THE UNIVERSITY OF ALBERTA

THE EFFECT OF KNEE POSITION AND ANGULAR VELOCITY ON THE FLEXOR:EXTENSOR RATIO OF THE KNEE

by

(C) KELLY ANN GOLEMBLASKI

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(SIGNED) Kelly Golemblaski

PERMANENT ADDRESS:

1023 Gillies Road

Sherwood Park, Alberta

T8A 1C8

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled The Effect of Knee Position and Angular Velocity on the Flexor:Extensor Ratio of the Knee submitted by Kelly Ann Golemblaski in partial fulfilment of the requirements for the degree of Master of Science.

S. W. Mendryk
....
Supervisor

....

S. Hunka
....

Date October 6, 1986

Abstract

It was the purpose of this study to determine the effects of knee position and movement velocity on the flexor:extensor (F:E) ratio of the knee. In an effort to promote a more complete understanding of the F:E ratio, the sub-purpose of the study was to examine the effects of velocity and position on each of the muscle groups that comprise the F:E ratio.

Using a sample of 30 physically active male subjects, the torque of the knee flexors and extensors was measured with a two channel Cybex II isokinetic device. Mean torque values of the flexors and extensors were recorded for peak torque and angle-specific (30, 45, 60, 75, and 90°) torque at velocities of .52, 1.05, 2.09, 3.14, and 4.19r/s. The F:E ratio (%), was calculated using these values. Angles of peak flexor and extensor torque were also recorded.

Repeated measures of both position and velocity were used for the analysis of variance (ANOVA) of the angle-specific measures (F:E ratio, flexor torque, and extensor torque). Because of the concern that repeated measures for position may have influenced the results, an additional analysis, which randomly grouped subjects according to position, was also conducted. As the results of the two analyses were very similar, further discussion of the results was based on the first analysis, which used repeated measures for both position and velocity. Repeated measures were also used for the analysis of variance of the peak measures (F:E ratio, flexor and extensor torque, and angles of peak flexor and extensor torque). All analyses accepted significance at the $P \leq 0.05$ level of confidence. Significant contrasts ($P \leq 0.05$) were determined using the method of Scheffe.

Test results demonstrated that the angle-specific F:E ratio increased as the leg moved from flexion to extension. Increased velocity also acted to influence the angle-specific F:E ratio, although not as distinctly.

At 45°, the F:E ratio was observed to approximate 100% at all velocities. Therefore, it is recommended that, especially when time is a consideration, the position of 45° be used to evaluate the F:E ratio.

Angle-specific torque of both the flexors and extensors decreased as velocity increased. Position also influenced both muscle groups - flexor torque increased as the leg was extended, whereas extensor torque decreased as the leg extended.

The peak F:E ratio increased as velocity increased. In contrast, peak torque of both the flexors and extensors decreased as velocity increased.

As velocity was increased, the angle of peak torque of both the flexors and extensors shifted in the direction of the movement - the angle of peak extensor torque became smaller in contrast to the increase in the angle of peak flexor torque (the extended position is zero degrees).

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Chapter I

INTRODUCTION

The Problem

Sports injuries are a multiple risk phenomenon with variable interaction of risk factors at any given time (57). Identification of risk factors is necessary so as to allow those individuals responsible for the care of athletes to take measures which reduce or eliminate the risk of injury. Table 1 identifies some of these factors and categorizes them into extrinsic and intrinsic factors. In the past, most attention was focused on the role of extrinsic factors in sports injuries. Although these factors still receive consideration, the focus is now mainly on intrinsic factors (57, 104).

Of these intrinsic factors, physical fitness, or perhaps more appropriately muscle fitness, has received considerable attention. The knee joint and its supportive muscles have probably been given the most attention. The knee has the highest incidence of disabling injury in sports (20, 49) and thus elicits concern from those responsible for the prevention and/or treatment of injuries.

As the bony configuration of the knee does not provide any real stability to the joint, stability must be provided by the muscles and ligaments (8, 16, 20, 47-49, 60, 81, 93). Although the role of both the ligaments and muscles in providing stability has been investigated, the role of the muscles appears to have received more attention in recent years. It is possible that the muscles have been given more attention because it has been recognized that an individual has more control over muscular strength than ligamentous strength, and therefore is better able to influence joint stability.

Various studies have indicated that the contraction of both the knee flexors and extensors serve to reduce the degree of abduction/adduction of the stressed knee (28, 60, 76, 99). Therefore, maintenance of adequate strength of the knee flexors and extensors is considered to play an important role in the prevention of injuries, reducing the severity of any,

Table 1

Risk Factors of Sports Injuries

Extrinsic Factors	Intrinsic Factors
Exposure	**Physical Characteristics**
Type of sports, rules	Age
Playing time	Sex
Position in the team	Somatotype
Level of competition	Physical fitness
	Previous injury
Training	Muscle tightness
	Joint instability
Environment	Structural anomalies
Playing surface	
Wheather conditions	**Psychosocial Characteristics**
Time of day	
Time of season	
Equipment	
Protective equipment	
Footwear	

Adapted from Lysens and associates (57)

injuries that do occur, and accelerating the rehabilitation and return to activity after an injury (1, 71, 81).

The relationship between the opposing muscle groups of the knee has also received considerable attention as a factor in the prevention of injuries to the knee joint and its supporting musculature (6, 7, 25, 29, 36, 45, 47, 48, 49, 52-54, 61, 102). In describing the relationship between the two muscle groups, the torque of the knee flexors is usually expressed as a percentage of the torque of the knee extensors. Expressed in this manner, the relationship is commonly referred to as the hamstring:quadricep ratio, although it may be more appropriate to declare it the flexor:extensor (F:E) ratio as other muscles assist the action of the hamstrings and quadriceps.

Although the F:E ratio has been reported to range from 43% to 90% (2, 5, 11, 15, 20, 23, 24, 26, 38, 40, 45, 59, 63, 66, 70, 71, 73, 74, 77, 78, 82, 85, 90,103), one value, (60%), is most often advocated as a goal for injury prevention (26, 45, 52, 70, 83,). However, there does not appear to be any real basis for the use of this value, other than convention, which began through the work of Karl Klein (70).

Beginning with Klein's work (45), attempts to correlate deviations from the recommended F:E ratio with the occurrence of injury have produced mixed results (6, 21, 24, 31, 45, 102,). The lack of consensus regarding the relationship between the F:E ratio and injury leads to three possible conclusions: (1) *no* relationship exists between the F:E ratio and injury, (2) there are too many confounding variables to establish a direct relationship, and (3) due to procedural errors in evaluating the F:E ratio, the value of 60% is not reliable and therefore a relationship cannot be demonstrated consistently. It is the third possible conclusion that forms the basis of the present investigation.

It appears the aforementioned procedural errors result from a disregard for the concept of "specificity of testing". Although the importance of "specificity of training" is fairly well documented, the principle of "specificity of testing" seems to have received less attention. Sutton (91) explains:

> Just as 'specificity of training' has been emphasized to direct conditioning programs to the demands of a particular sport, 'specificity of testing' should be emphasized to direct evaluation procedures to simulate conditions that cause a specific injury to an athlete in a particular activity.

Although it is recognized that it is difficult, if not impossible (with present technology), to provide evaluation procedures which simulate functional activities precisely, past methods of evaluating the F:E ratio are open to criticism. The majority of studies which have attempted to correlate the F:E ratio with injury occurrence employed static or isometric measurements (6, 24, 45, 102). Because sports are dynamic by nature, it would be more appropriate to assess the F:E ratio under dynamic conditions. Since the introduction of isokinetic testing, which allows for regulation of velocity, numerous studies have evaluated the effect of increasing velocity on the magnitude of the F:E ratio. The general consensus of these studies is that the F:E ratio increases as velocity increases (2, 5, 8, 11, 17, 26, 31, 34, 38, 40, 65, 78, 79, 82, 88, 94, 98, 103). However, only a very small number of these studies attempted to examine the relationship between injury and the F:E ratio. Capiau (11), however, reported that the ability to predict hamstring injuries was improved by using the F:E ratio established at increasingly higher velocities. At velocities of 1.05, 3.14, and 5.24 radians per second (r/s) (60, 180, and 300°/s), prediction success rates were 50, 69, and 64%, respectively (11).

Most of the studies that demonstrated a significant increase in the F:E ratio used a relatively large increment (2.09 to 2.62r/s; 120 to 150°/s) between velocities. Smaller increments would allow for a wider spectrum of velocities to be assessed and present a more complete understanding of the relationship between the F:E ratio, velocity, and injury (103).

Most isometric and isokinetic evaluations of the F:E ratio have one thing in common; both assess the F:E ratio using the strongest joint positions for each of the involved muscle groups. Two problems, in relation to specificity of testing , result from the practice of using positions of maximal torque. Firstly, use of the positions of peak torque determines that the flexors and extensors are to be evaluated at different joint positions. However, during functional activities the two muscle groups function at the same joint position. Therefore, assessing the F:E ratio using angles of peak torque is in direct conflict with the principle of test specificity. Secondly, the knee moves through a range of motion during activity, necessitating evaluation at several joint positions in order to satisfy the principle of test specificity.

Ideally, the specific velocities and positions at which the F:E ratio is evaluated should be based upon knowledge of those positions and velocities at which injury occurs. If a significant relationship between the F:E ratio and the potential for injury could then be established, the F:E ratio would become a much more credible tool in both the prevention and rehabilitation of athletic injuries. Unfortunately, present technology makes it difficult, if not impossible, to determine the joint positions and movement velocities at which injuries occur.

