A COMPARISON OF TORQUE CHARACTERISTICS PRODUCED
BY THE KNEE FLEXORS AND EXTENSORS DURING
CONTINUOUS CONCENTRIC AND ECCENTRIC LOADING
IN POWER ATHLETES AND AEROBICALLY TRAINED RUNNERS

by

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It was the purpose of this investigation to evaluate continuous concentric and eccentric isokinetic loading of the knee extensors (KE) and flexors (KF) at 90, 135, and 180 deg/sec⁻¹ in power athletes (PA), aerobically trained runners (ATR), and a control group of moderately active individuals (MA). A total of sixty healthy subjects (N= 20/group), aged 18-35 years, were assigned to one of the three groups after physiological assessment consisting of vertical jump and maximal oxygen consumption (VO₂ max) was performed. Gravity corrected concentric and eccentric average isokinetic torque was measured from 75-30° of knee flexion and knee flexion-extension ratios (KF-E ratios) were calculated.

A three-way ANOVA with two repeated measures (angular velocity and muscle group) was calculated for each measured contraction type (concentric and eccentric). A third three-way ANOVA with two repeated measures (angular velocity and contraction type) was computed for the analysis of KF-E ratios. Significant findings were further analyzed using Scheffé's post hoc comparisons. Finally correlations between the ability to produce concentric and eccentric torque for the KE and KF and VO₂ max, vertical jumping ability, and skeletal muscle mass (SMM) were examined using Person Product Moment Correlations.

It was found that the power group produced significantly greater average concentric and eccentric isokinetic torque than either the endurance (concentric and eccentric at p< 0.01) or
sedentary (concentric at $p< 0.05$ and eccentric at $p< 0.01$) groups for both the KE and KF while the last two groups did not significantly differ ($p> 0.05$). For all groups isokinetic torque produced both eccentrically and concentrically by the KE was significantly greater at $p< 0.001$ than that produced by the KF at each angular velocity examined. As well, eccentric KF-E ratios were significantly greater ($p< 0.001$) than those produced concentrically for each of the three groups for all angular velocities.

The power groups had significantly greater concentric and eccentric KF-E ratios ($p< 0.01$) than either the endurance or sedentary groups of subjects who did not differ significantly. Concentric KF-E ratios significantly increased with increasing angular velocities for both the endurance and sedentary groups ($p< 0.02$) while eccentric ratios did not significantly change with increasing angular velocity in any of the three groups of subjects. Finally, there were significant correlations between the ability to generate torque both concentrically and eccentrically by the knee extensors and knee flexors and vertical jumping ability while $\text{VO}_2\text{max}$ nor SMM significantly correlated with vertical jumping ability.

These findings are important when designing individualized conditioning and rehabilitation programs for athletes who are training for activities which require different velocities of muscular contraction.
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Chapter 1

INTRODUCTION

Past isokinetic assessment of the knee joint has been performed to investigate several different areas of interest to both the fields of research and rehabilitation which include: monitoring progress following the repair or reconstruction of knee ligament(s), the examination of hamstring and quadricep torque curves after either knee joint or thigh muscle injury, the relationship between muscle strength and muscle fibre composition, and knee flexion-extension ratios. It is this last area, the focus of many studies, which examines the relationship between hamstring muscle strain and knee flexor-extensor (KF-E) imbalance. Although it is believed that an abnormal KF-E ratio may have some association with such injury (Holmes & Alderink 1984, Bailey & Bremiller 1981, Burkett 1970, Heiser et al. 1984), definite proof has yet to be established (Nosse 1982).

Muscle strain injuries (MSI) have a high rate of incidence in those sports which require some degree of sprinting, jumping, and/or rapid acceleration (Arge 1985, Garrett 1983, Stanton & Purdam 1989). Brubaker & James (1974) as reported by Arge (1985), found that in runners, 33% of all injuries were of the MSI variety; a 50% rate of incidence in those athletes participating in sprint events.

One idea which has been offered to explain the abnormal frequency of these injuries is muscle imbalance. The term
muscle imbalance (MI) refers to an asymmetrical difference which exists between extremities or between the agonist and antagonist of the same extremity which may include strength, power, power-endurance, or other value when examining the same subject (Grace 1985). This imbalance is currently measured by evaluating average and/or peak isokinetic torque of agonist and antagonist, dividing the two measures with the result being the ratio. This balance, or lack there of, is deemed as being ipsilateral or contralateral (Gillum et al. 1979, Heiser et al. 1984).

**IMBALANCE VS ASYMMETRY**

Previous studies have examined KF-E ratios using many different testing procedures and groups of subjects. One aspect which has been common to all, however, is the use of the term MI. To date, research examining this relationship has suggested that MI between the KF and KE is "unhealthy", possibly contributing to the occurrence of hamstring MSI (Burkett 1970, Burkett 1976, Cooper & Fair 1978, Stafford & Granna 1984). The use of this term in such a manner is incorrect. One should consider that because the KE and KF are two separate and distinct groups of muscle with different actions, innervations, and are composed of different percentages of Type II muscle fibres (Garrett 1983, Polgar 1973), imbalances should exist between these two groups of muscle. Considering the structural differences between the KE and KF perhaps a more appropriate term to describe an "unhealthy" difference in
torque production is asymmetry.

There are two different types of asymmetry: functional and structural. Structural asymmetry measures differences which can be associated with physical characteristics such as differences in muscle size, innervation(s), origin(s) and insertion(s), and muscle fibre composition. Therefore, structural asymmetry between the KE and KF should be expected. However, gross structural asymmetrical differences between legs, such as significantly different thigh circumferences, can be pathological in nature.

The second form of asymmetry is that of a functional nature. Functional asymmetry examines the different aspects of muscle function measured in a variety of ways regardless of structural status which include the coordination of muscular contraction, speed of movement/joint angular velocity, and strength. Functional asymmetry either between the KE and KF and/or between the left and right leg can be considered as predisposing one to injury.

Previous studies have indicated that peak and average torque is greater for the quadriceps than which the hamstrings are capable of producing at all angular velocities presently available for testing (Baltzopolous & Brodie 1989, Ghena et al. 1991, Sanderson et al. 1984). Thus, if the KE are significantly stronger than the ipsilateral KF, any cocontraction of these two muscle groups may result in the knee flexors being overpowered by the force produced by the knee extensors. Such an occurrence may result in hamstring MSI (Sutton 1984).
The literature addresses the measurement of isokinetic knee flexion and extension torque from many different perspectives. In recent years there have been several advances in the capabilities of isokinetic dynamometers which have revolutionized this entire area of research. Studies were once limited to isokinetic concentric evaluation of muscle, now isokinetic eccentric characteristics can also be examined.

By investigating KF-E torque eccentrically, we can further advance our knowledge concerning KF-E torques, their ratios, and possible relationship to eccentric hamstring MSI.
STATEMENT OF THE PROBLEM

The purpose of this study was two-fold: 1) to examine the relationship between concentric and eccentric torque as produced by the knee flexors and extensors and their KF-E ratios in a manner which best simulated the length-tension relationships found during running and 2) to examine the differences in the ability to produce torque between power athletes (PA), aerobically trained runners (ATR), and a group of moderately active individuals (MA).

DEFINITIONS

For the purpose of clarification, the following definitions are considered applicable throughout the study.

1) **Torque** -- a turning or rotary force; the product of a force and the perpendicular distance from the line of action of the force to the axis of rotation

2) **Average Torque** -- the average recorded value measured during a trial regardless of its position in the range of motion

3) **Power Subject** -- any subject who performs a vertical jump of 65 cm or greater and does not achieve a value of 60 ml/kg/min on the VO2 max test

4) **Aerobically Trained Subject** -- any subject who performs a VO2 max test of greater than or equal to 60 ml/kg/min and does not achieve a value of 65 cm on the vertical jump test
5) **Moderately Active Subject** — any subject who cannot perform a vertical jump of 65 cm nor can achieve a value of 60 ml/kg/min on the VO₂ max test

6) **Concentric** — muscle contraction which occurs when the involved muscle shortens while contracting

7) **Eccentric** — muscle contraction which occurs when the involved muscle lengthens while contracting

**DELIMITATIONS**

The results of the study were delimited by:

1) Sample size, sex, age, level of athletic status

2) Ability of the tester to ensure that correct procedures and techniques were employed in the measurement of physiological tests, anthropometry, and torque evaluation

3) The specific angles in the ROM which torque measurements were examined

**LIMITATIONS**

The results of this study were limited by:

1) Errors of data collection by the Beckman Metabolic Measurement Cart. This was minimized by calibrating the Beckman before each aerobic endurance test and by standardizing the testing procedures and instructions for all subjects.

2) Errors of data collection by the Kin-Com isokinetic dynamometer as well as errors that can occur in the accuracy of reading values off the recording chart. These were mini-
mized by calibrating the Kin-Com before each testing session and through the standardization of testing procedures and instructions.

3) Alteration in subject body position during testing which was minimized through the use of stabilization straps.

4) The subject reporting accurately that no previous lower extremity injury had occurred.

5) Ability of the subjects to perform correctly on the Kin-Com.

6) Any reference between running angular velocities and those available for testing on the Kin-Com remembering that the speed of running has been estimated to occur at 800 deg/sec\(^{-1}\) and the maximal speed available for testing on the Kin-Com is 210 deg/sec\(^{-1}\).

ASSUMPTIONS

The construct of this study included the following assumptions:

1) That the results of the isokinetic torque tests were dependant upon the effort and cooperation of each subject.

2) That the measurements recorded were only as accurate as instrumentation allowed.
HYPOTHESES

It was hypothesized that:

1) Torque produced concentrically and eccentrically by the knee extensors will be significantly greater than that produced by the knee flexors for all groups at all velocities.

2) PA will produce significantly greater concentric and eccentric torque for both the knee flexors and extensors than either the ATR or MA groups at all velocities.

3) PA will have significantly greater concentric and eccentric KF-E ratios than the MA and ATR groups for each velocity of contraction.

4a) For all groups at each angular velocity, eccentric KF-E ratios will be significantly greater than concentric ratios.

4b) As angular velocity increases concentric ratios will increase while eccentric ratios will remain unchanged for all three groups.

5) Vertical jumping ability will significantly correlate with torque production while VO₂ max and skeletal muscle mass will not significantly correlate.
SIGNIFICANCE OF THE STUDY

Hamstring MSI are notorious for their slow rate of healing and high incidence of recurrence, thus they can be severely debilitating. Knowledge of healthy athlete's KF-E ratios, measured both concentrically and eccentrically may be of assistance to several different people who assist in the training of athletes. This information could be used as a measuring tool to determine if their athletes are capable of producing and withstanding the forces present associated with their particular event.

As well, this knowledge may be useful during the rehabilitation of athletes who have experienced hamstring MSI or other injury such as damage to knee ligament(s) where the thigh musculature plays a significant role in rehabilitation. This knowledge, collected on individuals who have not previously experienced hamstring injury, could be used as a guideline which aids the physiotherapist in determining if the injured athlete is ready to return to competition without risking further injury.

Rothstein et al. (1987) have stated that previous studies performed in this field have been filled with errors which are discovered as more research is performed, evaluation methods are refined and test equipment is improved. Due to previous errors further investigation in this area using strict test procedures so 'sprint-like' torques can be measured remembering the limitations of the isokinetic devices such as the Kin-Com must be performed.
Therefore, this study was designed to further examine concentric and eccentric torques of the knee flexors and extensors and KF-E ratios in power athletes, aerobically trained runners, and moderately active individuals over three different velocities of muscle contraction. Of further interest to this investigation was the relationship between whole body skeletal muscle mass, vertical jumping ability, and VO₂ max to torque production.
Chapter 2
LITERATURE REVIEW

This part of the paper is divided into five sections: previous methods of examining muscle strength and function, analysis of the running motion, torque production and muscle fibre composition, knee flexion-extension assessment, and faults with previous related research.

METHODS OF EXAMINING MUSCLE STRENGTH AND FUNCTION

Past research has identified two separate methods of measuring muscle asymmetry: isometrically/isotonically and isokinetically.

Isometrically / Isotonically

Knee flexion and extension scores as well as KF-E ratios were initially performed isometrically using a cable tensiometer before isokinetic dynamometers became popular, their results measured in 'pounds of force'. As a result, force for that particular group of muscles being examined could be measured at only one specific joint angle. Subjects would exert maximum effort at a fixed position within the range of motion, and thus static strength could be determined for that particular joint angle (Gleim 1978). Force measurements would be taken at other joint angles throughout the range of motion (ROM) in a similar manner, but the strength of the muscle group throughout its ROM could only be properly calculated by correl-
ating the strength measurement to the precise joint angle at which the measurement was taken (Sutton 1984).

