these metabolites as they are not as readily carried away to be processed and the buffering capability of the blood present in the muscle is overstressed.

The peak torque differences present between groups in this study with the lean CSA of the thigh accounted for would indicate a difference between the groups at the muscle fiber level. Previous studies finding differences between participants with different muscular composition have related this to differences in type II/type I fiber ratio or absolute levels of type II muscle fibers in the working muscle (Lorentzon et al., 1988; Sleivert et al., 1995; Taylor et al., 1997). This would indicate that the power athletes in this study may possess a greater number of type II muscle fiber and/or a greater type II/type I muscle fiber ratio in the m. vastus medialis.

The differences between athlete groups in the isometric tests on the fatigue parameters would also indicate differences in fiber type composition. Type I fibers, while generating less torque per unit of cross-sectional area, are more resistant to fatigue. If the endurance group possesses a greater percentage of type I fibers, then they would produce less absolute peak torque per given CSA of working muscle but the peak torque should not decline as rapidly as that of the power group. This is exactly what was shown as the power group had a greater absolute peak torque, but peak torque declined more rapidly than the endurance group when expressed as a percentage of initial peak torque.

Recommendations for Future Research

The small number of participants in this research may have prevented some actual differences from being statistically significant by decreasing the power of the statistical
analyses. This was unavoidable as all available qualified athletes in the university athletic program were used. If a larger sample of qualified athletes could be used then some further measures may reach the level of significance.

From the data, it appears that higher repetitions and greater resistance (lower isokinetic testing speed) increase the differences between groups in regards to the fatigue correlates. The combination of higher repetitions with lower isokinetic testing speed might provide the greatest delineation of group differences. This protocol could not be used in the present research, as speed differences had not been established and to make combinations of higher repetitions with lower testing speeds would have greatly increased the number of isokinetic tests. Also, the protocol was designed to keep the time per test approximately equal, so that the slower the movement of the lever arm, the fewer number of repetitions could be completed in the same amount of time as a faster testing speed. Because these speed differences have now been examined, future research might utilize the most discriminating speeds to decrease the number of tests necessary. Thus, a different protocol using 120 deg·sec\(^{-1}\) or 180 deg·sec\(^{-1}\) with even higher repetitions than those used in this research might reveal greater group differences. The lack of differences in the median frequency measures between groups may be directly related to an inadequate number of repetitions, as most previous successful median frequency-related studies have used 120 or more repetitions per test.

Future research should utilize a multiple lab visit protocol and possibly fewer numbers of tests in the format suggested above. Participants tended to get more mentally fatigued than physically fatigued by the multiple tests in a single visit. One problem with
multiple visits with athletes is with differences in training schedule, it is hard to find several days when they have had exactly the same training the days prior to visit so that results won’t be affected by inadequate recovery from training. Another problem is that it is hard to schedule athletes for multiple visits during their competitive season, but they may not give the same responses in their more untrained state during off-season. Power athletes in the present study were at the end of off-season volleyball at the time of testing and may not have been in as highly trained as during the regular season. The endurance athletes were in the peaking phase at the end of the track season. Since this group consisted of athletes specializing in events ranging from 800 m to 3000 m during the track season, results might have been different if they had been tested during the cross country season when individual training schedules would have been more similar.

In terms of representing synchronization, a more detailed approach needs to be used than the E/T ratio. The current study only took the RMS of the EMG signal for the 250 ms prior to peak torque for each repetition. A greater difference may be found between groups if a greater time window is used, assuming that EMG activity from eccentric or controlling actions are not included. Another addition may be to collect EMG data from antagonist muscle groups so that co-contraction or agonist/antagonist EMG activity ratios can be utilized to indicate the amount of reciprocal inhibition.

Further research in this area may allow determination of the muscular differences in athletes without the use of invasive procedures such as muscle biopsy. This may be used in determining the most appropriate sport or running distance for a particular athlete, when combined with other measures of performance. If the detection of muscular
differences were further refined, it may be possible to determine muscular level adaptations to a specific training protocol that may not be apparent in performance. If it is shown that cellular adaptations have taken place, but performance has not proportionately increased, then biomechanical or psychological factors may need to be investigated.
APPENDIX A

INFORMED CONSENT FORM
Muscular Differences Between Female Power and Endurance Athletes
The University of North Texas
Strength Laboratory

Consent to Participate in a Research Study

You have been asked to participate in a research study which will examine the differences in muscle activity between female athletes involved in different training modes. The information obtained in this study may provide valuable information concerning the relationship between training mode, training history, and body type on muscle recruitment and fatigue. Please feel free to ask any questions you may have regarding this study.

I hereby consent to participate in Allen Akers' study of "Muscular Differences Between Female Power and Endurance Athletes." I fully understand that I will be performing maximal knee extensions. I will also be measured for anthropometric (body type) data. In addition, the exercise which I am going to perform has been demonstrated for me. I will visit the strength lab one time for approximately one hour for testing. I have also been fully informed on the risks (e.g., muscle soreness, irregular heartbeat, increased blood pressure during muscle contraction, and skin irritation due to electrode prepping) involved in the testing procedures. I have been informed that information given by me to the experimenter will be kept confidential and that I will not be referred to by name or identifier in any subsequent publications or presentations of the research. Finally, I have been informed that I am free to withdraw this consent and withdraw from the study at any time.

If I have any questions or problems that arise in connection with my participation in this study, I should contact Allen Akers, the principal investigator at 565-3057 (work) or 387-5163 (home).

I, _______________________________, have read the above and have decided to participate in the study described above. My signature also indicates that I understand the contents of this consent form. A copy of this form will be provided to me.

__________________________________  ______________________________
Signature                                      Date

__________________________________
Principal Investigator

THIS STUDY HAS BEEN REVIEWED BY THE UNIVERSITY OF NORTH TEXAS COMMITTEE FOR THE PROTECTION OF HUMAN SUBJECTS (Phone: 565-3940).
Name: ________________________________

Last 3 ssn: __________

Age: _____

Height: _____ in _____ cm

Weight: _____ lbs _____ kg

Midthigh circumference: _____ cm

Suprapatellar circumference: _____ cm

Knee joint breadth: _____ cm

Midpatellar to inguinal length: _____ cm

Midpatellar to lateral malleolus: _____ cm

Bodyfat: _____ %

Triceps: _____ Supra iliac: _____ Midthigh: _____

Fa: _____ hours/week (Frequency of aerobic exercise)

Ha: _____ weeks (How long this aerobic frequency has been maintained)

Fan: _____ hours/week (Frequency of anaerobic exercise)

Han: _____ weeks (How long this anaerobic frequency has been maintained)

BMI: _____

LMI: _____

LCSA thigh: _____ cm

Peak Torque: _____ Nm

Peak EMG: _____ mV
REFERENCES


for Measuring Body Composition. National Academy of Science, Washington, DC.