Assessment of the F:E ratio, therefore, is limited to a spectrum of positions and velocities, which may include those at which injury occurs.

The Purpose

Attempts to establish a relationship between the F:E ratio of the knee and the occurrence of athletic injuries have produced mixed results. Evaluation procedures which do not accurately simulate conditions at the time of injury may be at least partly responsible for producing these mixed results. The dynamic nature of sports suggests that movement velocity and knee position may be variables capable of influencing the F:E ratio and thus should be considered in any attempts to establish a relationship between the F:E ratio and injury. Therefore, it was the purpose of the present investigation to determine the effects of knee position and movement velocity on the F:E ratio of the knee. In an effort to promote a more complete understanding of the F:E ratio, the sub-purpose of the investigation was to examine the effects of velocity and position on each of the muscle groups that comprise the F:E ratio.

Limitations

1. All subjects were volunteers without any history of significant injury to the right lower extremity.
2. A given subject's motivation to perform with maximal effort could not be controlled. However, through standard verbal instructions given by the test administrator, subjects were encouraged to produce a maximal effort.

Delimitations

1. Thirty healthy male athletes, 18-30 years of age, attending the University of Alberta volunteered to act as subjects.
2. Five joint positions (30, 45, 60, 75, and 90° of flexion) were examined.
3. Five velocities (.52, 1.05, 2.09, 3.14, 4.19r/s; 30,60,120,180, and 240°/s) were

examined.

Definitions

TORQUE: A force which acts about an axis of rotation. It is the product of force times its perpendicular distance from the axis of rotation (64).

Chapter II

REVIEW OF THE LITERATURE

Factors Influencing Torque

It would seem reasonable that, because the F:E ratio symbolizes the relationship between the flexors and extensors, those factors which act to alter the torque capabilities of the flexors and extensors would also, to some degree, alter the magnitude of the F:E ratio. Therefore, a brief overview of some of the factors which effect the torque capabilities of muscles is appropriate.

The amount of torque a muscle is capable of producing is not constant; varying from individual to individual, as well as within a given individual. Some of the factors which produce variation in torque include gender (27, 29, 38, 62, 78, 103), body size (27, 38, 94), age (26, 27, 29, 44, 62, 66, 67, 74, 94, 100), fiber type (32, 37, 58, 69, 75, 95), and cross-sectional area (30, 69, 87). Other factors, such as the particular muscle being considered (4, 14, 51, 103), the number of joints a muscle crosses (18, 19, 30, 33, 35, 56, 69), the movement velocity of the limb (3, 30, 32, 50, 63, 64, 68, 69, 72, 75, 79, 83, 88, 89, 92, 95, 103), and the position of the joint (3, 4, 9, 10, 12-14, 18, 19, 33, 39, 42, 51, 83, 86, 92, 100) also effect the amount of torque a muscle can produce.

It is not within the scope of the present study to discuss all of the aforementioned factors. Only the latter two, movement velocity and joint position, will be discussed further.

Position: Angle of Pull and Length-tension Relationships

As the position of the joint changes, changes occur in both muscle length and the angle of pull of the muscle (37, 42). The muscle length influences the muscle tension, or force, and the angle of pull determines the length of the muscle moment arm (3, 42, 98). As torque is the product of force times its perpendicular distance from the axis of rotation (moment arm)(64), it is apparent why the length and angle of pull of the muscle is important.

In the human body, the total range of length changes a muscle can undergo is limited and varies from roughly 70% to 140% of the resting length (3, 96, 98). In general, the optimal length for producing tension is slightly greater than resting length - approximately 120% to 130% (3, 30, 96). Muscle lengths above or below the optimal length result in less tension being produced (3, 30, 96, 100).

An angle of pull of 90° corresponds to the largest muscle lever arm, and thus, the greatest mechanical advantage (3, 42, 98). Angles of pull smaller and larger than 90° represent smaller lever arm lengths, and thus, a lesser mechanical advantage (3, 98).

Williams and Stutzman (100) describe the relationship between angle of pull and muscle length:

> As the joint moves through its arc the 'prime mover' muscles become shorter, thereby declining in their ability to exert tension; at the same time the angle of application of the muscle force or forces usually becomes more advantageous.

The preceding statement would seem to imply that length and angle of pull act to offset each other and, thus, cause joint torques to be constant through the range of motion. Several studies, however, demonstrated that joint torques are not, in fact, constant through the range of motion (4, 9, 10, 12-14, 18, 19, 33, 39, 42, 51, 83, 86, 92, 100).

The knee extensors, for example, exhibit increases in torque as the leg moves from flexion to extension, reaching a maximum between 50° and 70° (9, 14, 17, 33, 53-55, 64, 73, 97, 100), with the 60° to 65° range being the most frequently reported (9, 53-55, 64, 97). After reaching the angle of peak torque, the torque begins to decline and reaches a minimum at full extension (9, 14, 33, 100). Figure 1 illustrates the changes in extensor torque which occur as a result of changing joint position.

In contrast to the knee extensor strength curve, which has a distinct maximal point, the knee flexor curve reflects a more gradual change in torque and, thus, the point of maximal torque is not as distinct (63, 67). The range of values reported for peak flexor torque is 10° to 45° (10, 14, 17, 53, 54, 59, 64, 73, 97, 100). Values appear to be fairly evenly distributed between approximately 10, 30 and 45° (10, 14, 17, 53, 54, 59, 64, 73, 97, 100).

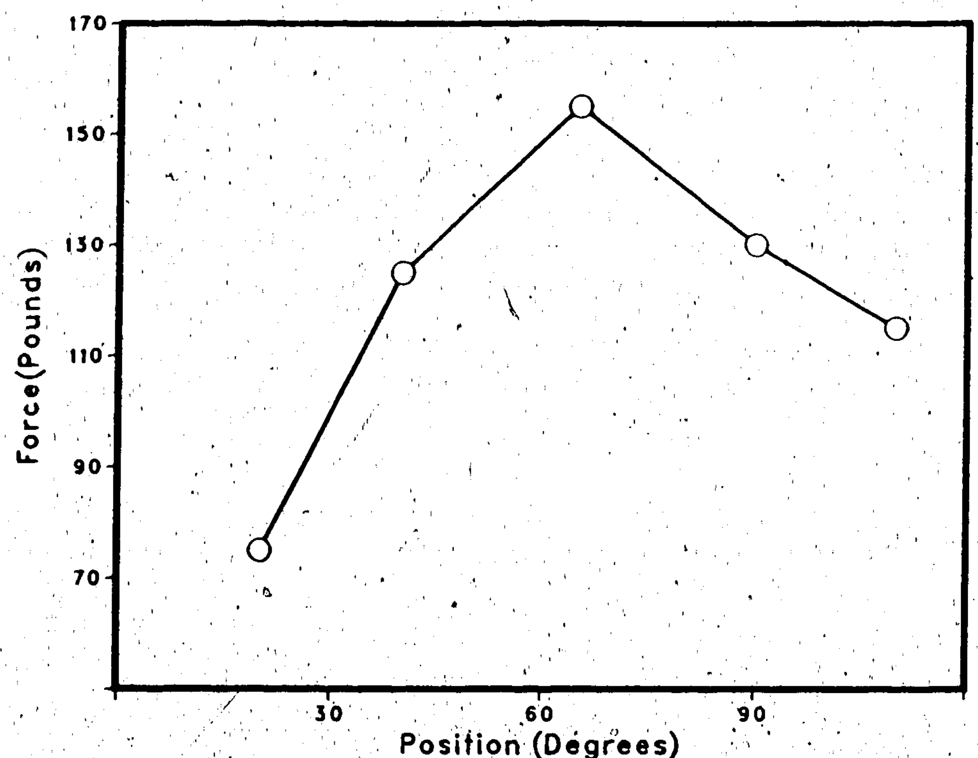

Figure 1: Strength Changes During Knee Extension

Adapted from Williams and Stutzman (100)

Figure 2 is representative of a typical knee flexor strength curve.

Both the knee flexors and extensors contain muscles which cross the hip joint as well as the knee joint. As a result, the position of the hip is important in determining the overall length of these muscles and, thus, the magnitude and angle of peak torque (13, 18, 19, 33, 35, 56). Discrepencies in the angles of peak torque, particularily for the knee flexors, may therefore be partly a result of researchers using different hip positions while assessing the knee.

As both the knee flexors and extensors exhibit the least torque when the muscles are shortest (51, 100), and for the most part demonstrate increased torque with lengthening of the muscles, the length-tension relationship appears to dominate over the angle of pull (51, 86, 100). However, it is important to remember that the torques produced at the knee joint, both in flexion and extension, are the result of several muscles acting as a group. Therefore, torque curves are reflective of the combined effects of the muscle length and angle of pull of the various involved muscles (3). As a result, the relative importance of muscle length and angle of pull at any specific point can only be determined through detailed analyses (51).

Movement Velocity

Velocity is another factor to consider when evaluating the torque output of a given muscle or muscle group. The results of past investigations indicate the amount of torque a muscle is capable of producing decreases as the movement velocity increases (7, 30, 69, 72, 75, 79, 83, 92, 95, 103). Richards (79), Scudder (83), and Thorstensson et al (95) all reported that the effect of velocity on knee extensor torque was angle-specific; the differences were greatest at the beginning of the range of motion tested when the muscles were nearest their normal resting length. Richards (79) and Scudder (83) also reported similar findings for the knee flexors. However, Scudder (83) did not indicate if the differences found for knee flexion were significant. Richards (79) found the effects of velocity on torque to be less dramatic for knee flexion.