The use of isotonic testing to measure the strength of a muscle group has also been employed in the past. This method of strength testing requires the subject to lift a predetermined weight, usually a certain percentage of the individual's body weight. The test would continue with incremental progression until the subject could no longer perform a complete ROM (Anderson et al. 1991). The primary limitation of this method of testing is that the maximum isotonic strength of a muscle group is only as strong as the force that it can produce at the weakest point in its ROM. Both the isometric and isotonic methods of evaluating muscle strength are similar in that they measured force only at one specific joint angle (Sutton 1984).

Isokinetically

With the development of an electromechanical device which kept limb motion at a constant predetermined velocity, an alternative method of evaluating muscular strength was made available in mid 1960's: isokinetics. Since its conception, isokinetic measurement has proved to be a superior alternative to previous methods of muscle assessment (Moffroid et al. 1969). By applying accommodating resistance to match the strength output of a particular muscle group being tested, the isokinetic system can objectively evaluate and record the magnitude and pattern of torque generated by a muscle group
across a specific joint (Gleim 1978). In so doing, it also allows an accurate and complete determination of muscle function between the ipsilateral and contralateral extremities and the agonist and antagonist muscle groups within the same extremity (Grace et al. 1984). A second benefit of isokinetic measurement is that it allows the velocity of contraction (angular velocity of the joint being measured) to be predetermined, thus evaluating muscle function at different angular velocities (Sutton 1984).

The early years of isokinetic testing made use of the CYBEX and then the CYBEX II isokinetic dynamometers. These machines are capable of measuring peak torque and the angle at which it occurs during the ROM, torque produced at specific angles, total work performed during a contraction, the average power of a contraction, and torque acceleration energy. All measurements can be examined at angular velocities ranging from 0 to 300 deg/sec\(^{-1}\) (Burdett & VanSwearingen 1987). Both, however, are capable of only evaluating isokinetic muscular contractions concentrically.

During the past decade there has been further advancement in the ability to perform functional muscle testing. Isokinetic machines which are capable of evaluating a muscle eccentrically in addition to concentric examination have been developed. The kinetic communicator (Kin-Com), one such instrument, is a hydraulically driven, microcomputer-controlled device designed to measure torque and work during eccentric and concentric isokinetic loading. The device's controlled modes of exercise
include isokinetic, isotonic, and passive joint movement. When a subject performs a movement on the Kin-Com, the dynamometer provides resistance via a rotating transducer arm. The Kin-Com and its on-line microsystem computer are capable of recording concentric and eccentric torque and work at velocities of movement from 0 to 210 deg/sec$^{-1}$ (Kin-Com, Med-Ex Diagnostics of Canada, Inc., 51 Leeder Ave., Coquitlam, B.C., V3K 3V5).

**ANALYSIS OF THE RUNNING MOTION**

As mentioned earlier, hamstring muscle strain has been found to be a common injury occurring to sprinters. Before we can associate any cause of such injury to the frequency, we must first discuss the running motion.

In reviewing the role of the KF and KE in the running motion, their function is to alternately act as both a prime mover and a stabilizer (Burkett 1976). The primary role of the KF is to contract eccentrically during the latter position of the swing phase, decelerating the lower leg and thigh until the leg swing is halted at a point approximately 30° from terminal extension (Stanton & Purdam 1989, Sutton 1984).

It is during this late swing phase, while the KF are eccentrically contracting, that Sutton (1984) suggests as one of the points during running that hamstring MSI is likely to occur. Stanton & Purdam (1989) quote Wood as reporting peak torque values of 150 Nm at the knee and 250 Nm at the hip during this phase of running. Torques such as these are known to limit how late in recovery that the KF can decelerate the
leg, making them prone to strain (Stanton & Purdam 1989). Ghena et al. (1991) and Klopfer & Greij (1988) have stated that the KF are, on average, weaker than the KE. Because this cocontraction has opposing forces the weaker muscle(s) must 'give'; thus resulting in MSI if sufficient asymmetry between these two groups of muscles exists. A further characteristic of the knee flexors is that, like most biarticular muscles, they have no intrinsic mechanism to localize their contraction to only one joint. It is therefore possible for them to exceed their capacity to stretch; the result being MSI.

Other studies have also reported the consequence(s) of such an asymmetry existing between the KF and KE (Arge 1985, Sanderson et al 1984, Sutton 1984). Arge (1985) stated that if the strength of the KF is low in comparison to the KE, the force of contraction may be insufficient to counteract the force of knee extension in the swing phase of gait or to provide adequate hip extension in the stance phase. This would result in an overstretch injury or MSI to the hamstring unit. Burkett (1970) suggested that asymmetry between these two groups of muscles, the KE and KF, was a causative factor in hamstring MSI. He also stated, however, that not everyone who possesses a muscle asymmetry will experience a hamstring MSI.

Unfortunately, one of the limitations when trying to relate the results of isokinetic testing to actual movement is that one assumes that muscle contracts at the same velocity as the limb, a second being that isokinetic dynamometers are not yet capable of measuring torque at those angular velocities
which occur during athletic activity. Klopfer & Greij (1988) quote others as reporting that various functional and sporting activities have angular velocities estimated to range from 700-2000 deg/sec\(^{-1}\): sprinting having angular velocities of approximately 800-1000 deg/sec\(^{-1}\) while walking has been reported to occur at 233 deg/sec\(^{-1}\) (Stafford & Granna 1984).

**TORQUE PRODUCTION AND MUSCLE FIBRE COMPOSITION**

In examining torque produced by the knee flexors and extensors during isokinetic testing many studies have also examined the composition of muscle fibre type in their subjects to see if relationships between these two variables (torque and muscle fibre type) exist. This research has shown that athletes such as weight lifters, sprinters, and jumpers; those who perform fast contractions with high tensions, have a greater percentage of fast twitch, Type II/non-oxidative as compared to slow twitch, Type I/oxidative muscle fibres in the same leg muscle (Costill et al. 1976, Melichna et al. 1989, Thorstensson et al. 1976b).

Thorstensson et al. (1976b) in examining active males found a correlation of \(r = 0.50\) between muscle performance as measured by isokinetic concentric contractions at five different angular velocities and Type II muscle fibre. They also found that motor units demonstrating higher tension outputs and shorter contraction times were shown to contain muscle fibre that could be classified as Type II with their histochemical techniques. They concluded that a high percentage of Type II
muscle fibre is one prerequisite for performing fast contractions with similar tension outputs.

In 1977, Thorstensson and colleagues reported in their review of the literature that endurance event athletes have a predominance of Type I muscle fibre and that \( \text{VO}_2 \text{ max} \) has been shown to be positively correlated with the percentage of Type I fibre. They also mentioned that with endurance training the aerobic potential and the relative area of Type I fibres have been reported to increase, predominantly recruited during contractions of low tension outputs. Type II fibres, however, have a metabolic profile that favors anaerobic energy production and appear to only be recruited when high tension and/or velocity are required. Examining sprinters, jumpers, downhill skiers, race walkers, orienteers, and a group of sedentary men, they found that:

1) skeletal muscle of endurance trained athletes possessed a predominance of Type I fibres
2) peak torque per Kg of body weight of endurance athletes were similar to those of sedentary men
3) a higher percentage of Type II fibres in sprinters/jumpers (X=61%) as compared to sedentary (X=56%) and endurance athletes (X\_range= 33-41%).

They concluded that the percent distribution of muscle fibre type is genetically determined as shown by Gollnick et al. (1973) and Thorstensson et al. (1976a) and that Type II
fibres are of significance for high force production during high speeds of movement. Thus, one would expect that among elite athletes in high power events such as sprinting and jumping, "natural selection" would have left only those with a high proportion of Type II fibres capable of competing at high skill levels.

Thorstensson et al. (1976a) performed an eight week training study which resulted in a significant increase in isometric dynamic strength. By comparing pre-post muscle biopsies of the vastus lateralis, they found that the percent distribution of Type I and Type II muscle fibres were not altered which was in accordance with other training studies performed on animals (Edgerton 1969) and in humans (Gollnick et al. 1973). It was noticed however, that the relative volume of fibre types in muscle was altered by a change in the Type I-Type II area ratios which increased with this strength training protocol.

Such a discovery indicates that selected hypertrophy of Type II fibres can occur with training. Thus although the number of fibres does not significantly change, the size of those fibres already present increases in response to training stimuli. They concluded that the results support the idea that fibre distribution is governed largely by genetic factors.

Costill et al. (1976) also support this line of thought. In their discussion they described an earlier study performed by Gollnick et al. (1973) which reported that fibre distribution remained unchanged in adult males following a five month training program which involved the pedalling of a bicycle
ergometer for one hour/day, four times/week at an intensity of 75-90% of their maximal aerobic capacity. However the oxidative capacities of both fibre types increased. Costill et al. suggested that contractile characteristics are developed early in life through genetics and only the metabolic qualities of muscle fibres adapt to exercise.

Melichna et al. (1989) also reported a positive relationship between VO₂ max, the percentage of Type I fibres, and the activities of mitochondrial enzymes. Other tests have shown a relationship with Type II muscle fibres and performance activities that include vertical jumping ability and quadricep strength (Vandewalle et al. 1987). The Vandewalle et al. study showed that those individuals who participated in sprint and power activities performed best in vertical jumping when compared to endurance and recreational athletes.

KNEE FLEXION-EXTENSION ASSESSMENT

The concept that athletes, who participate in sports which are deemed to be of high risk, achieving and maintaining a desirable KF-E ratio to prevent possible hamstring MSI has been debated in the literature for the past two decades (Arvidsson et al. 1981, Burkett 1970, Gilliam et al. 1979, Grace et al. 1984, Heiser et al. 1984, Holmes & Alderink 1984, Oberg et al. 1986, Sanderson et al. 1984, Scudder 1980, Wyatt & Edwards 1981). It was Klein & Allman in 1969 who first reported a concentric KF-E ratio of 0.60 or 60% at a testing velocity of 60 deg/sec⁻¹. Coplin in 1971, as reported by several authors,
was the first to recommend that a ratio of 60% exist between the knee extensors and flexors to prevent possible MSI involving the hamstrings suggesting that such a ratio would minimize the amount of stress placed on the knee. Unfortunately it was not mentioned as to how these data were collected. The concentric KF-E ratio has been reported to vary from 39 to 85% (Cooper & Fair 1978, Ghena et al. 1991, Gilliam et al. 1979, Grace et al. 1984, Heiser et al. 1984, Holmes & Alderink 1984, Moffroid et al. 1969, Oberg et al. 1986, Sanderson et al. 1984, Smith et al. 1981, Watkins & Harris 1983).

Sanderson and colleagues (1984) and Scudder (1980) were unable to confirm similar results as those studies mentioned previously. Scudder found and reported a concentric ratio of 62% even when increasing angular velocities were used with nonathletic subjects. Sanderson et al. reported concentric ratios averaging around 44% using 60 and 180 deg/sec\(^{-1}\) as angular velocities in 18-25 year old male and female non-athletic subjects.

It is Sanderson et al. who suggested that the difference found between their work and that performed previously is that while the others did not take in to account the weight of the lower leg, for the effect(s) of gravity, their study did. They also found that when the ratios that were measured during their study were left uncorrected for gravity the torque readings obtained resembled those of previous studies. That is, increasing concentric KF-E ratios with increasing velocities.
When a gravitational correction factor was calculated little
difference existed between torques at the different speeds.

In a more recent study Ghena et al. (1991) examined the
torque characteristics of the knee extensors and flexors during
concentric and eccentric loading in 100 male university varsity
athletes (18-25 yrs). Of these subjects, 60 were involved in
sprint-type activities. Measuring concentrically at 60, 120,
300, and 450 deg/sec\(^{-1}\) and eccentrically at 60 and 120 deg/
sec\(^{-1}\) their results indicated:

1) concentric KF and KE torque decreased with
increasing angular velocity, the KF decreasing at
a slower rate while eccentric torque increased

2) concentric KF-E ratios increased as angular
velocity increased while eccentric ratios
remained unchanged

3) eccentric ratios were greater than concentric
ones at the same velocities
FAULTS WITH PREVIOUS RELATED RESEARCH

The problem with previous research is that several procedural and theoretical errors have been revealed as this area expands and testing equipment is improve. These include:

1) exclusive measurement of concentric contractions
2) hip angle and subject position during testing
3) lack of gravity correction
4) time to reach pre-set angular velocity
5) inclusion of fat mass when examining torque per kilogram of body weight

Exclusive measurement of concentric contractions

To date, the majority of experiments have examined only the concentric capabilities of the KE, KE, and their ratios; trying to relate these measures to the frequency and incidence of hamstring MSI. Although isokinetic dynamometers which have the ability to measure eccentric muscular contraction such as the Kin-Com have existed for the past half decade, research has still been performed concentrically when examining F-E ratios of the knee. Such isolated research does not aid in the understanding of eccentric isokinetic characteristics of the knee flexors and extensors which previously has been stated as an area of possible weakness predisposing hamstring MSI, especially in sprinters. Kramer & MacDermid (1989) have examined the eccentric characteristics of the knee extensors in previously uninjured young females, Ghena et al. (1991) have measured
torque produced both concentrically and eccentrically of the knee flexors and extensors in male university athletes, and Klopfer & Greij (1988) in previously uninjured untrained males and females, but such investigation is rare.

**Hip angle and subject positioning during testing**

Previous studies have examined their subjects in a supine only position for both KF and KE torque measurements. To make examination of subjects as sport specific as possible then positioning during data collection must allow the examined muscle(s) to perform as they would during athletic competition.

Worrell et al. (1990) examined isokinetic torque produced by the KF in both supine and prone test positions. They found average torque to be greater in the prone testing position than when trials were performed supine and that eccentric torque was greater than concentric torque in the prone trials. They concluded that the prone position allows maximal force development of the KF while maintaining muscle length-tension relationships similar to what occurs during running. They also stated that such a testing position should be used when evaluating KF torque for activity. It was also mentioned that during sprinting the KF are contracting concentrically and eccentrically at both the knee and hip joints and it appears that this situation can closely be simulated in prone testing.

Also with the area of subject positioning is the degree of hip flexion which is maintained during data collection. Worrell, Perrin & Denegar (1989) reported that close examin-
ation of KF and KE role during athletic participation indicates its strength is more appropriately assessed from a supine position of $10^\circ$ of hip flexion. They quote Mann (1982) as saying that the knee flexor position during athletic participation is best assessed with hip flexion of $0-10^\circ$.

**Lack of gravity correction**

Correcting for gravity is another important oversight by many previous researchers. Knowing that during knee extension in a supine test position not only must force be exerted to propel the transducer arm, but is also used in the raising and supporting of the lower leg throughout the entire range of motion one must correct for this action. If not corrected for then the torque recorded is not a valid measure. The same can also be said during the knee flexion phase. A correction factor must be calculated into the value obtained during this part of the test because the weight of the lower leg in extension is drawn to the ground naturally by gravity. This assistance in the propulsion of the lower leg in knee flexion enhances those torque measurements obtained for the KF and hinders those results of the KE. With prone testing of the KF then gravity problems are the same as in supine KE testing.

Such correction factors have been reported by Hart et al. (1984) and Sanderson et al. (1984), both citing methods used by Winter et al. (1981). However, Nelson & Duncan (1983) have suggested a correctional factor for flexion and extension at the knee which is less costly and has the same reliability as
those suggested by Winter. Newer isokinetic dynamometers such as the Kin-Com have built into their software gravity correction equations, thus allowing instantaneous corrections to be computed.

**Time to reach pre-set angular velocity**

Isokinetic assessment of KF-E torque has, in the past, not considered the influence of acceleration in the collected data. Kannus (1991) reported that previous isokinetic evaluation of peak torque is affected by the time it takes the pre-set angular velocity to be reached thus causing a false change in the angle at which peak torque occurs. The limb to be tested must first achieve the velocity that has been predetermined before true results can be measured. The greater the angular velocity of the test, the longer it takes for the limb to attain terminal velocity (Kannus 1991, Jensen et al. 1991).

Kannus (1991) stated that with isokinetic testing people who possess high levels of strength and power characteristics, such as elite athletes, may be able to work effectively at extreme knee angles. He further stated that they are better able to achieve a maximal effort much quicker after beginning movement and are capable of maintaining this high level of effort until the end of the ROM thus changing the shape of the measured torque curve. He suggested that this ability is due to an athlete's superior reaction time and neural control of the contracting muscles as compared to nonathletic individuals or people with knee joint injury. Piette et al. (1986) found
that during concentric knee extensor contractions torque was significantly increased during the first $15^\circ$ at $180\ \text{deg/sec}^{-1}$ and the first $5^\circ$ at $30\ \text{deg/sec}^{-1}$ when 0, 50, and 100% maximal voluntary isometric contractions (MVIC's) were used as pre-load forces.

In their review of the literature Jensen et al. (1991) reported that one of the features of the Kin-Com is static pre-loading which requires the subject to first apply an operator-selected force to the transducer arm before motion is allowed. Referring to Gransberg & Knuttson (1983), they suggested that static pre-loading could be used as a method of allowing a more accurate measurement of maximal dynamic muscle performance at the beginning of motion. Piette et al. (1986) examined different pre-loading levels at two speeds: 30 and $180\ \text{deg/sec}^{-1}$. It was Jensen et al. (1991) who stated that such an increase in the torque produced during the early phase of the testing range as a result of pre-loading will affect the whole-curve analysis by increasing the area under the torque curve.

To further investigate the effects of pre-loading, Jensen et al. (1991) examined concentric and eccentric KE performance using two static pre-load levels. Using a test ROM from $100-30^\circ$ of knee flexion and pre-load force of 50N and 75% of MVIC, they found when the 75% MVIC pre-load was used quicker tension development and greater torque was produced for the first $15^\circ$ concentrically and for the first $20^\circ$ eccentrically than what was measured using the 50N pre-load force. Once predetermined angular velocity was attained no significant differences
between the two pre-load levels were found to exist. They also reported that the initial higher level of tension development allows the muscle to quickly work closer to its maximal level of fibre recruitment and thus an increase in the average torque and concluded that by using a percentage of each subject's MVIC as a pre-load force, more accurate testing can take place and a more gradual rise to peak torque with high pre-load levels can occur.

**Inclusion of fat mass when torque corrected for body weight**

When previous studies examined the influence of body weight per kilogram on the amount of torque that was able to be produced by the KF and KE they did not account for the amount of adipose tissue, bone, and skin adding to the weight of each subject. A more appropriate method would be to measure the mass of skeletal muscle of each individual and relate this lean body mass to the amount of torque that could be produced. Muscle, not adipose is responsible for producing forces which allow motion and therefore, should be measured so that such investigation can be performed.

A noninvasive method of calculating muscle mass was developed by Martin et al. (1990). They suggested that a method of measuring skeletal muscle would be useful when examining elite-level athletes since athletes of different sports may vary between muscle mass and fat mass.

In the examination of twelve male cadavers (aged 50-94), they performed the following anthropometric measurements:
skinfold thickness at triceps, subscapular, biceps, anterior thigh, and medial calf and circumference measurements taken on the forearm, arm, thigh, and medial calf. Limb girths were then corrected for skinfold thickness using the circular model of the limb cross-section and limb muscle girths estimated. They then dissected and weighed all skeletal muscle, free of skin, adipose tissue, bone, or organs finding simple girth correlation coefficients of $r = 0.824$-$0.942$. When corrected for the skinfold measurement these increased to $r = 0.896$-$0.990$. They determined that from these results that the two best predictors of muscle mass were forearm circumference ($r^2 = 0.93$) and mid-thigh circumference ($r^2 = 0.89$) which were increased when skinfold-corrected circumferences were used.

They decided that in order to reduce sampling error a third variable should enter their prediction equation, corrected calf girth and thus developed the following equation:

$$MM = STAT (0.0553 CTG^2 + 0.0987 FG^2 + 0.0331 CCG^2) - 2445$$

where MM is the total skeletal muscle mass (g), STAT is stature (cm), CTG is thigh circumference corrected for the anterior thigh skinfold thickness (cm), FG is the uncorrected forearm circumference, and CCG is calf circumference corrected for the medial calf skinfold thickness (cm).
Chapter 3
PROCEDURES

METHODOLOGY
A total of sixty males aged 18-35, having no previous history of lower extremity muscle or joint injury, volunteered as subjects. After being informed of the risks associated with each test procedure and their consent given, subjects were evenly separated into three groups dependant upon their physiological test results.

TESTING PROCEDURES
All physiological measures were performed at the Buchanan Exercise Science Laboratory located at the Aquatic Centre, UBC while torque measurements were performed on the Kin-Com isokinetic dynamometer (Kin-Com, Med-Ex Diagonstics of Canada, Inc., 51 Leeder Ave., Coquitlam, B.C., V3K 3V5) located at the school of Rehabilitation Medicine, Pathokinesiology Laboratory at the Acute Care Hospital, UBC.

The initial visit included the recording of each individual's height, weight, and anthropometric measurements as described by Martin et al. (1990). Once this was complete subjects were allowed to perform a self designed warm-up until they were ready to proceed.

The vertical jump test consisted of each subject performing three standing vertical jumps as described by Baumgartner & Jackson (1987). The VO₂ max test required each subject to
run at an initial velocity of 8.05 km/hr with 0.805 km/hr increases in velocity every minute thereafter as described by Parkhouse et al. (1985). If a subject reached the sixteen minute mark and was able to continue then the next workload increment consisted of an increase in the grade of the treadmill of two percent and would increase by two percent every minute thereafter until exhaustion. Metabolic gas analysis was data analyzed using the Hewlett Packard model 3052-A data acquisition system. For all subjects the vertical jump test preceded VO₂ max assessment.

A second visit was required by those individuals who met the grouping criteria and consisted of an isokinetic evaluation of the dominant limb's knee flexors and extensors. Isokinetic evaluation included the measurement of average torque of the dominant limb knee flexors and extensors during five maximum continuous concentric and eccentric contractions from 85-15° at angular velocities of 90, 135, and 180 deg/sec⁻¹. After performing a self designed warm-up the dominant limb of each subject was determined by asking which leg they would prefer to kick a soccer ball with. Subjects were initially placed in a supine position for the examination of the knee extensors and then in a prone position for the knee flexors such that a hip angle of 10° was maintained during data collection for both positions. The next step was to locate the lateral femoral epicondyle which was used to visually align the axis of the Kin-Com's transducer arm to the anatomical axis of
the knee as described by Kramer & MacDermid (1989). The length of each subject's fibula on the dominant leg was then measured. The leg pad on the force transducer, attached at the distal end, was positioned such that it corresponded to 75% of the fibular length and then a stabilization strap, to limit excessive movement during trials, was positioned across the pelvis.

The test ROM was then entered into the Kin-Com's computer as was the angular velocity. Next, a familiarization period was allowed which consisted of five trails: three submaximal followed by two maximal continuous concentric and eccentric contractions. This was performed prior to each trial for each velocity and muscle group. Prior to familiarization however, each individual's maximal voluntary isometric contraction (MVIC) was measured using the Kin-Com's isometric feature. The pre-load force used before the transducer arm moved during data collection corresponded to the 75% MVIC value for each subject as described by Jenson et al. (1991). If subjects were confident with their performance during the practice attempts they were allowed a two minute rest. Those subjects who did not feel competent were allowed further practice trials until confident and were then given a two minute break.

Gravity was corrected for prior to the commencement of the trials. This correction involved the manipulation of the transducer arm into a horizontal position which was checked using a level. This angle was entered into the Kin-Com's computer and used for reference. Then the transducer arm was
positioned so that the subject's limb was 10° from full knee extension and it was at this point that the force applied by the leg to the transducer arm due to gravity was measured and recorded. This was performed prior to the evaluation of each muscle group.

The order in which the trials occurred was randomized with the knee extensors always being the first group tested for their three speeds and then the knee flexors. This was done to minimize any affect that learning may have on subsequent trials. In an attempt to limit the effect of positive and negative acceleration during the isokinetic trials only those torques produced from 75-30° of knee flexion were used in the data analysis as shown by Jensen et al. (1991).

Each subject was instructed when to begin and when to stop the exercise and was told to give a maximal effort throughout the entire test ROM. Verbal encouragement was not given by the tester during data collection and subjects were not permitted to view the display monitor or to grasp handles to further support themselves. Upon the completion of each trial a further two minute rest interval was allowed before the next trial began.
DESIGN AND CHARACTERISTICS OF THE DATA

One-way randomized groups analyses of variance were performed when examining the differences between each of the three groups of subjects for physical characteristics: one analysis for each of height, weight, and age), physiological characteristics: one analysis for each of VO₂ max and vertical jump (VJ), and anthropometric characteristics: one analysis for each of skeletal muscle mass (SMM) and percent body weight accounted for by skeletal muscle.

Secondly, two analyses of variance (ANOVA's) one for each of concentric and eccentric contractions: 3 (athletic group) X 3 (angular velocities) X 2 (muscle groups) factorial experiments with repeated measures on the last two factors, were performed. These three groups were examined at three different angular velocities: 90, 135, and 180 deg/sec⁻¹ for both the knee extensors and flexors. The three subject groups, three angular velocities, and two muscle groups were the three independent variables respectively. The dependent variables for these analyses were the torque measured during the two different types of contractions which were examined as measured from 75-30° of knee flexion. Measured torque was corrected for skeletal muscle mass by dividing the absolute torque by the percent body weight that was composed of skeletal muscle mass which was present in each subject (Nm/kg corrected).

A third factorial analysis was performed to examine if differences existed between eccentric and concentric KF-E ratios. A 3 (athletic group) X 3 (angular velocities) X 2
(ratio contraction types) analysis of variance with repeated measures on the last two factors was performed; once again the three levels of the first independent variable were power athletes, endurance athletes, and sedentary subjects. The second independent variable included the three testing velocities which the contractions occurred at: 90, 135, and 180 deg/sec\(^{-1}\) and the third independent variable was concentric KF-E and eccentric KF-E ratios. The dependent variable for this analysis was the average torque (Nm/kg corrected) ratio calculated by dividing the knee flexor torque by the knee extensor torque as measured from 75-30° of knee flexion.