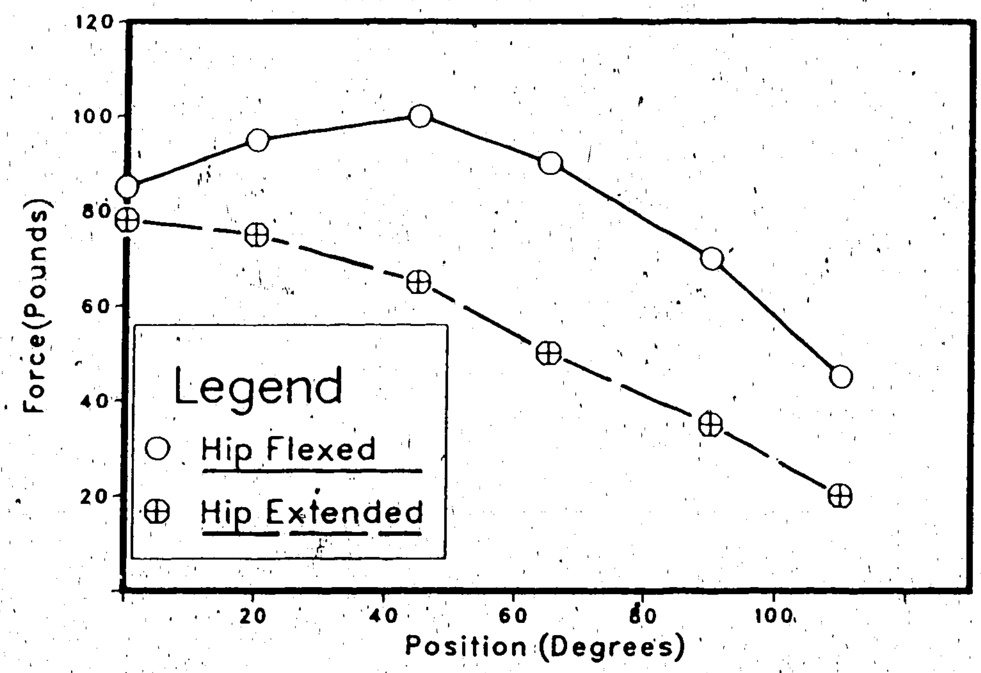

Figure 2: Strength Changes During Knee Flexion

Adapted from Williams and Stutzman (100)

In addition to causing torque output to decline, increasing velocity also results in a shift of the angle at which peak torque occurs (72, 73, 83, 92, 95). Generally, as velocity increases, the angle of peak torque shifts in the direction of the movement - the angle of peak extensor torque becomes smaller in contrast to the increase in the angle of peak flexor torque (assuming the extended position is zero degrees) (0°) (72, 73, 83, 92, 95).

Flexor:Extensor (F:E) Ratio

For approximately the last 25 years, those individuals involved with the prevention and rehabilitation of sports related injuries have asserted that the knee flexors must be a minimum of 60% as strong as the extensors if injury and/or re-injury is to be prevented (26, 45, 52, 70, 83). Although research concerning the F:E ratio had been conducted prior to that of Karl Klein (45-48), the literature seems to indicate that it is Klein's work that forms the basis of the aforementioned assertion (70).

Klein (45, 47, 48) used cable tensiometry for his research involving football players as subjects. The flexors were tested with the subject lying prone with the knee flexed 15°. In contrast, the extensors were evaluated with the subject seated and leaning back on extended arms and the knee flexed to an angle of 65°. Under these conditions, Klein found the F:E ratio to be approximately 60% (45, 47, 48).

In an earlier study, Houtz, Lebow, and Beyer (39) used strain gauges to assess the effect of posture on the strength of the knee flexors, extensors, and the associated F:E ratio. Subjects were examined in three postures (seated, supine, and prone) and seven knee positions (15, 30, 45, 60, 75, 90, and 105°). Generally, the F:E ratio was greatest at 15° and became progressively smaller as the knee was flexed to 105°. Although the same general pattern existed for all postures, the magnitude of the F:E ratio differed between postures. The differences between the three postures at each joint position is represented graphically in Figure 3. It can be readily seen that assessing the F:E ratio at different knee and/or hip positions can result in dramatically different outcomes.

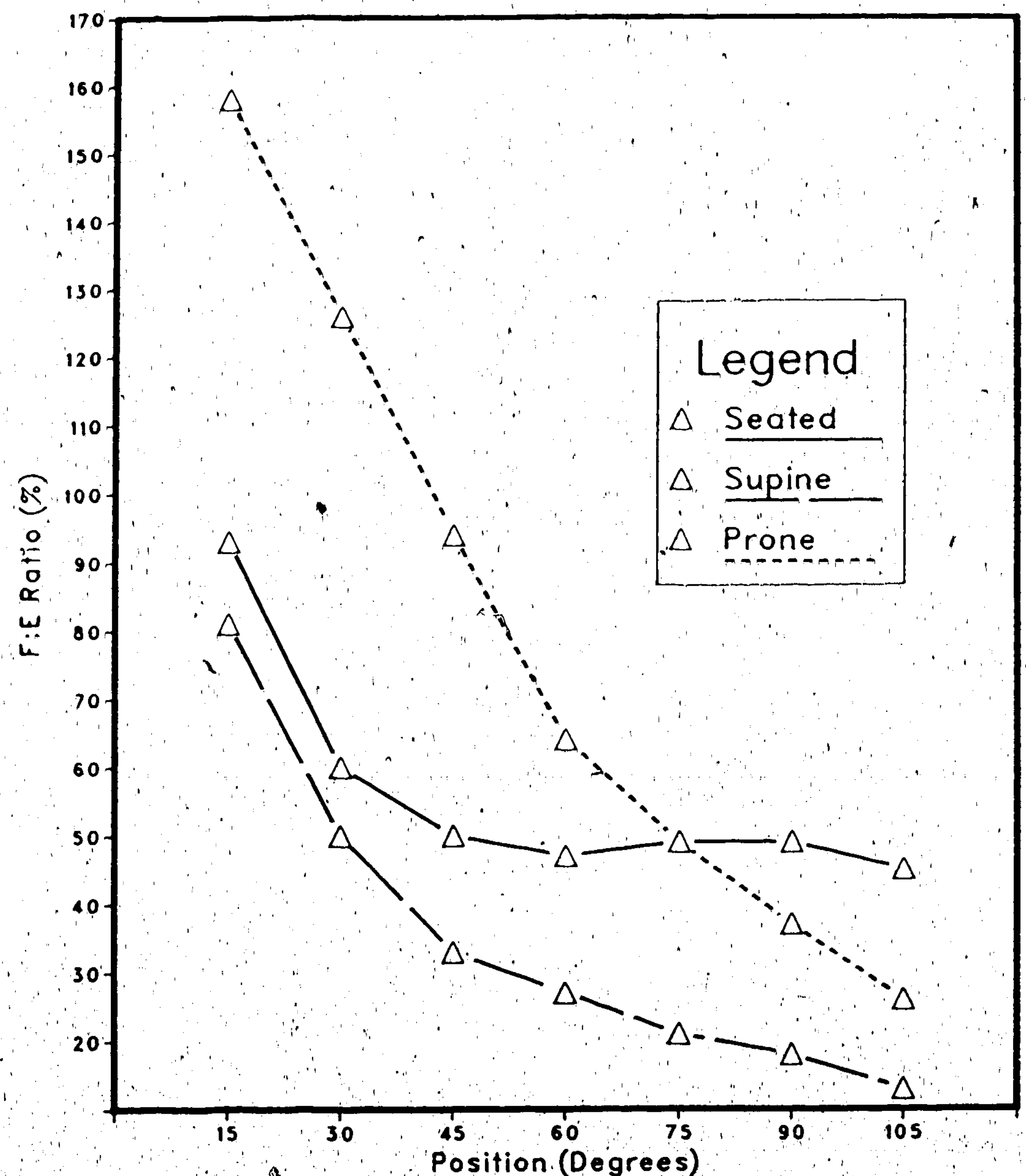

Figure 3: Flexor:Extensor Ratios of Different Postures

Adapted from Houtz, Lebow, and Beyer (39)

The introduction of isokinetic testing in the late 1960's allowed researchers to examine muscular performance under dynamic conditions which more closely approximated functional activities. Scudder (83) used normal male subjects to compare the F:E ratio at six different velocities 0, .31, .63, .94, 1.26, and 1.57r/s (0, 18, 36, 54, 72, and 90°/s). Using these velocities, the F:E ratio was found to be quite constant at approximately 62%. It is possible a significant difference was not found because the velocities Scudder (83) chose fell within a relatively small range, especially compared to those thought to be required for functional activities.

Wyatt and Edwards (103) examined knee function at 1.05, 3.14, and 5.24r/s (60,180, and 300°/s). An equal number of males and females were used in their study. No significant difference in the F:E ratio was found between the two groups. At 1.05, 3.14, and 5.24r/s (60,180, and 300°/s), the F:E ratio was found to be roughly 71%, 78%, and 84%, respectively. The increases in the F:E ratio with increasing velocity were found to be significant.

Whereas Wyatt and Edwards (103) used non-athletes as subjects, Morris et al (65) used 12 male collegiate middle-distance and distance runners. Subjects were tested both isometrically and isokinetically. The knee angle for isometric testing was 50° for both flexion and extension. Peak torques were used for isokinetic testing at velocities of .52, 1.05, 3.14, 4.19, and 5.24r/s (30, 60, 180, 240, and 300°/s). Isometric testing found the F:E ratio to be 74%. Little difference was found between .52 and 1.05r/s (30 and 60°/s). However, as the velocity was increased to 3.14, 4.19, and 5.24r/s (180, 240, and 300°/s), the F:E ratio increased to 76, 83, and 87% respectively.

Hagerman and Staron (34) studied seasonal variations among physiological variables in nine elite oarsmen. The F:E ratio was evaluated using six velocities (.50, 1.10, 2.10, 3.20, and 4.20r/s). The respective F:E ratios were approximately 69, 72, 75, 82, 92, and 114%.

Rankin and Thompson (78), starting with the 1976-77 school year, routinely tested all incoming athletes (freshmen and transfers, male and female) in all sports at Michigan State University. Angular velocities of 1.05r/s and 3.14r/s (60°/s and 180°/s) were used for the entire study and 5.24r/s (300°/s) beginning with the 1979-80 school year. At velocities of 1.05r/s and 5.24r/s (60°/s and 300°/s), no significant difference was found between males and females. At 1.05r/s (60°/s), the F:E ratio was approximately 62%; at 5.24r/s (300°/s) the F:E ratio was approximately 82%. At 3.14r/s (180°/s), males and females differed significantly; females had an F:E ratio of 71% and males had an F:E ratio of 76%. Means and standard deviations, according to gender and sport, for each of the three test velocities, are given in Figure 4. In general, the F:E ratio increased as velocity increased.

Sixty varsity football players were subjects in a study by Stafford and Grana (90). Three different velocities of 1.57, 3.14, and 5.24r/s (90, 180, and 300°/s) were used to measure the F:E ratio. Measurements were taken from both the dominant (leg used to kick soccer ball) and non-dominant legs. The dominant leg was found to have a significantly lower F:E ratio at all velocities. Changes in the F:E ratio were significant for both limbs, however. At 1.57, 3.14, and 5.24r/s (90, 180, and 300°/s) respectively, the values of the F:E ratio were (dominant/non-dominant) 67/68, 73/75, and 82/85%.

Berg and associates (5) examined muscular fitness of thirteen members of the 1982-83 women's basketball team at the University of Nebraska at Omaha. Both the right and left limbs were evaluated at velocities of 1.05, 2.09, 3.14, 4.19, and 5.24r/s (60, 120, 180, 240, and 300°/s). The respsective F:E ratios were (left/right) 67/63, 71/67, 74/72, 79/76, and 84/79%. It's interesting to note that the F:E ratio was lower in the right knee for all velocities; it was not reported if this difference was significant.

Although considerable research exists concerning the F:E ratio of the knee, very little research examines the effect of knee position on the magnitude of the ratio. However, the information that does exist indicates that the F:E ratio is significantly altered by changing the position of the joint (39, 66, 68). The majority of the literature deals with the effect of velocity on the F:E ratio (determined using peak torque of the flexors and extensors). Only Scudder (83) and Sitler (85) determined that the F:E ratio was *not* significantly altered by changes in velocity. The remaining researchers found that the F:E ratio was significantly

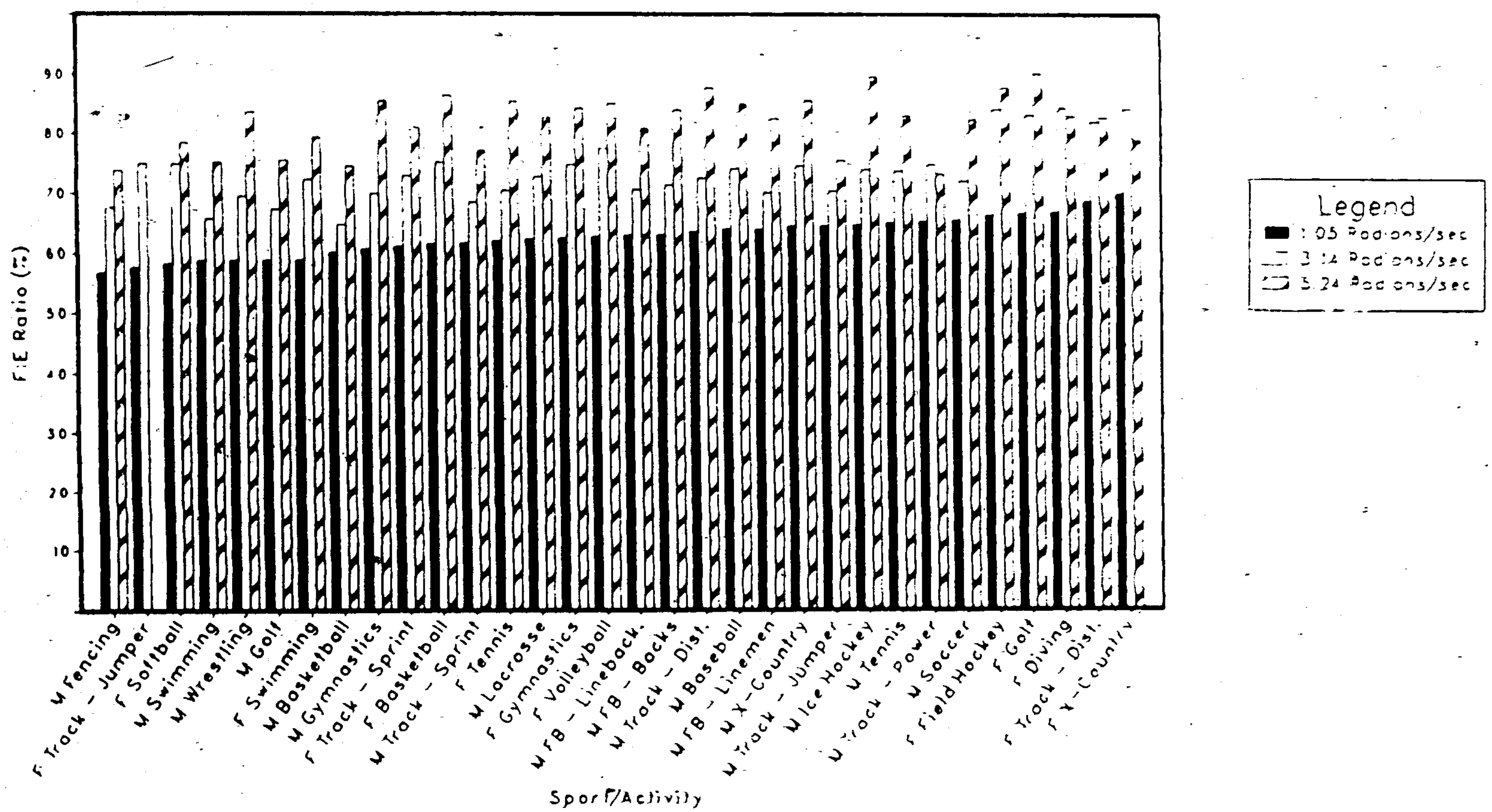

Figure 4: Peak F:E Ratios at 1.05, 3.14, and 5.24r/s

Adapted from Rankin and Thompson (78)

altered by alterations in movement velocity (2, 5, 8, 11, 23, 26, 31, 34, 38, 40, 65, 66, 68, 73, 78, 79, 82, 88, 94, 98, 103). With the exception of the data of Fillyaw et al (23), the F:E ratio increased as the velocity was increased.

Chapter III

METHODOLOGY

Subjects

After obtaining informed consent, thirty male athletes (volunteers) were assessed to determine the effect of knee position and velocity on the F:E ratio of the knee. The age range of the subjects was 18 to 30 years of age, with a mean age of 23.5 years. A summary of age and sport/activity characteristics of the sample is contained in Appendix A. Because maximum effort was required to ensure the accuracy of the test results, individuals with an athletic background who could be motivated to perform maximally were selected. As well, all subjects were without any chronic or acute injuries that may have effected the function of the knee, and thus, the accuracy of the measurements.

Measurement Apparatus

The Cybex II (Plate 1) measures muscular torque output in foot-pounds at pre-selected velocities from isometric contractions (0r/s) to faster functional velocities (5.24r/s; 300°/s). The unique feature of the Cybex II is related to its ability to control the velocity at which the lever arm moves. Once a velocity is selected, the lever arm cannot be accelerated beyond that velocity, regardless of the input torque. Therefore, increased muscular output encounters an equal counterforce, rather than increased accceleration, as would occur in conventional exercise machines (63).

Using a heated stylus, a dual channel recorder provides a print-out of torque and position (Appendix B) during the entire range of motion. The Cybex II has been reported to provide both valid (r=0.999)(64) and reliable (r=0.995 to 0.998) (64, 84) measurements. Validity was assessed using known loads applied to the Cybex II lever arm at specified angles in the range of motion (64). Cybex II measurements have also been determined to be reliable (r=0.93 to 0.99) when taken over a period of days (43).