Lastly, Pearson Product Moment Correlation Coefficients were calculated to examine the relationships between torque and vertical jumping ability, \(\text{VO}_2\) \text{max}, and skeletal muscle mass as measured according to Martin et al. (1990).

Statistical significance was accepted at the p< 0.05 level with statistical calculations performed using the BMDP 1V, 2V, and BMDP 8D statistical packages (BMDP-Biomedical Computer Statistical Software 1981) and Scheffé's post hoc pairwise analyses were performed for all significant F ratios.
Chapter 4

RESULTS AND DISCUSSION

RESULTS

A total of 72 individuals were physiologically evaluated for maximal oxygen consumption (\(\dot{V}O_2\) max) and vertical jumping ability. Of these, 60 participated as subjects in this study: 20 per group. Of the three groups examined, the power athlete group (PA) had the most varied composition with ten subjects training for track sprint events (50 – 200m), five for jumping events (long, triple, and/or high), two were varsity basketball players, and three participated in varsity hockey. The moderately active group (MA) was comprised of varsity golfers (N= 12) and people who were participating in personal fitness activities (N= 8). Finally, the aerobically trained runner group (ATR) consisted of eighteen individuals who were training for competition distances of greater than 800m (range 800m – marathon) and two subjects who were training for triathlons.

Physical Characteristics

The means and standard deviations for each of the three groups of subjects physical characteristics can be located in Table 4.1. In this study there were no significant differences (p> 0.05) in height between the three groups even though, on average, PA were taller than either the ATR or MA groups as seen in Figure 4.1. Although the PA and MA groups were significantly heavier (p< 0.001) than the ATR group, the ATR group
was significantly older (p< 0.001) than either of the other two groups of subjects. For both height and weight there were no significant differences between the MA and PA groups (p> 0.05).

**TABLE 4.1**

Physical Characteristics

<table>
<thead>
<tr>
<th></th>
<th>PA</th>
<th>sd</th>
<th>ATR</th>
<th>sd</th>
<th>MA</th>
<th>sd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height(cm)</td>
<td>182.5</td>
<td>4.90</td>
<td>178.6</td>
<td>7.19</td>
<td>179.8</td>
<td>7.56</td>
</tr>
<tr>
<td>Weight(kg)</td>
<td>81.6</td>
<td>6.77</td>
<td>70.5</td>
<td>4.48</td>
<td>80.3</td>
<td>8.05</td>
</tr>
<tr>
<td>Age(years)</td>
<td>22.2</td>
<td>2.75</td>
<td>27.8</td>
<td>4.07</td>
<td>22.7</td>
<td>3.33</td>
</tr>
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</table>
FIGURE 4.1
Group Physical Characteristics

<table>
<thead>
<tr>
<th></th>
<th>HEIGHT (cm)</th>
<th>WEIGHT (kg)</th>
<th>AGE (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>182.5</td>
<td>81.6</td>
<td>22.2</td>
</tr>
<tr>
<td>ATR</td>
<td>178.9</td>
<td>70.5</td>
<td>27.8</td>
</tr>
<tr>
<td>MA</td>
<td>179.8</td>
<td>80.3</td>
<td>22.7</td>
</tr>
</tbody>
</table>
Physiological Characteristics

The three groups were classified using two different physiological evaluations: the vertical jump and the VO$_2$ max tests. As seen in Table 4.2 the ATR group had a significantly greater mean VO$_2$ max score relative to body weight (p< 0.001) than either the PA or MA groups who did not differ (p> 0.05). However, when vertical jumping ability was examined the ATR and MA groups did not significantly differ (p> 0.05) while the PA group significantly out jumped (p <0.001) either of the other two groups of subjects. Graphical representation for this analysis can be located in Figure 4.2.

<table>
<thead>
<tr>
<th>TABLE 4.2</th>
<th>Physiological Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PA</td>
</tr>
<tr>
<td>V.Jump(cm)</td>
<td></td>
</tr>
<tr>
<td>V02max(ml/kg/min)</td>
<td>70.7</td>
</tr>
<tr>
<td></td>
<td>4.26</td>
</tr>
<tr>
<td>V02max(ml/kg/min)</td>
<td>51.1</td>
</tr>
<tr>
<td></td>
<td>2.50</td>
</tr>
</tbody>
</table>
FIGURE 4.2
Group Physiological Characteristics

<table>
<thead>
<tr>
<th></th>
<th>VER.JUMP(cm)</th>
<th>VO2max(ml/kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>70.7</td>
<td>51.1</td>
</tr>
<tr>
<td>ATR</td>
<td>48.9</td>
<td>64.4</td>
</tr>
<tr>
<td>MA</td>
<td>51.6</td>
<td>49.1</td>
</tr>
</tbody>
</table>

Legend:
- PA
- ATR
- MA
Anthropometric Characteristics

The PA group was significantly greater than either the MA (p < 0.01) or ATR (p < 0.001) groups as seen in Table 4.3 and Figure 4.3, while the MA group was significantly greater than the ATR group (p < 0.05) when skeletal muscle mass was calculated. When body weight was corrected for skeletal muscle, derived by dividing skeletal muscle mass by body weight, the PA group were significantly greater than either the MA (p < 0.002) or ATR (p < 0.02) groups. These last two groups were not significantly different from each other. Graphical representation can be located in Figure 4.3.

**TABLE 4.3**

<table>
<thead>
<tr>
<th></th>
<th>PA</th>
<th>ATR</th>
<th>MA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skeletal Muscle Mass (kg)</td>
<td>52.4 5.76</td>
<td>42.6 5.43</td>
<td>47.2 6.67</td>
</tr>
<tr>
<td>% Body Weight Accounted for by Skeletal Muscle</td>
<td>64.2 4.96</td>
<td>60.3 5.61</td>
<td>58.6 4.43</td>
</tr>
</tbody>
</table>
FIGURE 4.3
Anthropometric Characteristics

<table>
<thead>
<tr>
<th></th>
<th>SMM (kg)</th>
<th>% of BW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>52.4</td>
<td>64.2</td>
</tr>
<tr>
<td>ATR</td>
<td>42.6</td>
<td>60.3</td>
</tr>
<tr>
<td>MA</td>
<td>47.2</td>
<td>58.6</td>
</tr>
</tbody>
</table>

SMM = Skeletal Muscle Mass
BW = Body Weight

In the present study torque was measured as a relative term also accounting for body weight: Nm/kg corrected. Body weight was corrected for the weight which was accounted for by adipose, bone, and other nonmuscular tissue. This was done by dividing the absolute torque by the percent body weight accounted for by skeletal muscle as described in the previous analysis of anthropometric characteristics. Therefore, in the following sections, concentric and eccentric torque has been corrected for skeletal muscle mass (Nm/kg corrected).

Corrected Concentric Torque

The means and standard deviations for the concentric knee extensor and flexor torque values produced at the three velocities are presented in Table 4.4 and graphically displayed in Figure 4.4. The athletic group X angular velocity X muscle group (3x3x2) repeated measures ANOVA for corrected concentric
torque revealed significant differences ($F=10.69$, $p<0.001$) between the three subject groups in their ability to produce torque concentrically when averaged over the two muscle groups and three angular velocities ($\bar{x}_{PA}=2.28$, $\bar{x}_{ATR}=1.97$, $\bar{x}_{MA}=2.04$). A Scheffé's post hoc analysis indicated that the PA group could produce significantly greater concentric torque than could the ATR ($p<0.01$) and MA groups ($p<0.05$), while there were no significant differences ($p>0.05$) between the MA and ATR groups.

A significant muscle main effect ($F=1489.08$, $p<0.001$) indicates that the corrected concentric torque produced was significantly greater for the KE than that for the KF when averaged over the three groups of subjects and three angular velocities ($\bar{x}_{KE}=2.72$, $\bar{x}_{KF}=1.47$).

The third and final main effect for this analysis, angular velocity, was also significant ($F=298.18$, $p<0.001$). When averaged over the three subject groups, and two groups of muscle, the concentric torque that could be produced at the three different test velocities were significantly different from each other ($\bar{x}_{90}=2.24$, $\bar{x}_{135}=2.11$, $\bar{x}_{180}=1.94$). Further post hoc analyses were performed which indicated that the concentric torque produced for $\bar{x}_{90}$ was significantly greater than $\bar{x}_{180}$ ($p<0.01$) and $\bar{x}_{135}$ ($p<0.05$), while $\bar{x}_{135}$ was significantly greater than $\bar{x}_{180}$ ($p<0.01$).

Although the athletic group $X$ angular velocity and the athletic group $X$ muscle group $X$ angular velocity interactions were not significant ($p>0.05$) the other two interactions in this analysis were. The significant muscle group $X$ angular
velocity interaction, as displayed in Figure 4.5, \((F = 42.26, p< 0.001)\) indicates that when averaged over the three groups of subjects, concentric torque produced by the KE decreased more rapidly from 90° through 180 deg/sec\(^{-1}\) than did that which was measured for the KF over the same velocities \((\bar{x}_{KE90}= 2.91, \bar{x}_{KE135}= 2.73, \bar{x}_{KE180}= 2.51 / \bar{x}_{KF90}= 1.56, \bar{x}_{KF135}= 1.48, \bar{x}_{KF180}= 1.36)\). Post hoc analysis revealed that the following comparisons were significantly different at \(p < 0.01\): \(\bar{x}_{KE90} > \bar{x}_{KE135}, \bar{x}_{KE90} > \bar{x}_{KE180}, \bar{x}_{KE135} > \bar{x}_{KE180}\), and \(\bar{x}_{KF90} > \bar{x}_{KF180}\), while at \(p< 0.05\) \(\bar{x}_{KF135}\) was significantly greater than \(\bar{x}_{KF180}\).

The significant muscle group X athletic group interaction \((F = 4.26, p< 0.02)\) reveals that concentric torque produced by the KE and KF was significantly different between the three groups of subjects when averaged over the three angular velocities \((\bar{x}_{KE-PA}= 2.85, \bar{x}_{KE-ATR}= 2.58, \bar{x}_{KE-MA}= 2.72 / \bar{x}_{KF-PA}= 1.70, \bar{x}_{KF-ATR}= 1.35, \bar{x}_{KF-MA}= 1.35)\). Further Scheffé's analysis indicated that at \(p< 0.01\) the following relationships were significantly different: \(\bar{x}_{KE-PA} > \bar{x}_{KE-ATR}\), and \(\bar{x}_{KF-PA}\) was significantly greater than either \(\bar{x}_{KF-MA}\) and \(\bar{x}_{KF-ATR}\). This interaction is graphically presented in Figure 4.6.
**TABLE 4.4**
Corrected Concentric Torque

<table>
<thead>
<tr>
<th>Athletic Group &amp; Muscle Group</th>
<th>Ang. Velocity (deg/sec-1)</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA KE</td>
<td>90</td>
<td>3.04</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>2.88</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>2.62</td>
<td>0.26</td>
</tr>
<tr>
<td>KF</td>
<td>90</td>
<td>1.81</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>1.73</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>1.56</td>
<td>0.19</td>
</tr>
<tr>
<td>ATR KE</td>
<td>90</td>
<td>2.76</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>2.59</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>2.40</td>
<td>0.43</td>
</tr>
<tr>
<td>KF</td>
<td>90</td>
<td>1.44</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>1.35</td>
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</tr>
<tr>
<td></td>
<td>180</td>
<td>1.25</td>
<td>0.22</td>
</tr>
<tr>
<td>MA KE</td>
<td>90</td>
<td>2.93</td>
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<tr>
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<td>135</td>
<td>2.73</td>
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<td>180</td>
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</tr>
<tr>
<td>KF</td>
<td>90</td>
<td>1.41</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>1.36</td>
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<tr>
<td></td>
<td>180</td>
<td>1.28</td>
<td>0.21</td>
</tr>
</tbody>
</table>

* significant Athletic Group main effect (F=10.69, p< 0.001)
* significant Muscle Group main effect (F=1489.08, p< 0.001)
* significant Angular Velocity main effect (F=298.18, p < 0.001)
FIGURE 4.4
Corrected Concentric Torque

Concentric Torque (Nm/kg corr. BW)

<table>
<thead>
<tr>
<th>Velocity (deg/sec-1)</th>
<th>KE90</th>
<th>135</th>
<th>180</th>
<th>KF90</th>
<th>135</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>3.04</td>
<td>2.88</td>
<td>2.62</td>
<td>1.81</td>
<td>1.73</td>
<td>1.56</td>
</tr>
<tr>
<td>ATR</td>
<td>2.76</td>
<td>2.59</td>
<td>2.40</td>
<td>1.44</td>
<td>1.35</td>
<td>1.25</td>
</tr>
<tr>
<td>MA</td>
<td>2.93</td>
<td>2.73</td>
<td>2.51</td>
<td>1.41</td>
<td>1.36</td>
<td>1.28</td>
</tr>
</tbody>
</table>

Muscle Group and Velocity (deg/sec-1)

Corrected for %BW due to Skeletal Muscle
FIGURE 4.5
Muscle Group x Angular Velocity Interaction

Concentric Torque (Nm/kg corr. BW)

<table>
<thead>
<tr>
<th></th>
<th>90</th>
<th>135</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>KE</td>
<td>2.91</td>
<td>2.73</td>
<td>2.51</td>
</tr>
<tr>
<td>KF</td>
<td>1.56</td>
<td>1.48</td>
<td>1.36</td>
</tr>
</tbody>
</table>

Velocity (deg/sec-1)

Averaged over the three groups
Concentric Torque (Nm/kg corr.)