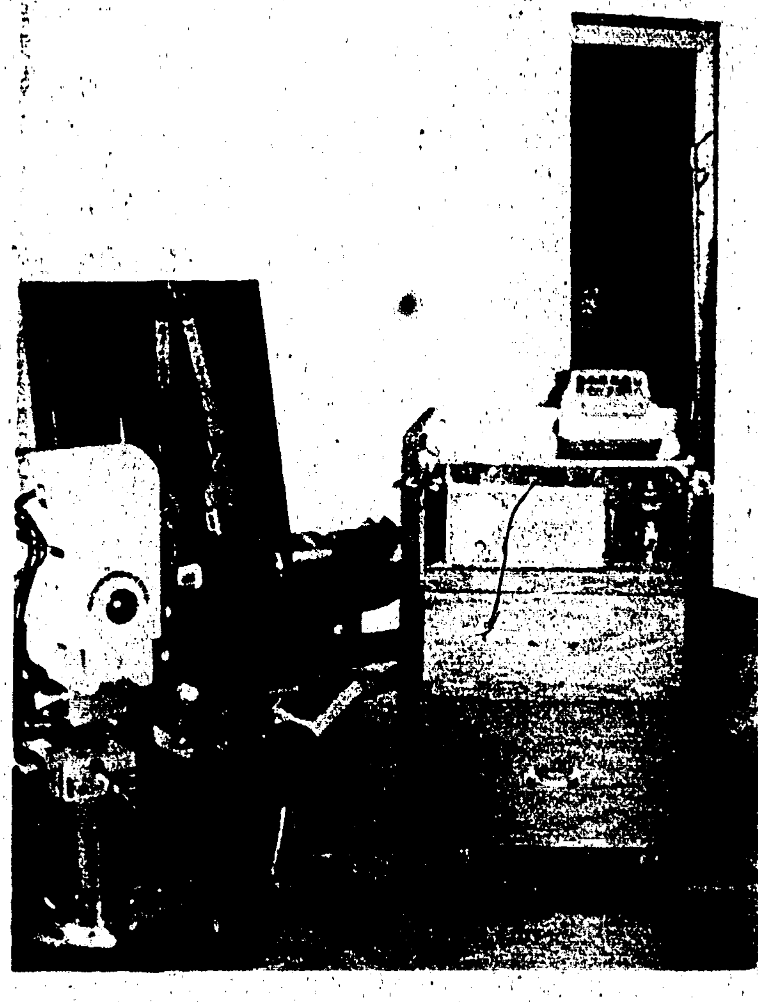

Plate 1: Measurement Apparatus: The Cybex II

Using the procedure outlined in Appendix C, the torque channel was calibrated at the beginning and at the end of each test day. Using the procedure in Appendix D, calibration of the electrogoniometer, which records joint position, was also conducted before and after each test day.

General Procedures

Subjects were required to be available for two sessions, separated by no more than one week. The first session was used to allow subjects to practice and become familiar with isokinetic exercise and to allow the researcher to screen subjects for any previously unrecognized pathologies that may have put the subject at risk and/or prevented accurate measurement of torque output. Measurements required for data analysis were taken from the second session only. All subjects were asked to refrain from participating in any strenuous physical activity on the day of their test. All subjects were required to warm up prior to commencement of the actual test procedure. The warm-up consisted of stretching and other exercises of the subject's choice as well as a standard warm-up on the test apparatus. The standard warm-up consisted of three repetitions at each of the five test velocities. The order of velocities was standard - 2.09, 3.14, 4.19, 1.05, and .52r/s (120, 180, 240, 60, and 30°/s).

Positioning and Stabilization

Each subject was seated in the test chair with the chair back maintained at an angle of 100° to the seat. Back spacer pads were utilized, if necessary, to ensure the relationship between the back support and the seat was maintained if the subject needed to be moved forward for correct alignment and positioning of the knee. The axis of rotation of the knee was aligned with that of the dynamometer. The right leg of each subject was fixed and locked in the start position of zero degrees (0°) of flexion (Plate 2), as measured via manual goniometer, by turning the velocity selector control to zero radians per second (0r/s). Reference points for determining zero degrees (0°) flexion included the greater trochanter,

Plate 2: Positioning and Stabilization of Subjects

lateral femoral condyle, and lateral malleolus.

Stabilization of each subject was achieved by using the shin pad and thigh straps (both thighs were secured) provided by Cybex II. As well, an adjustable shoulder harness and seatbelt was used for upper body and hip stabilization. For comfort, football thigh pads were placed under the straps at the hips and knees. A folded towel was placed under the shoulder straps. Subjects were asked to grasp the side handgrips for further stabilization and to ensure consistent hand positioning.

Testing Procedure

Once the subject was positioned and stabilized, the standard warm-up was conducted. Each subject was then allowed a three minute rest prior to beginning the test. During this time, any necessary adjustments in position and/or stabilization were made.

At the end of the three minute rest period, the subject was asked to assume the start position. The Cybex II Dual Channel Recorder was checked to ensure that the appropriate torque and position scales had been selected. With the velocity selector set at one of the five test velocities, the order of which was randomly assigned, and the chart recorder set at 25mm/s, each subject was asked to perform five maximal leg flexion and extension movements. At the completion of five repetitions, the subject rested for two minutes prior to continuing to the next velocity. Peak torque and torque output at 30, 45, 60, 75, and 90° were measured from the torque curves on the printout utilizing the Cybex II Chart Data Card (Appendix E). Torque output was not measured at zero degrees (0°) because most subjects could not reach this position at the slowest velocities. Measurements were not taken at 15° because of the presence of the "torque overshoot phenomenon" during flexion. The mean of all five repetitions was used for data analysis. See Appendix F and Appendix G for samples of data record sheets.

Data Analysis

Mean torque values of the flexors and extensors were converted to Newton-meters (Nm) and were recorded for peak torque and torque at 30, 45, 60, 75, and 90° at velocities of .52, 1.05, 2.09, 3.14, and 4.19r/s (30, 60, 120, 180, and 240°/s). The F:E ratio was then calculated using these results. Angles of peak flexor and extensor torque were also recorded.

The effects of knee position and angular velocity on angle-specific flexor torque, extensor torque, and the associated F:E ratios were analyzed using analysis of variance (ANOVA) statistical programs with repeated measures. Peak flexor and extensor torque, peak F:E ratios, and the angles of peak flexor and extensor torque also used ANOVA with repeated measures to examine the effects of angular velocity.

With repeated measurement designs, there is concern that performance under prior treatments may effect performance under subsequent treatments, resulting in carry-over effects that may obscure the true meaning of the results (22). In the present investigation, randomization of the order of test velocities was utilized to surmount the potential problem of carry-over effects with respect to velocity. The nature of testing, however, did not allow for the same measures to be taken to prevent possible carry-over effects of position. Therefore, in order to determine if carry-over effects may have been operating, two analyses were conducted on the angle-specific data. The first analysis used repeated measures for both velocity and position and was designated as the repeated measures analysis of variance (RMANOVA). The second analysis randomly grouped subjects according to position and used repeated measures on velocity only. Therefore, it was designated as the grouped analysis of variance (GANOVA). All analyses, including those examining peak variables, accepted significance at the $P \leq 0.05$ level of confidence. Scheffe's method of multiple contrasts was used to determine where significant differences occurred. Significance was accepted at the $P \leq 0.05$ level of confidence.

Chapter IV

RESULTS AND DISCUSSION

Repeated measures analysis of variance (RMANOVA) and grouped analysis of variance (GANOVA) both revealed significant main and interaction effects for both the knee flexors and extensors ($P \leq 0.05$). However, the number of significant position and interaction contrasts was reduced when GANOVA was used. Repeated measures analysis of variance (RMANOVA) of the flexor:extensor (F:E) ratio revealed that both main and interaction effects were significant ($P \leq 0.05$). In contrast, the GANOVA revealed that position and interaction effects remained significant, whereas velocity effects did not. The number of position and interaction contrasts was substantially reduced when GANOVA was used to analyze the data. The only significant velocity contrast using RMANOVA (1.05r/s vs. 4.19r/s) was insignificant when GANOVA was used.

The means of both analyses are represented graphically in Figures 5,6, and 7. It can be seen that the means of the two analyses are very similar. As the sample size per group, and, therefore, the degrees of freedom, for GANOVA ($n=6$) was considerably smaller than that of RMANOVA ($n=30$), it is not possible to determine with certainty if the contrasting results of the two analyses was due to carry-over effects or the differences in sample size/degrees of freedom.

The order of the positions through which the knee passes is determined by the structure and function of the knee and therefore cannot be altered if continuous movement is to occur. Therefore, provided movement during testing is continuous, the use of RMANOVA may be more appropriate as it reflects the actual order of events in functional activities. It does, however, introduce a degree of dependence among the repeated measures which would not be present in the GANOVA. Consequently, the discussion of the results will be based upon the results obtained using RMANOVA. The means and standard deviations of the GANOVA data are found in Appendix H.

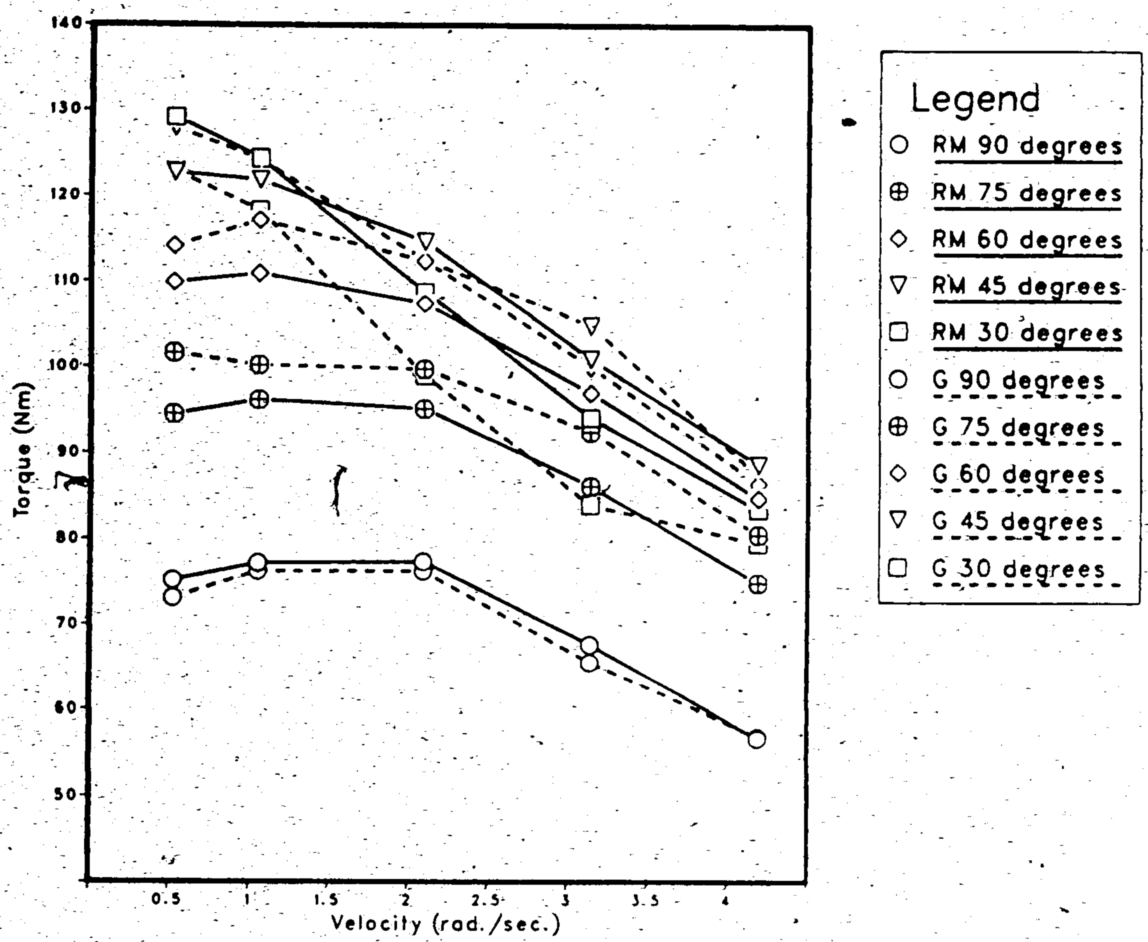

Figure 5: Angle-specific Flexor Torque
Results of RMANOVA (RM) and GANOVA (G)

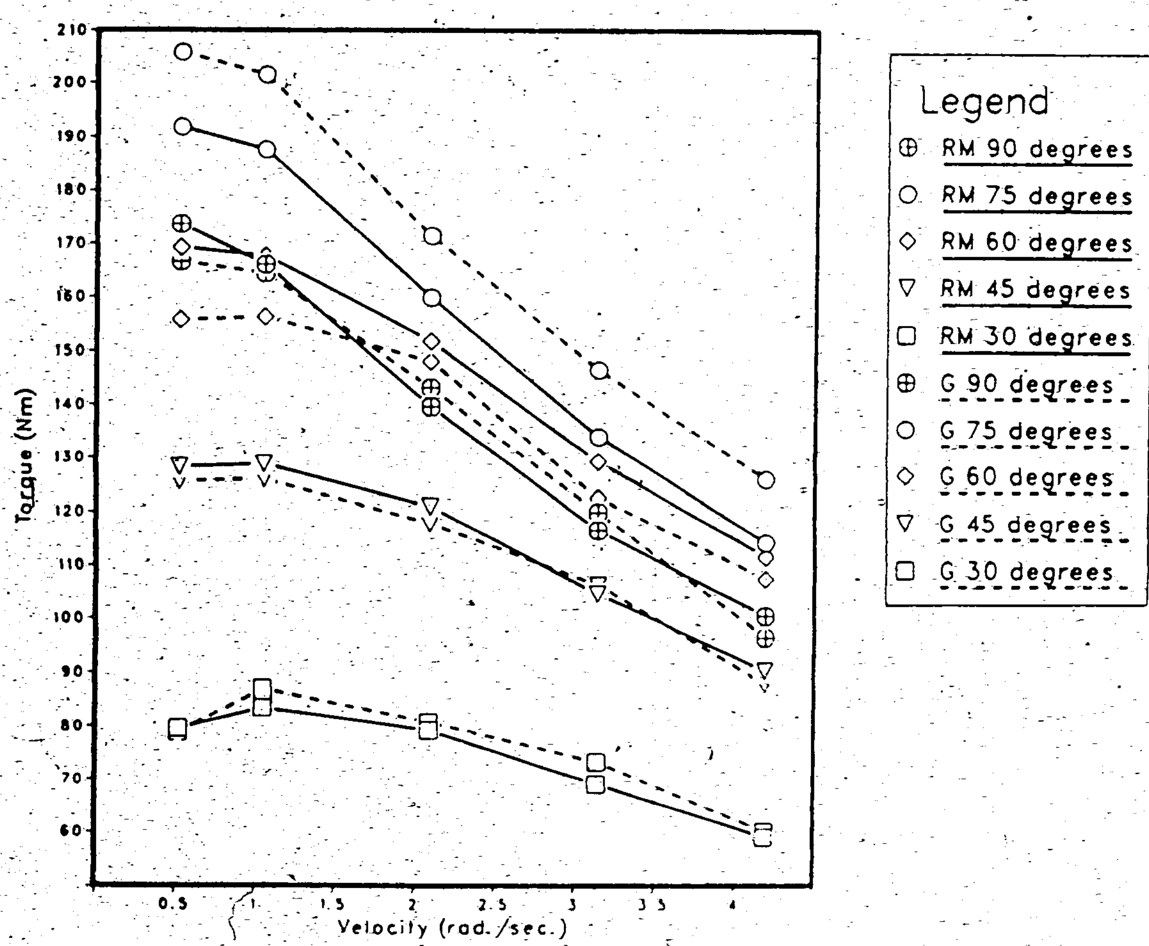

Figure 6: Angle-specific Extensor Torque
Results of RMANOVA (RM) and GANOVA (G)

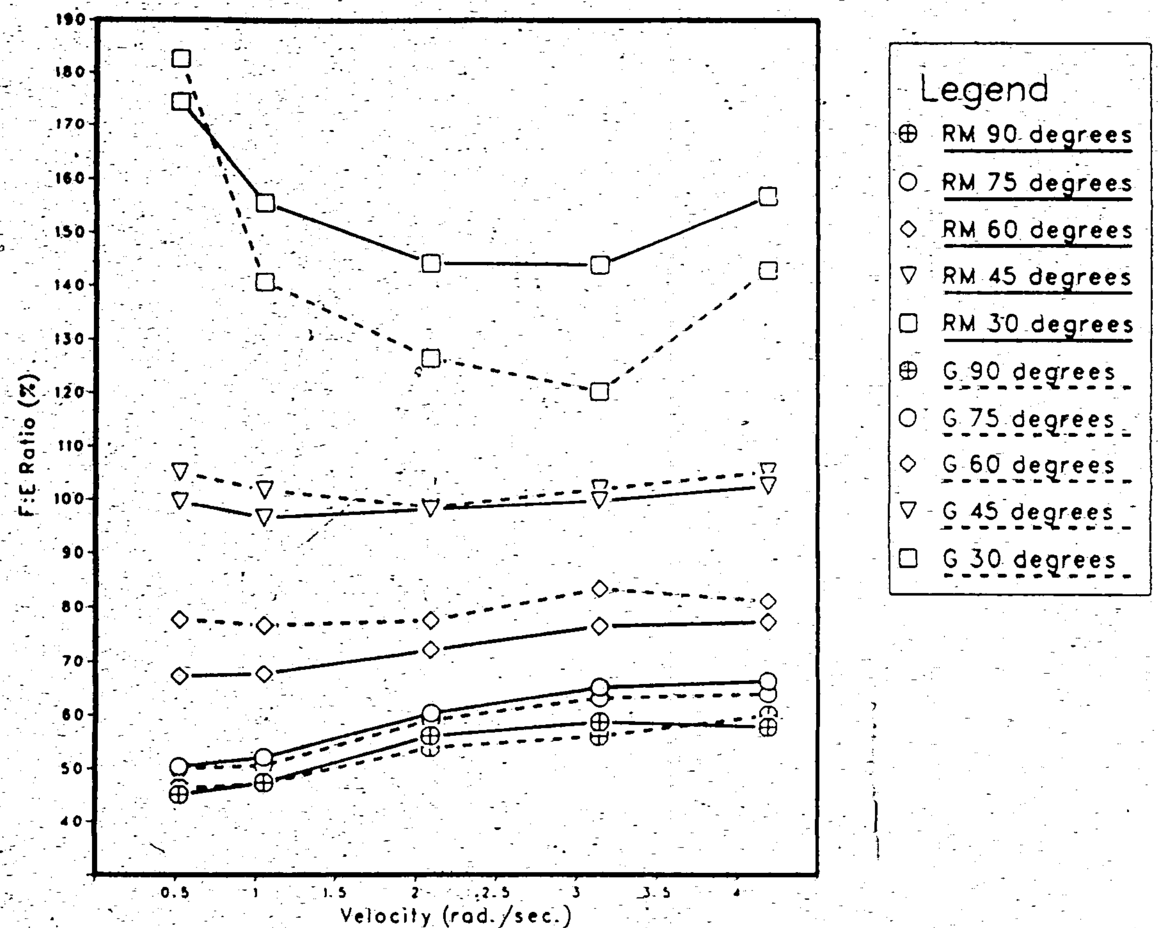

Figure 7: Angle-specific Flexor:Extensor (F:E) Ratios
Results of RMANOVA (RM) and GANOVA (G)

The remainder of the results and discussion are presented in three major sections: Torque of the Flexors and Extensors, Angle-specific Flexor:Extensor (F:E) Ratios, and Peak F:E Ratios.