Concentric Torque (Nm/kg corr.)

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>KE</th>
<th>KF</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>2.85</td>
<td>1.70</td>
</tr>
<tr>
<td>ATR</td>
<td>2.58</td>
<td>1.35</td>
</tr>
<tr>
<td>MA</td>
<td>2.72</td>
<td>1.35</td>
</tr>
</tbody>
</table>

Averaged over angular velocity
Corrected Eccentric Torque

Means and standard deviations for the 3 (athletic group) X 2 (muscle group) X 3 (angular velocity) repeated measures ANOVA for corrected eccentric torque are presented in Table 4.5 and graphically represented in Figure 4.7. This analysis revealed that significant differences between the three groups of subjects ($\bar{x}_{PA} = 2.61$, $\bar{x}_{ATR} = 2.22$, $\bar{x}_{MA} = 2.29$) in their ability to produce eccentric torque exist when averaged over the two muscle groups and three angular velocities ($F = 12.72$, $p < 0.001$). When Scheffé's post hoc analyses were performed it was found that the PA group could produce greater eccentric torque than could either the ATR or MA groups at the $p < 0.01$ level of significance. However, there were no significant differences ($p > 0.05$) between the MA and ATR groups.

A significant muscle main effect ($F = 2395.85$, $p < 0.001$) indicates that the ability for the KE to produce eccentric torque is significantly greater than that which is produced by the KF when averaged over the three angular velocities and subject groups ($\bar{x}_{KE} = 3.01$, $\bar{x}_{KF} = 1.74$).

The third main effect, angular velocity, was not significant at $p < 0.05$ ($F = 1.50$, $p > 0.20$). This indicates that there were no significant differences in the corrected eccentric torque that could be produced for the three angular velocities when averaged over the three groups of subjects and two groups of muscle ($\bar{x}_{90} = 2.38$, $\bar{x}_{135} = 2.37$, $\bar{x}_{180} = 2.38$).

Only the muscle group X athletic status interaction was significant ($F = 17.01$, $p < 0.001$) indicating that the differ-
ences between the ability of the KE and KF to produce eccentric torque is influenced by the demands of one's activity when averaged over the three angular velocities \((\bar{X}_{KE-PA} = 3.14, \bar{X}_{KE-ATR} = 2.88, \bar{X}_{KE-MA} = 3.00 / \bar{X}_{KF-PA} = 2.08, \bar{X}_{KF-ATR} = 1.56, \bar{X}_{KF-MA} = 1.58)\) as seen in Figure 4.8. Significant post hoc comparisons for this interaction were found to exist between \(\bar{X}_{KE-PA} > \bar{X}_{KE-MA}, \bar{X}_{KF-PA} > \bar{X}_{KF-ATR}\) and \(\bar{X}_{KF-MA}\) at \(p < 0.01\) and \(\bar{X}_{KE-PA} > \bar{X}_{KE-ATR}\) at \(p < 0.05\).

The other interactions for this analysis: the muscle group X angular velocity, athletic group X angular velocity interaction, and the three way interaction for athletic group X muscle group X angular velocity for this analysis were not significant \((p > 0.05)\).


**TABLE 4.5**  
Corrected Eccentric Torque

<table>
<thead>
<tr>
<th>Athletic Group &amp; Muscle Group</th>
<th>Ang. Velocity (deg/sec-1)</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA KE</td>
<td>90</td>
<td>3.13</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>3.14</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>3.14</td>
<td>0.27</td>
</tr>
<tr>
<td>KF KE</td>
<td>90</td>
<td>2.10</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>2.06</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>2.09</td>
<td>0.22</td>
</tr>
<tr>
<td>ATR KE</td>
<td>90</td>
<td>2.88</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>2.88</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>2.88</td>
<td>0.45</td>
</tr>
<tr>
<td>KF KE</td>
<td>90</td>
<td>1.57</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>1.54</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>1.57</td>
<td>0.32</td>
</tr>
<tr>
<td>MA KE</td>
<td>90</td>
<td>3.00</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>2.99</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>3.00</td>
<td>0.15</td>
</tr>
<tr>
<td>KF KE</td>
<td>90</td>
<td>1.58</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>1.58</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>1.59</td>
<td>0.20</td>
</tr>
</tbody>
</table>

* significant Athletic Group main effect *(F=12.72, p< 0.001)*  
* significant Muscle Group main effect *(F=2395.85, p< 0.001)*  
* nonsignificant Angular Velocity main effect *(F=1.50, p> 0.20)*
FIGURE 4.7
Corrected Eccentric Torque

Eccentric Torque (Nm/kg of corr. BW)

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>Velocity (deg/sec-1)</th>
<th>KE90</th>
<th>135</th>
<th>180</th>
<th>KF90</th>
<th>135</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td></td>
<td>3.13</td>
<td>3.14</td>
<td>3.14</td>
<td>2.10</td>
<td>2.06</td>
<td>2.09</td>
</tr>
<tr>
<td>ATR</td>
<td></td>
<td>2.88</td>
<td>2.88</td>
<td>2.88</td>
<td>1.57</td>
<td>1.54</td>
<td>1.57</td>
</tr>
<tr>
<td>MA</td>
<td></td>
<td>3.00</td>
<td>2.99</td>
<td>3.00</td>
<td>1.58</td>
<td>1.58</td>
<td>1.59</td>
</tr>
</tbody>
</table>

Corrected for %BW due to Skeletal Muscle
FIGURE 4.8
Muscle Group x Athletic Group Interaction

Eccentric Torque (Nm/kg corr.)

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>KE</th>
<th>KF</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>3.14</td>
<td>2.08</td>
</tr>
<tr>
<td>ATR</td>
<td>2.88</td>
<td>1.56</td>
</tr>
<tr>
<td>MA</td>
<td>3.00</td>
<td>1.58</td>
</tr>
</tbody>
</table>

Muscle Group

Averaged over angular velocity
Knee F-E Ratios

The means and standard deviations for the 3 (athletic groups) × 3 (angular velocity) × 2 (contraction type) repeated measures ANOVA for calculated concentric and eccentric KF-E ratios can be located in Table 4.6 and is graphically represented in Figure 4.9. This analysis found a significant difference (F = 32.85, p < 0.001) to exist between the three groups of subjects for their combined concentric and eccentric calculated ratios when averaged over the three levels of angular velocity and two levels of contraction types (\(\bar{X}_{PA} = 63.1\), \(\bar{X}_{ATR} = 52.8\), \(\bar{X}_{MA} = 51.2\)). Post hoc analyses revealed that the PA group had combined concentric and eccentric KF-E ratios that were greater than either the ATR or MA groups at the p < 0.01 level of significance while there were no significant differences (p > 0.05) between those ratios calculated for the MA and ATR groups.

When averaged over the three groups of subjects and three angular velocities there were significant differences between concentric ratios and those measured eccentrically (F = 42.74, p < 0.001). For all groups the concentric ratios were lower than eccentric ratios (\(\bar{X}_{CON} = 53.7\), \(\bar{X}_{ECC} = 57.7\)).

There were significant differences between the three angular velocities (F = 4.52, p < 0.02) when averaged over the three groups of subjects and two contraction types (\(\bar{X}_{90} = 55.3\), \(\bar{X}_{135} = 55.5\), \(\bar{X}_{180} = 56.3\)). Further Scheffé's analysis indicated that ratios produced at 180 deg/sec\(^{-1}\) were significantly greater (p < 0.05) than those produced for either 90 or 135
deg/sec\(^{-1}\) while those produced for 90 and 135 deg/sec\(^{-1}\) were not significantly different \((p > 0.05)\).

Significant interactions included a contraction type X athletic group \((F = 4.18, p < 0.03)\) and a contraction type X angular velocity \((F = 4.69, p < 0.02)\) while the athletic group X angular velocity and the athletic group X contraction type X angular velocity interactions were not significant. When averaged over the three angular velocities the differences between concentric and eccentric ratios were different among the three groups of subjects. While the ATR and MA groups produced similar ratios both concentrically and eccentrically, the PA group ratio's were significantly greater eccentrically as compared to their concentric ratios \((\overline{X}_{CON-PA} = 59.9, \overline{X}_{CON-ATR} = 51.5, \overline{X}_{CON-MA} = 49.7 / \overline{X}_{ECC-PA} = 66.7, \overline{X}_{ECC-ATR} = 54.1, \overline{X}_{ECC-MA} = 52.7)\) as displayed in Figure 4.10. Post hoc analysis revealed that \(\overline{X}_{ECC-PA}\) was significantly greater than \(\overline{X}_{ECC-ATR}\) and \(\overline{X}_{ECC-MA}\) at \(p < 0.01\), while \(\overline{X}_{CON-PA}\) was significantly greater than \(\overline{X}_{CON-ATR}\) and \(\overline{X}_{CON-MA}\) at \(p < 0.01\).

The significant contraction type X angular velocity interaction indicates that when averaged over the three subject groups the difference in the ratios that were produced concentrically and eccentrically were significantly different between the three angular velocities. As seen in Figure 4.11, as the speed of contraction increased concentric ratios increased while eccentric ratios remained unchanged \((\overline{X}_{CON90} = 52.7, \overline{X}_{CON135} = 53.6, \overline{X}_{CON180} = 54.7 / \overline{X}_{ECC90} = 57.9, \overline{X}_{ECC135} = 57.3, \overline{X}_{ECC180} = 57.9)\). Pairwise comparison revealed that \(\overline{X}_{CON90}\)
was significantly greater than $\overline{x}_{\text{CON180}}$ while $\overline{x}_{\text{CON135}}$ was significantly greater than $\overline{x}_{\text{CON180}}$ at the $p < 0.01$ level.
### TABLE 4.6
**KF-E Ratios**

<table>
<thead>
<tr>
<th>Athletic Group &amp; Contraction Type</th>
<th>Ang. Velocity (deg/sec-1)</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA CON</td>
<td>90</td>
<td>59.6</td>
<td>5.25</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>60.2</td>
<td>4.51</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>59.8</td>
<td>5.22</td>
</tr>
<tr>
<td>ECC</td>
<td>90</td>
<td>66.7</td>
<td>3.71</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>65.7</td>
<td>4.23</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>66.6</td>
<td>4.28</td>
</tr>
<tr>
<td>ATR CON</td>
<td>90</td>
<td>50.8</td>
<td>7.21</td>
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<td></td>
<td>135</td>
<td>51.1</td>
<td>6.19</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>52.6</td>
<td>9.45</td>
</tr>
<tr>
<td>ECC</td>
<td>90</td>
<td>54.4</td>
<td>7.10</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>53.4</td>
<td>6.53</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>54.4</td>
<td>6.73</td>
</tr>
<tr>
<td>MA CON</td>
<td>90</td>
<td>47.8</td>
<td>6.14</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>49.5</td>
<td>5.82</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>51.7</td>
<td>6.07</td>
</tr>
<tr>
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<td>90</td>
<td>52.6</td>
<td>5.38</td>
</tr>
<tr>
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<td>135</td>
<td>52.8</td>
<td>5.24</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>52.7</td>
<td>5.85</td>
</tr>
</tbody>
</table>

* significant Athletic Group main effect (F=32.85, P< 0.001)
* Significant Contraction Type main effect (F=42.74, P< 0.001)
* significant Angular Velocity main effect (F=4.52, P< 0.02)
FIGURE 4.9
KF-E Ratios

Ratio % (KF/KE x 100%)

Contraction and Velocity (deg/sec-1)

<table>
<thead>
<tr>
<th></th>
<th>PA</th>
<th>ATR</th>
<th>MA</th>
</tr>
</thead>
<tbody>
<tr>
<td>C90</td>
<td>59.6</td>
<td>50.8</td>
<td>47.8</td>
</tr>
<tr>
<td>135</td>
<td>60.2</td>
<td>51.1</td>
<td>49.5</td>
</tr>
<tr>
<td>180</td>
<td>59.8</td>
<td>52.6</td>
<td>51.7</td>
</tr>
<tr>
<td>E90</td>
<td>66.7</td>
<td>54.4</td>
<td>52.6</td>
</tr>
<tr>
<td>135</td>
<td>65.7</td>
<td>53.4</td>
<td>52.8</td>
</tr>
<tr>
<td>180</td>
<td>66.6</td>
<td>54.4</td>
<td>52.7</td>
</tr>
</tbody>
</table>
FIGURE 4.10
Contraction Type x Athletic Group Interaction