Torque of the Flexors and Extensors

The torque output of the knee flexors and extensors was examined at 15° increments as the leg moved at velocities of .52, 1.05, 2.09, 3.14, and 4.19r/s (30, 60, 120, 180, and 240°/s). The respective means and standard deviations are presented in Table 2. A graphic presentation of the results for the flexors and extensors are illustrated in Figures 8 and 9, respectively.

Figures 8 and 9 illustrate that torque output varies considerably with the position of the joint and the velocity of the movement. Repeated measures analysis of variance (RMANOVA) confirmed that main and interaction effects were significant ($P \leq 0.05$). Multiple contrasts of velocity and position main effects revealed:

1. Significant differences existed between all velocities, with the exception that .52r/s (30°/s) was *not* different from 1.05r/s (60°/s), for both the flexors and extensors.
2. In flexion, all positions were significantly different, with the exception that 30° was *not* different from 45°.
3. In extension, 60° was *not* significantly different from 90°; all other contrasts were significantly diffefent.

The results of the interaction contrasts for the flexors are presented in Table 3. The large number of significant contrasts makes detailed discussion impossible. However, some important features include:

1. *All* contrasts between 45° and 90° are significant.
2. At velocities less than 2.09r/s (120°/s), changes in torque resulting from an increase in velocity are minimal and, with a few exceptions, are *not*

Table 2

Means and Standard Deviations of the Knee Flexors and Extensors

Velocity (r/s)	Position (Deg.)	Flexors Mean	Flexors SD	Extensors Mean	Extensors SD
	30	129.17	26.88	79.60	24.54
	45	122.72	22.01	128.22	31.07
.52	60	109.89	18.33	169.31	36.82
	75	94.53	16.77	191.77	38.52
	90	75.20	15.05	173.65	36.69
	30	124.35	24.48	83.45	21.75
	45	121.86	20.94	128.78	27.36
1.05	60	110.93	18.06	167.75	31.51
	75	96.22	16.37	187.58	32.22
	90	77.22	15.28	166.14	24.40
	30	108.75	22.81	79.18	21.70
	45	114.70	18.77	120.91	26.41
2.09	60	107.35	16.80	151.83	26.89
	75	95.12	14.86	159.91	25.90
	90	77.36	13.94	139.67	26.12
	30	94.13	20.64	69.09	21.90
	45	110.94	17.97	104.63	25.45
3.14	60	97.04	15.58	129.29	24.56
	75	86.19	13.37	134.03	21.94
	90	67.64	13.00	116.51	21.60
	30	83.44	17.74	58.96	22.08
	45	88.68	16.29	90.28	23.76
4.19	60	84.75	14.50	111.61	21.97
	75	74.89	13.90	114.22	20.20
	90	56.72	15.58	100.48	19.28

n=30
Torque is in Nm

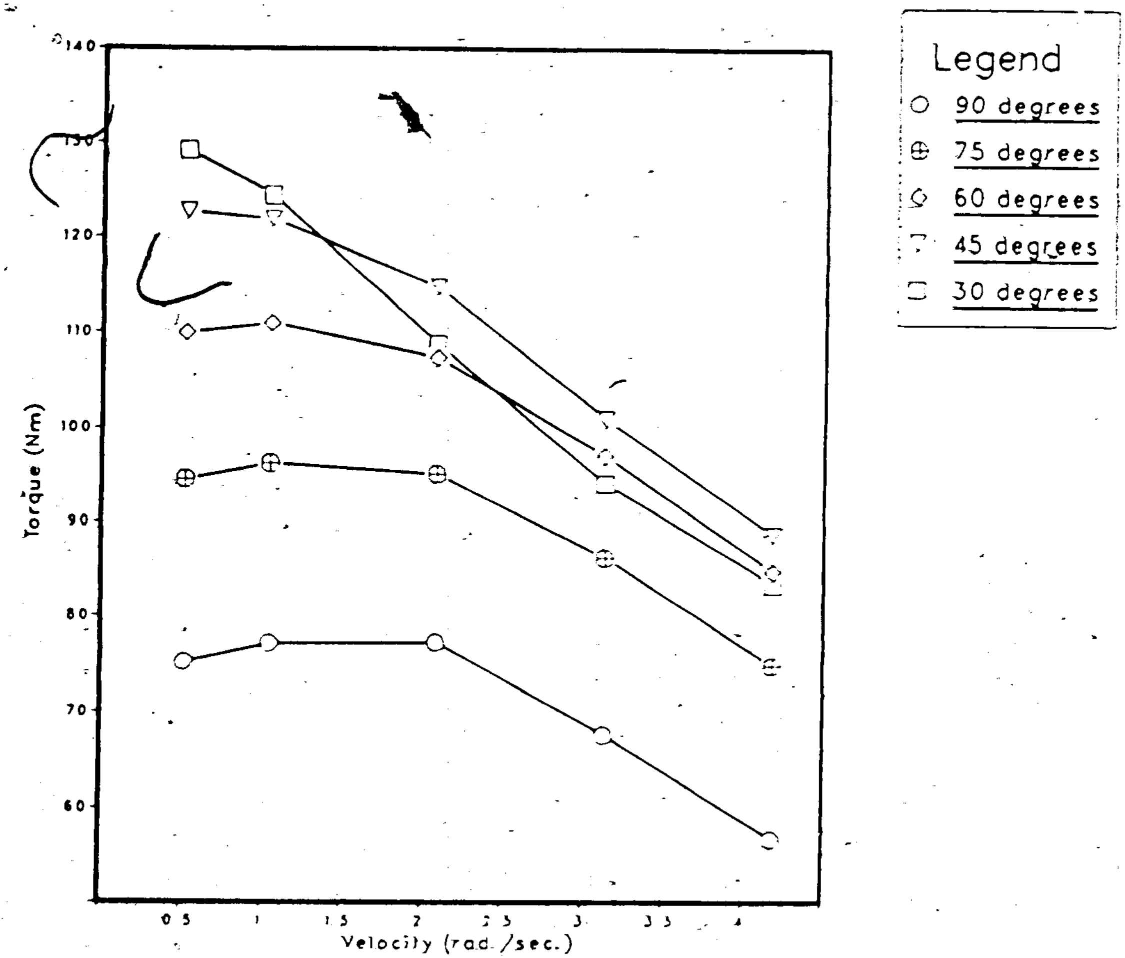

Figure 8: Angle-specific Flexor Torque

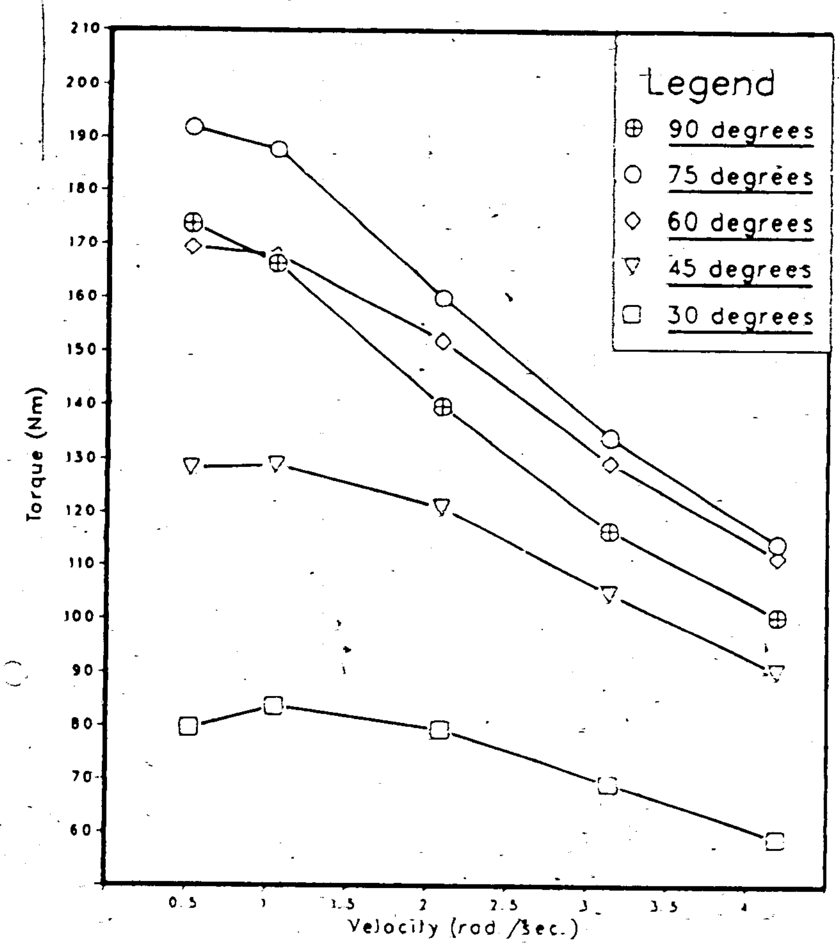

Figure 9: Angle-specific Extensor Torque

Table 3

Contrasts of Knee Flexion Torque at Selected Joint Angles and Angular Velocities†

Pos		30				45					60					75					90				
Pos	Vel	1.05	2.09	3.14	4.19	.52	1.05	2.09	3.14	4.19	.52	1.05	2.09	3.14	4.19	.52	1.05	2.09	3.14	4.19	.52	1.05	2.09	3.14	4.19
30	.52		•	•	•			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	1.05		•	•	•			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	2.09			•	•	•	•		•	•			•	•	•	•	•	•	•	•	•	•	•	•	•
	3.14				•	•	•	•			•	•	•		•				•	•	•	•	•	•	•
	4.19					•	•	•	•		•	•	•	•		•	•	•		•	•			•	•
45	.52							•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	1.05								•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	2.09								•	•				•	•	•	•	•	•	•	•	•	•	•	•
	3.14									•	•	•			•				•	•	•	•	•	•	•
	4.19										•	•	•	•						•	•	•	•	•	•
60	.52													•	•	•	•	•	•	•	•	•	•	•	•
	1.05													•	•	•	•	•	•	•	•	•	•	•	•
	2.09													•	•	•	•	•	•	•	•	•	•	•	•
	3.14														•				•	•	•	•	•	•	•
	4.19															•	•	•		•	•			•	•
75	.52																		•	•	•	•	•	•	•
	1.05																		•	•	•	•	•	•	•
	2.09																		•	•	•	•	•	•	•
	3.14																			•	•	•	•	•	•
	4.19																								•
90	.52																								•
	1.05																							•	•
	2.09																							•	•
	3.14																								•

† Velocities are in radians per second
*Significant difference (P≤0.05)

significant. In contrast, at velocities greater than 2.09r/s (120°/s), decreases in torque were more dramatic and were significant.