Ratio % (KF/KE x 100%)

ECCENTRIC    CONCENTRIC

<table>
<thead>
<tr>
<th>Contraction Type</th>
<th>ECCENTRIC</th>
<th>CONCENTRIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>66.7</td>
<td>59.9</td>
</tr>
<tr>
<td>ATR</td>
<td>54.1</td>
<td>51.5</td>
</tr>
<tr>
<td>MA</td>
<td>52.7</td>
<td>49.7</td>
</tr>
</tbody>
</table>

Contraction Type

- PA
- ATR
- MA

Averaged over velocity
FIGURE 4.11
Contraction Type x Angular Velocity Interaction

ECCENTRIC

<table>
<thead>
<tr>
<th>Velocity (deg/sec)</th>
<th>Ratio % (KF/KE x 100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>57.9</td>
</tr>
<tr>
<td>135</td>
<td>57.3</td>
</tr>
<tr>
<td>180</td>
<td>57.9</td>
</tr>
</tbody>
</table>

CONCENTRIC

<table>
<thead>
<tr>
<th>Velocity (deg/sec)</th>
<th>Ratio % (KF/KE x 100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>52.7</td>
</tr>
<tr>
<td>135</td>
<td>53.6</td>
</tr>
<tr>
<td>180</td>
<td>54.7</td>
</tr>
</tbody>
</table>

Averaged over the three groups
Correlations

The correlation matrix can be seen in Table 4.7. As hypothesized, the correlations between VO₂ max and the ability to produce torque; both concentric and eccentric, for the knee flexors and extensors averaged over the three groups of subjects, are negatively correlated and nonsignificant: \( r = -0.24 \) for CKE, \(-0.28\) for CKF, \(-0.27\) for EKE, and \(-0.24\) for EKF; \( r \text{critical at } \alpha(0.01, \text{df} = 57) = 0.33 \) for all correlations.

Also nonsignificant were the correlations between SMM (kg) and torque as produced concentrically and eccentrically by the KE and KF when averaged over the three groups: \( r = 0.02 \) for CKE, \(0.29\) for CKF, \(0.02\) for EKE, and \(0.31\) for EKF; \( r \text{critical at } \alpha(0.01, \text{df} = 57) = 0.33 \) for all correlations.

The significant, moderately positive correlations between the ability to produce torque and vertical jumping ability of \( r = 0.44 \) for CKE, \(0.68\) for CKF, \(0.48\) for EKE, and \(0.74\) for EKF suggests that the greater one's ability to vertically jump using the protocol as described previously the greater torque a person will be able to generate using the methods as employed for this study (\( r \text{critical at } \alpha(0.01, \text{df} = 57) = 0.33 \)).
## TABLE 4.7
Correlation Matrix

<table>
<thead>
<tr>
<th></th>
<th>VER.JUMP</th>
<th>VO2 MAX</th>
<th>SMM</th>
<th>CKE</th>
<th>CKF</th>
<th>EKE</th>
<th>EKF</th>
</tr>
</thead>
<tbody>
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<td>VER.JUMP</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO2 MAX</td>
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<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMM</td>
<td>0.49</td>
<td>-0.41</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CKE</td>
<td>0.44</td>
<td>-0.24</td>
<td>0.02</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CKF</td>
<td>0.68</td>
<td>-0.28</td>
<td>0.29</td>
<td>0.57</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EKE</td>
<td>0.48</td>
<td>-0.27</td>
<td>0.02</td>
<td>0.86</td>
<td>0.56</td>
<td>1.00</td>
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</tr>
<tr>
<td>EKF</td>
<td>0.74</td>
<td>-0.24</td>
<td>0.31</td>
<td>0.69</td>
<td>0.88</td>
<td>0.71</td>
<td>1.00</td>
</tr>
</tbody>
</table>
DISCUSSION

This study was unique in that torque was corrected not only for gravity before KF-K ratios were calculated, but was corrected for the percent of an individual's body weight which could be accounted for by skeletal muscle mass. As such, the results obtained are different than what earlier research has reported. While previous studies have used a multitude of test protocols, only recently has work been performed which has analyzed the KE and KF ability to produce isokinetic eccentric torque. As well, for this study, average torque was measured instead of the more often used measures of peak or angle specific torques. Kramer & MacDermid (1989) stated that peak torque can occur at different joint angles and is thus affected by angular velocity and muscle action. Average torque, however, allows a more appropriate assessment if the ability of a muscle to produce force is of interest. This study was performed with a two-fold purpose. The first was to examine both concentric and eccentric torques as produced by the flexors and extensors of the knee in a manner which best simulated those muscle length-tension relationships found during running. The second purpose of this study was to examine the differences in ability to produce torque between power athletes, aerobically trained runners, and moderately active persons in an attempt to determine if there are differences between them.
**Group Differences**

Mentioned previously, subjects for this study were grouped after vertical jumping ability and maximal oxygen consumption were measured. As anticipated, the PA group significantly outperformed the MA and ATR groups by 44.6% and 37.0% respectively when vertical jumping ability was assessed while these last two groups did not significantly differ. These results correspond to what previous studies have reported for PA and ATR vertical jumping differences (Melichna et al. 1989, Vandewalle et al. 1987).

When maximal aerobic capacity was measured the ATR group significantly outperformed the PA and MA groups. These last two did not significantly differ. For this study, the mean score for the ATR group was 64.4 ml/kg/min while Melichna et al. found $\text{VO}_2\text{max}$ for their endurance subjects to be 68 and Crielaard & Pirnay (1981) reported 77.6 ml/kg/min for their subjects. $\text{VO}_2\text{max}$ recorded for our PA group was also lower than what was reported by Crielaard & Pirnay and Melichna et al. for their sprint/power athletes. They recorded values of 60 and 59 ml/kg/min respectively while the PA for this study had a mean of 51.1 ml/kg/min and the MA subjects had a mean of 49.1.

Anthropometric measurement of skeletal muscle mass revealed higher adipose tissue-free mass for the subjects of this study than what was reported by Martin et al. (1990). Martin et al. (1990) reported cadaveric dissected muscle masses
which ranged from 27.4% to 49.1% of the body mass in older persons (> 50 years) and in studies which corrected for adipose tissue these results ranged from 36.6% to 59.4%. They hypothesized that athletes who participated in activities which required strength would have results, as calculated by their prediction equation, which were greater than what they reported.

For this study, PA were calculated to have a mean skeletal muscle mass of 52.4 kg while the means for the ATR and MA groups were 42.6 kg and 47.2 kg. When skeletal muscle mass was divided by total body weight, resulting in the percentage of body weight that could be accounted for by skeletal muscle mass these results increased to 64.2, 60.3, and 58.6% for each of the PA, ATR, and MA groups.

Martin et al. (1990) reported that despite the limitations of having a cadaver sample, their proposed equation appears to provide the best estimate of skeletal muscle mass to date in that it is the only cadaver-validated equation and it gives values which are consistent with all known dissection data.

The PA group of subjects were able to produce significantly greater torque, both concentrically and eccentrically, than either the ATR or MA groups at all velocities and for both muscle groups while there were no significant differences between the ATR and MA groups for either contraction or between the two groups of muscle. This is in accordance with previous studies which have examined the differences in torque production between similar groups of subjects. The PA group performed significantly higher vertical jumps than either of the
other two groups which, according to the 1989 study that was performed by Melichna and associates, indicates that their leg muscles have a predominantly higher percentage of Type II muscle fibre than the other groups. It has been reported (Costill et al. 1976, Melichna et al. 1989, Thorstensson et al. 1976b, Thorstensson et al. 1977) that high levels of Type II muscle fibres are found in elite calibre athletes who compete in sprinting and jumping events and that these muscles are capable of producing high levels of force at all angular velocities.

Gregor et al. (1979) found that for their female subjects the sprinters were able to produce greater isokinetic concentric torque than could the endurance group when the knee extensors were examined. Thorstensson et al. (1976b) reported that it is reasonable to suggest that a high percentage of Type II muscle fibre is one prerequisite for performing fast contractions with appreciable tension outputs. Henneman et al. (1965) and Olson & Swett (1966) provided a basis for Thorstensson and colleagues (1976b) statement reporting that motor units containing predominantly Type II muscle fibre have larger axons, higher conduction velocities, and relatively higher thresholds.

Thorstensson et al. (1977) reported that for their study, subjects with the lowest percentage of Type II fibre produced the lowest torque when angular velocity was highest. Therefore, the amount of force which can be produced during fast contractions is influenced by the amount of Type II fibres in muscle (Thorstensson et al. 1976a, Thorstensson et al. 1976b).
It should thus be expected that individuals who are anaerobically trained and of a high level of skill to have greater percentages of Type II muscle fibres in their leg muscles allowing them to be able to produce greater torque than individuals with a lesser percentage of Type II muscle fibre in their leg muscles. As previously discussed in the literature review, (see section Muscle fibre composition) the extent to which an individual is endowed with Type I or II muscle fibres is genetically determined. With training, only the relative size of muscle fibres will be enhanced while minimal change to the composition of muscle fibre will occur. Individuals who train aerobically will have hypertrophied Type I muscle fibres while those training anaerobically will have Type II muscle fibres which are enlarged although for either athlete the percent composition of fibre type which genetically occurs in their muscles will not change significantly.

Concentric and Eccentric Contractions

This study further supports previous research (Bennett & Stauber 1986, Ghena et al. 1991, Highgenboten et al. 1988, Kramer & MacDermid 1989, MacIntyre & Wessel 1988, Poulin et al. 1992, Tredinnick & Duncan 1988, Westing et al. 1988, Worrell et al. 1991) finding that eccentric torque was significantly greater than concentric torque for each of the three groups of subjects at all velocities, and for both groups of muscles. It has been reported elsewhere (Asmussen 1952, Kaneko & Komi 1984, Komi 1973a, Rodgers & Berger 1974) that eccentric muscle
actions are more efficient than concentric muscle actions, using less oxygen than do concentric contractions of comparable muscle unit activity. Stauber (1989) also stated that greater physiological cost occurs during concentric contractions than for work performed eccentrically, this difference becoming greater as velocity of contraction increases. It was Stauber in his review of eccentric muscle actions who reported that there are two mechanisms, which during eccentric work, reduce energy expenditure these being: 1) altered recruitment of motor units (increased EMG) and 2) decreased energy utilization of active muscles which develop tension while being stretched.

Asmussen (1952) stated that during eccentric contractions fewer motor units are employed to produce a contraction than what is required for concentric contractions. Thus, when a muscle is fully activated it is able to produce more torque eccentrically than concentrically providing similar muscle length-tension relationships exist. Rodgers & Berger (1974) and Walmsley et al. (1986) both cited several references which also stated that greater levels of tension occurred eccentrically than what occurs for either isometric or concentric contractions at the same joint angle. Asmussen (1952) and Komi (1973a) have further stated that the difference in the ability to produce force between concentric and eccentric contractions is velocity dependent. If velocity of contraction increases maximal eccentric force will also increase while maximal concentric force decreases. Therefore, the faster muscle contraction occurs the greater the difference between eccentric
and concentric work while corresponding muscle unit activity (EMG) remains fairly constant (Komi 1973b).

It was found for this study, when averaged over the three groups of subjects, the average isokinetic concentric torque that was produced significantly decreased for both the KE and KF as angular velocity increased. Hill's initial force-velocity (F-V) research on isolated animal muscle found that during concentric work the force which could be applied to move an object decreased as speed of contraction increased. This would continue to occur until a velocity was reached where even an unloaded muscle could not shorten. For eccentric work the opposite was true; with an increase in the speed of contraction the force which could be applied also increased to a certain point where it would then level off.

Many studies examining F-V relationships have attempted to compare their results to those reported by Hill. Research examining concentric F-V relationships found that as contraction velocity increased the force that was produced decreased as found by Hill (Asmussen et al. 1965, Fillyaw et al. 1986, Gilliam et al. 1979, Holmes & Alderink 1984, Komi 1973, Oberg et al. 1986, Sanderson et al. 1984, Smith et al. 1981, Stafford & Granna 1984, Thorstensson et al. 1977, Wyatt & Edwards 1981). It has been hypothesized that such a decline could be due to a decrease in the amount of time for motor fibre recruitment (Rodgers & Berger 1974), muscle fibre composition (Poulin et al. 1992, Thorstensson et al. 1977), or muscle activity level (Thorstensson et al. 1977). Ghena et al. (1991) also reported
that others believe gender may play a role in the reduction of concentric force with increasing angular velocity.

Studies which have also analyzed eccentric F-V relationships have reported mixed results. That is not all have found eccentric torque to increase as the velocity of contraction increases. Walmsley et al. (1986) found that eccentric wrist extensor torque significantly increased while Tredinnick & Duncan (1988) found that for males knee extensor eccentric torque increased very slightly from 60 to 180 deg/sec\(^{-1}\). Worrell et al. (1991) found increasing knee extensor and flexor eccentric torque with increasing angular velocities in university athletes from 60 to 180 deg/sec\(^{-1}\). Westing et al. (1988) reported that when voluntary maximal eccentric contractions of the knee extensors were measured isokinetically at 30 through 270 deg/sec\(^{-1}\) torque did not significantly increase with increasing angular velocity while Westing et al. (1990) again reported that knee extensor eccentric torque did not appreciably increase at test velocities of 60, 180, and 360 deg/sec\(^{-1}\).

Eccentric torque produced by the three groups of subjects in this study did not differ significantly, remaining fairly constant for both the KE and KF as velocity of contraction increased. Eloranta & Komi (1980) found eccentric torque to be greater than concentric torque in the knee extensors of college males, however, no significant differences in eccentric torque between velocities were found. Kramer & MacDermid (1989) reported that for their female subjects concentric knee extensor torque significantly declined as angular velocity increased.
while eccentric torque showed only a 3-5% variance which did not significantly differ at velocities between 45 and 180 deg/sec\(^{-1}\); increasing very slightly, plateauing, or decreasing. They further stated that this was in agreement with several previous studies which examined both the knee and elbow. Jorgensen (1976), and Hanten & Ramberg (1988) both reported that eccentric torque increased and then decreased for their subjects.

Conflicting F-V results were also reported by Ghena et al. (1991) and Poulin et al. (1992). Poulin et al. found eccentric torque to decrease in their younger male subjects from 90 to 180 deg/sec\(^{-1}\), but increased for their older male subjects. They reported several other studies which have also found concentric peak torque to decrease while eccentric peak torque increased slightly or plateaued. Ghena and colleagues (1991) found no significant differences to exist in their male subject's ability to produce eccentric torque for both the knee extensors and flexors at angular velocities of 60 and 120 deg/sec\(^{-1}\).

Westing et al. (1988) performed a study which examined eccentric and concentric F-V characteristics of male knee extensors. They had subjects perform maximal voluntary, electrically stimulated, and a combination of both types of contractions during isometric, concentric, and eccentric actions. They also reported that eccentric torque did not increase with corresponding increases in angular velocity. It was reported that a combination of electrical stimulation and maximal vol-
untary contraction produced the greatest amount of force while force recorded during electric stimulation alone best resembled the F-V model. The lowest force recorded occurred when maximal voluntary contractions were measured without accompanying stimulation. They suggested that the failure for eccentric torque to significantly increase with increases in angular velocity could be due to a neural mechanism becoming active during maximal contractions of in situ muscle which restricts the muscle's ability to produce maximal tension. They reported that such a tension-restricting mechanism has been suggested to maintain a "safe" maximal level of tension during isometric and low velocity contractions.

In a 1990 study by Westing et al., they hypothesized that electrical stimulation of a muscle would be similar to the proposed F-V studies performed on isolated animal muscle. This would explain why the electrical stimulation contraction they measured in their subjects resembled the original F-V curve in their 1988 study. By performing such a contraction many neural interactions at the spinal level are bypassed. Once again results similar to their earlier study were obtained. They concluded that it is indeed possible that neural inhibition could be partially responsible for causing the flattening of the eccentric torque curve during maximal voluntary contraction, that is eccentric torque not increasing with increasing velocity. Stauber (1989) also mentioned that eccentric force recorded for in situ testing is lower than an isolated muscle stimulated electrically thus a neural mechanism must be present
which helps to protect muscle from injury.

Other factors which have been mentioned as possibly being related to eccentric torque not increasing with corresponding increases in angular velocity include subject positioning during data collection. Previous work has almost exclusively examined torque measurements with subjects in either a sitting or semi-reclined position for testing of both the knee extensors and flexors (Bohannon et al. 1986, Currier 1977, Worrell et al. 1989). For this study subjects were examined with a hip angle of 10\(^\circ\) in a prone (KF) or supine (KE) position and were not allowed to grasp any hand rails for further support.

Another hypothesis as to why there has been a conflict with the eccentric F-V relationship is a lack of subject familiarity with eccentric contractions which are produced under test conditions. Several studies, including the present one, have reported that they collected data with the only form of familiarization consisting of pre-test repetitions which were performed immediately prior to data collection. Subjects for this study commented that performing this computer-controlled contraction was the most difficult portion of the study. Several needed extra practice trials before they were comfortable with this section of the test. If a practice session was performed less than a week prior to data collection then subject familiarity with producing controlled eccentric contractions on an isokinetic dynamometer might result in better similarity to the force-velocity curve.

Walmsley et al. (1986) have suggested that a failure for
eccentric torque to increase with increasing angular velocity is perhaps due to different test velocities and/or different muscle groups tested. However, Hinson (1976), as reported by Kramer & MacDermid (1989) suggested that during isokinetic in situ testing the joint's angular velocity is constant but the linear velocity of the muscle action is not. Therefore, only general comparisons should be made between human isokinetic testing and the F-V relationship because clinical responses to changes in angular velocity are more important than comparison to the classic model.

Finally, Chapman (1985) reported that although the F-V relationship as proposed by Hill has not been verified as being universally applicable for all muscle groups within the human body, there is evidence which suggests that some form of the F-V relationship, the result of a combination of separate intrinsic F-V relationships within the muscle group, does exist. He further stated that the F-V relationship can never be truly viewed as fundamental since many of the conditions under which it is tested apparently modify the relationship which include force length relationships, level of muscle activation, prior state of muscle contraction, and the role that different fibre types have in muscular contraction.

**Knee Extensor and Flexor Torque**

As hypothesized, the knee extensors of all three subject groups produced significantly greater concentric and eccentric torque than the knee flexors at each test velocity examined.
These results are supported by the past findings of Ghena et al. (1991), Harding et al. (1988), Highgenboten and colleagues (1988), Klopfer & Greij (1988), Pieter et al. (1989), Sanderson et al. (1984), and Smith et al. (1981). Pieter et al. (1989) stated that one should expect KE torque to be greater than KF torque considering it has a larger muscle mass.

One study, however, has reported that torque produced by the KF exceeded that of the KE. Klopfer & Greij, whose study was performed concentrically using angular velocities of 300 deg/sec\(^{-1}\) and greater on the Biodex B-2000 isokinetic dynamometer, reported that for their untrained female subjects, KF torque was greater than that for the KE at each test velocity. They found that KF torque actually increased with increasing angular velocities.

Several suggestions were offered as to why this occurred including that during the extension phase of exercise there is an increase in KF activity which occurs as the result of an attempt to slow the lower leg during the extension phase of exercise (See literature review: Analysis of Running Motion). Klopfer & Greij hypothesized that if the knee flexors were composed predominantly of Type II muscle fibre then an increase in the amount of torque which could be produced with increase in velocity may be expected. Conversely, if knee extensors were predominantly comprised of Type I fibres then a decrease in torque production with an increase in velocity may be expected which is supported by the work of Thorstensson et al. (1977).
This is a very unique finding in that it is the only study to report torque produced by the KF to exceed that capable by the KE. One other possible factor which might explain this result is the fact that their untrained female subjects performed concentric contractions at velocities of contraction which are not commonly examined. As well, remembering the statement by Ghena et al. (1990), it is believed that there is a gender difference in the rate at which concentric torque decreases as the velocity of contraction increases.

The results which were measured for the KE of all three groups were higher than anticipated considering the supine test position which was used. As mentioned previously, several studies have examined the differences in the ability to produce torque from seated, semi-reclined, and/or supine positions. Worrell et al. (1989) reported that torque produced by the knee extensors in a seated position (80° of hip flexion) was significantly greater than what was recorded from a supine test position (10° hip flexion). Worrell et al. (1989) further stated that the optimal length-tension relationship of the rectus femoris muscle occurs between 50 and 80° of hip flexion. Any position less than 50° or greater than 90° does not provide an optimal relationship and will thus result in a decrease in the amount of torque which is produced.

Currier (1977) reported significant differences between a seated and semi-reclined position, however, Bohannon et al. (1986) did not. Bohannon and colleagues found that no signif-
significant differences existed in the torque produced from positions of 30 and 80° of hip flexion for the KE. They reported that possible differences between their study and that performed by Currier were due to different subject stabilization techniques. Their subjects were not permitted to grasp handles while Currier's subjects were allowed this method of stabilization.

For the present study, subjects were examined for KE torque in a supine position of 10° hip flexion, not the optimal length-tension relationship as suggested by Worrell et al. (1989), and were not permitted to grasp the handles. However, instead of using an arbitrary pre-load force of 25 or 50N as some studies have done (Bennett & Stauber 1986, Hageman et al. 1988, Tredinnick & Duncan 1988, Worrell et al. 1990, Worrell et al. 1991), 75% of a subject's MVIC was used to determine the pre-load force level. Jensen et al. (1991) reported that a 75% MVIC pre-load helped to reduce any affect that positive or negative acceleration may have had in influencing torque. Further reference to Jensen and colleagues work can be located in the "Faults with previous research" section of the literature review. The author believes that the higher than anticipated results for the knee extensors may be accounted for due to the use of this high level of pre-load as well as the different methods of stabilization.

Several authors have reported that as the velocity of contraction increases the amount of torque that can be produced concentrically decreases at a much faster rate for the KE than for the KF (Ghena et al. 1991, Hageman et al. 1988, Holmes &

The results of this study support earlier research also finding that during concentric contractions KE torque decreases at a greater rate than does KF with increasing angular veloci-
ty, however KF torque did not exceed KE torque. When the rate of decline between angular velocities was examined it was found that MA and PA groups demonstrated similar levels of decline with increasing angular velocity when concentric torque was measured for the KE while the ATR group had the least amount of decline. When analyzing the differences between 90 to 135 deg/sec\(^{-1}\) the MA group of subjects demonstrated the greatest decline in KE concentric torque: 0.20 Nm/kg corr., while the ATR and PA groups rate of decline was measured to be 0.17 and 0.16 Nm/kg corr. respectively. When differences in KE torque were analyzed between the test velocities of 135 and 180 deg/sec\(^{-1}\) the PA group demonstrated the greatest rate of decline (0.26 Nm/kg corr.) while the MA and ATR groups declined only 0.22 and 0.19 Nm/kg corr. respectively.

As for the rate of decline when KF torque was evaluated between the angular velocities of 90 and 135 deg/sec\(^{-1}\) the ATR group showed only a slightly greater rate (0.09 Nm/kg corr.) than did the PA group (0.08 Nm/kg corr.) while the MA group only decreased 0.05 Nm/kg corr.. Decline in the measured concentric KF torque between 135 and 180 deg/sec\(^{-1}\) was greatest for the PA at 0.17 Nm/kg corr. while the ATR and MA groups demonstrated a decline of 0.1 and 0.08 Nm/kg corr. respectively.
Garrett (1983) reported that the KF are known to have relatively high levels of Type II muscle fibre and are involved in intense contractions. Polgar et al. (1973), who examined the composition of percent muscle fibre in several different muscles, also stated that the KF have a high percentage of Type II fibre and further suggested that these muscles are more involved with exercise of high intensity and force production. Thus if the KF have higher levels of Type II muscle fibre than the KE they are more capable of producing greater torque at high velocities of contraction as compared to the KE. Thorstensson et al. (1976b) reported that motor units which recorded higher tension outputs and shorter contraction times were shown to contain a greater percentage of Type II fibre as compared to Type I muscle fibre in their subjects.

With this knowledge that during concentric contractions torque produced by the KE decreases at a greater rate than for the KF further explanation of the results reported by Klopfer & Greij (1988) can occur. It is conceivable that for their particular group of untrained females, beginning at the angular velocity of 300 deg/sec\(^{-1}\) there is a change in which group of muscles can produce the greatest torque; from KE to KF, thus explaining why recorded concentric KF torque was greater than that produced by the KE.
KF-E Ratios

Significantly greater concentric and eccentric KF-E ratios were found to exist between the PA group and both the MA and ATR groups of subjects while the ratios produced by these last two groups were not significantly different from each other. The author suggests that higher KF-E ratios may be required by PA athletes to compete successfully as well as to prevent injury.

Unfortunately much of the previous research which examined KF-E ratios has failed to correct for gravity. This error results in an inflated ratio as reported by Fillyaw et al. (1986) and Sanderson et al. (1984) when both the knee flexors and extensors are examined in a supine position. Thus, uncorrected studies can not be used to develop standards which aid the athlete, coach, and/or physiotherapists in determining if an individual is capable of withstanding those forces specific to their activity or if they are at risk for future possible injury. The present study performed was unique in that the KF-E ratios, like measured concentric and eccentric torque, were not calculated using solely the torque values measured or torque corrected for individual body weight, but was corrected for the percent of an individual's body weight which could be accounted for by skeletal muscle mass.

For each of the three groups of subjects in this study the concentric KF-E ratios were significantly lower than those calculated for eccentric contractions. This was especially
seen in the PA group where the difference between concentric and eccentric KF-E ratios was on average 6% while differences for each of the other two groups was between 1 and 5%. It is suggested by the author that because power athletes are required to perform at high velocities of movement and are at times required to perform so that high extrinsic loads are placed upon them large eccentric KF-E ratios are required to adequately perform and do so without injury.

Such findings have been reported elsewhere (Ghena et al. 1991, Highgenboten et al. 1988). Highgenboten et al. (1988) reported concentric ratios of 54% for their untrained young males (15-24 years), 51% for their older male subjects (25-34 years) and eccentric ratios of 60% for both groups when examined at 50 deg/sec^{-1}. Ghena et al. (1991) found eccentric ratios of 64.6% and 65.0% at 60 and 120 deg/sec^{-1} respectively while concentric ratios were 55.3, 57.7 at 60 and 120 deg/sec^{-1} increasing to 60.9 and 80.4% at test velocities of 300, and 450 deg/sec^{-1} for their subjects who were male university athletes competing in a variety of sports. Unfortunately they were not able to measure eccentric ratios at angular velocities greater than 120 deg/sec^{-1} due to equipment restrictions.

One finding which has been common to nearly every study examining KF-E ratios is for concentric ratios to increase as the velocity at which they are calculated for increases (Ghena et al. 1991, Klopfer & Greij 1988, Sanderson et al. 1984). This rising concentric torque ratio can be explained by past findings which reported that KE torque declines at a more rapid
rate than KF torque during concentric contractions. Thus, there is less of a difference between the two muscle groups as velocity increases and the calculated ratio will be greater than at a lesser angular velocity. It would be of great interest to this field of research if a study was performed which examined the hamstring MSI athlete population to see if they demonstrated a higher difference and if so how this might be associated with hamstring MSI.

The results of the concentric KF-E ratios, for this study, support the previous research which found KF-E ratios to rise as angular velocity increased for both the MA and ATR groups, however, the PA group's concentric ratios remained relatively unchanged. This would suggest that, for the PA group, the amount of decline in concentric torque production for both the KE and KF was approximately similar. This is logical because elite sprint athletes have been shown to have higher levels of Type II muscle fibre in all leg muscles as reported by Thorstensson et al. (1977). It is therefore possible that for this group of subjects, the KE and KF had similar percentages of Type II fibres. Only two studies to date have reported gravity corrected eccentric ratios (Ghena et al. 1991, Highgenboten et al. 1988) and unfortunately only one at differing velocities. Ghena et al. (1991) found a very small increase in the eccentric ratio produced for their subjects using velocities of 60 and 120 deg/sec⁻¹.

The eccentric KF-E ratios remained steady across angular velocities for each of the three groups in this study because
eccentric torque for each group's KE and KF did not differ as velocity increased, conflicting with the force-velocity relationship. A rise in the eccentric KF-E ratio as angular velocity increased would require torque produced by the knee flexors to increase at a greater rate than for the knee extensors. Stanton & Purdam (1989) felt that sprinters which sustained hamstring MSI had lower knee flexor eccentric torque especially at higher angular velocities. Thus this may be an area where persons prone to hamstring MSI are deficient or display a degree of asymmetry.

Both the concentric and eccentric ratios found for this study are quite similar to those reported by Ghena et al. (1991) when the power and endurance groups are averaged together as was the case for their study. The MA KF-E ratios calculated for this study were slightly higher than those reported by Sanderson et al. (1984) for their sedentary subjects: concentric KF-E ratios for males to be 44 and 48% at test velocities of 60 and 180 deg/sec\(^{-1}\) respectively while their female subjects had ratios of 39 and 42% respectively at the same velocities. The moderately active results were, however, much lower than what Klopfer & Greij (1988) reported for both their male and female subjects. Klopfer & Greij calculated untrained males KF-E ratios at angular velocities of 300, 330, 360, 400, and 450 deg/sec\(^{-1}\). They found that these concentric ratios were 72.9, 84.1, 82.8, 85.5, and 97.1% respectively. For their untrained females ratios of 110, 108, 112, 114, and 108% were found to exist at the same velocities.
KF-E ratios at both velocities were found to be similar to what was recorded for our endurance group, thus being much lower than what was found to exist for our power subjects. Highgenboten et al. (1988), whose eccentric results were reported earlier, found eccentric KF-E ratios which were approximately 7% higher when examined at 60 deg/sec\(^{-1}\) as compared to our MA group whose ratios ranged from 52.6 to 52.8 at velocities of 90-180 deg/sec\(^{-1}\).

Previous literature has suggested that the KF-E ratios measured can be affected by age (Ghena et al. 1991, Weltman et al. 1988), skill level and respective training which accompanies a high level of skill (Oberg et al. 1986), position played (Gilliam et al. 1979), velocity of contraction (Holmes & Alderink 1984, Worrell et al. 1989), gender (Komi & Buskirk 1972, Rodgers & Berger 1974), and hip position (Worrell et al. 1989). Gilliam et al. (1979) proposed that each individual has a separate and distinct KF-E ratio which is "ideal" for them dependent upon physical characteristics, sport of participation and position.

Significance of KF-E Asymmetry

Several studies have attempted to associate hamstring muscle strain injury and KF-E asymmetry/imbalance. Heiser et al. (1984) found that in college football players a dramatic reduction in hamstring injuries occurred following a specially designed prophylactic rehabilitation program which increased
every player's KF-E ratio to at least 60%. Burkett (1970), in predicting hamstring MSI in professional football players and track athletes, found that an asymmetry of greater than 10% between the right and left knee flexors resulted in a greater occurrence of hamstring MSI and further stated that a reduction in knee extensor and flexor strength differences would be useful in the prevention of hamstring strains.

In a larger, retrospective study Knapik et al. (1991) reported that lower extremity injury was more prevalent in their female collegiate athletes if 1) a difference of 15% or greater existed between the right and left knee flexors when examined at 180 deg/sec\(^{-1}\) and 2) if a KF-E ratio of less than 75% was present when calculated at 180 deg/sec\(^{-1}\).

All of these studies and others have reported different KF-E ratios which should be maintained for injury prevention (See literature review: KF-E Assessment). Because few studies agree on normative ratios which should exist in attempts to prevent injury perhaps KF-E ratios are indeed sport and/or position specific as suggested by Gilliam et al. (1979) and Holmes & Alderink (1984). More research needs to be performed which examines not only the association between KF-E muscle asymmetry and hamstring muscle strain injury in larger samples like the Knapik et al. study but also the effect of between leg asymmetry. This work, however, needs to be performed with consideration to simulating length-tension relationships specific to that sport in which the measured KF-E ratios are to be associated with. As well, research should be performed to
investigate if KF-E ratios can be changed with training over a
period of time. To date no study has examined the effects of
training on KF-E ratios.

Goal of Rehabilitation

Considering that few valid studies have been performed
which investigate uninjured athletes encompassing a variety of
ages, weights, sports/positions, and gender an accurate rela­
tionship between KF-E ratios and rehabilitation can not occur.
As well, current isokinetic dynamometers are not capable of
achieving the angular velocities which are present during
athletic competition. Thus no one is definite as to how
individuals respond to such velocities under test conditions.

Further investigation of eccentric knee extensor and
flexor torque and their ratios must be undertaken which exam­
ines different groups of athletes considering the lack of
research which examines eccentric muscle actions. Eccentric
and concentric research, if the results are to be compared to
the forces present during competition such as the running
motion, need to be performed in a manner which closely approx­
imates the knee extensor and flexor length-tension relation­
ships that are present during running. Many previous studies
have not considered examining KE and KF in positions which
simulate length-tension relationships similar to those which
occur during running even though they relate their results to
athletes who compete in activities which these relationships
occur. This must be performed if the results are to be used as
a database to aid coaches, trainers, and/or physiotherapists in determining if an athlete is prepared to withstand the forces experienced during their particular sport.

This investigation has revealed several questions which must be answered concerning the rehabilitation of a hamstring muscle strain injured athlete which include:

1a) Should we aim for less of a decline in torque as angular velocity increases?

b) Is a decline in torque with increasing angular velocity related to the incidence of hamstring MSI?

2) Should we aim for an increase in the KF-E ratio to levels beyond those established for similar individuals?

3a) What role does the eccentric KF/E ratio play?

b) Should a high eccentric ratio be achieved and maintained?

Until such investigation has been performed the practice of using KF-E ratios and individual muscle torque scores to assess the progress and readiness of an athlete during rehabilitation is speculative.

Knee F-E ratios, however, cannot be considered as being the only factor which dictates whether or not an individual will sustain a hamstring MSI. The effect(s) of muscular fatigue, flexibility, and asynchronous neural stimulation of individual muscles within a muscle group, in combination, or
associated with a KF-E asymmetry must also be considered as having some relationship with the incidence of hamstring MSI. Therefore, research must also be performed which examines these possible factors. Although much has been discovered about the way in which muscle functions during athletic activity there still remains many unanswered questions as to how events such as muscle strain injuries of the hamstring muscle complex occur. It is only through comprehensive research that these questions will be answered.
Chapter 5
SUMMARY AND CONCLUSIONS

Summary

The main purpose of this study was to examine the relationship between concentric and eccentric torque as produced by the knee flexors and extensors over three different velocities of contraction in three different groups of subjects: power athletes, aerobically trained athletes, and moderately active individuals.

Sixty subjects were separated evenly among the three groups following physiological assessment consisting of the vertical jump and VO₂ max tests. Anthropometric measurements were taken to estimate the skeletal muscle mass for each subject and isokinetic concentric and eccentric torque was measured at 90, 135, and 180 deg/sec⁻¹ for each of the knee extensors and flexors. For both muscle groups, testing was performed with 10° of hip flexion, the knee extensors examined in a supine test position while the knee flexors were assessed for torque production in a prone position.

Isokinetic testing results showed that the PA produced significantly greater average concentric and eccentric torque for both groups of muscle at each angular velocity than the ATR or MA groups (p< 0.05). As well, calculated KF-E concentric and eccentric ratios were significantly greater for the PA group than the MA or ATR groups (p< 0.01) at each angular
velocity.

It was also found that for each of the three groups of subjects isokinetic torque produced concentrically and eccentrically by the KE was significantly greater (p < 0.001) than that produced by the KF. Eccentric KF-E ratios were significantly greater (p < 0.001) for each group at all velocities of contraction than as compared to measured concentric ratios. As angular velocity increased, concentric ratios demonstrated a corresponding significant increase (p < 0.02) while eccentric ratios did not significantly differ with changes in angular velocity.

Pearson Product correlations showed that for this study vertical jumping ability was significantly correlated with the ability of the knee extensors and flexors to generate concentric and eccentric torque while vertical jumping ability was not significantly correlated with either VO2 max or SMM.

Conclusions
1. Significant differences existed between the power group and the moderately active and aerobically trained runner groups in ability to produce concentric and eccentric isokinetic average torque for both the knee extensors and flexors at all angular velocities. There were no significant differences between the aerobically trained runner and moderately active groups in concentric or eccentric torque production.
2. For both the knee extensors and flexors concentric average isokinetic torque significantly decreased as the velocity of contraction increased in all three groups of subjects. Eccentric average isokinetic torque, however, did not significantly increase nor decrease for any of the three groups of subjects.

3. The power group's KF-E ratios were significantly greater both concentrically and eccentrically at each angular velocity than either the aerobically trained runner or moderately active groups of subjects. These last two groups not being significantly different from one another.

4. Average isokinetic concentric and eccentric torque for the knee extensors and flexors is significantly correlated with vertical jumping ability while estimated skeletal muscle mass and \( \text{VO}_2 \text{ max} \) is not significantly correlated.

RECOMMENDATIONS

1. Further research should be performed which measures isokinetic concentric and eccentric knee extensor and flexor torque and their ratios in a testing position which best simulates the length tension relationship found during running.

2. Inclusion of a pre-test practice session which would allow subjects to become familiar with producing mechanically assisted eccentric contractions.
3. Instead of calculating torque corrected for body weight, skeletal muscle mass, or lean body mass examine thigh muscle girths/mass and relate this measure to the amount of isokinetic torque which can be produced.

4. A prospective study which evaluates a large sample of individuals, who are approximately the same age, skill level, and are exposed to similar training methods, for their KF-E concentric and eccentric ratios should be performed. These individuals would then be monitored for a set period of time (i.e. two years) to see which individuals develop hamstring MSI so that KF-E ratios can be established in an attempt to prevent future injury.
REFERENCES


Olsen CB, Swett CP. A functional and histochemical characterization of motor units in a heterogenous muscle (flexor