3. As the leg is flexed, the ability of the muscles to produce torque is diminished, with the largest decreases occurring between positions of greater flexion (ie: 75° and 90°).

Interaction contrasts for the knee extensors are presented in Table 4. The important features evident in Table 4 and Figure 9 include:

1. With a few exceptions, torque at 30° is significantly less than torque at all other positions evaluated.
2. Decreases in torque with increasing velocity are evident almost immediately - at all positions torque begins to decrease at velocities greater than 1.05r/s (60°/s). The decrease in torque, however, is more pronounced and produces more significant differences at the positions of greatest flexion.
3. As the leg extends, the ability of the muscles to produce torque is diminished, with the largest decreases occurring between positions of greater extension (ie: 45° and 30°).

The considerable variation in torque output of both the knee flexors and extensors, as illustrated through Figures 8 and 9, demonstrates the angle of pull and length-tension relationships discussed earlier. These relationships, as well as the force-velocity relationship, are also depicted when angle-specific torque is expressed as a percentage of peak torque (Figures 10 and 11). Peak torques and the angles of peak torque at each velocity, for both the flexors and extensors, are presented in Table 5.

Both the flexors and extensors produce the most torque *near* the beginning of their respective range of motion (ie: 0° for the flexors and approximately 105° for the extensors), indicating that the length-tension relationship is the dominant factor in determining torque through the range of motion. As a result, as the leg moves through a range of motion, one

Table 4

Contrasts of Knee Extension Torque at Selected Joint Angles and Angular Velocities†

Pos.		30				45					60					75					90				
Pos.	Vel.	1.05	2.09	3.14	4.19	.52	1.05	2.09	3.14	4.19	.52	1.05	2.09	3.14	4.19	.52	1.05	2.09	3.14	4.19	.52	1.05	2.09	3.14	4.19
	.52				*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	1.05			*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30	2.09				*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	3.14					*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*
	4.19					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	.52								*	*	*	*	*		*	*	*	*		*	*	*			*
	1.05								*	*	*	*	*		*	*	*	*		*	*	*			*
45	2.09								*	*	*	*	*			*	*	*			*	*	*		*
	3.14									*	*	*	*	*		*	*	*	*		*	*	*		
	4.19										*	*	*	*	*	*	*	*	*	*	*	*	*	*	
	.52												*	*	*	*	*		*	*			*	*	*
	1.05												*	*	*	*	*		*	*			*	*	*
60	2.09													*	*	*	*		*	*	*	*		*	*
	3.14														*	*	*	*		*	*	*			*
	4.19															*	*	*	*		*	*	*		
	.52																	*	*	*	*	*	*	*	*
	1.05																	*	*	*	*	*	*	*	*
75	2.09																		*	*			*	*	*
	3.14																			*	*	*		*	*
	4.19																				*	*	*		
	.52																						*	*	*
	1.05																						*	*	*
90	2.09																							*	*
	3.14																								*

†Velocities are in radians per second
*Significant difference (P≤0.05)

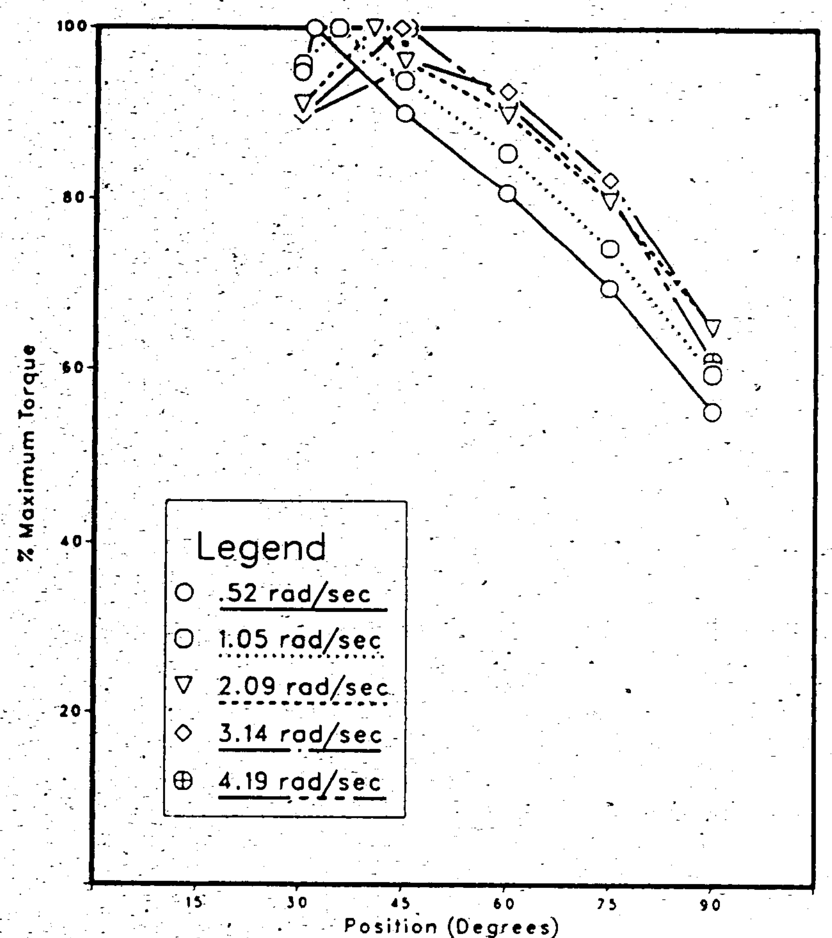

Figure 10: Flexor Torque Curves at Five Selected Velocities

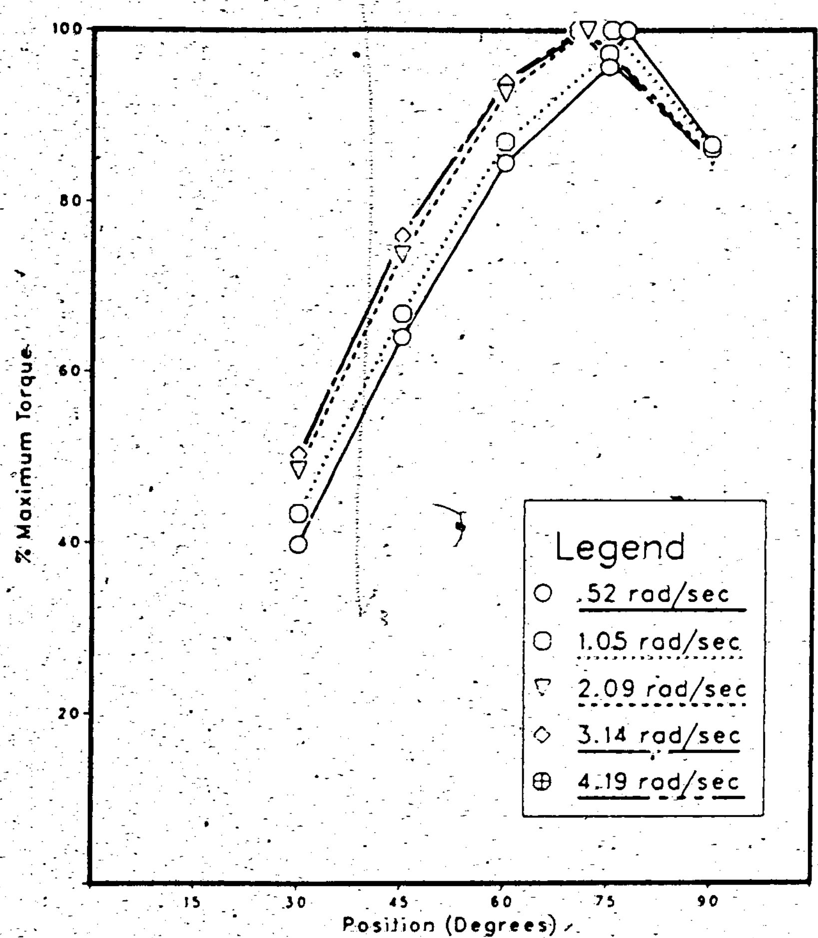

Figure 11: Extensor Torque Curves at Five Selected Velocities

Table 5

Peak Torque and Angle of Peak Torque
of the Flexors and Extensors

Velocity	Flexors				Extensors			
	Torque		Angle		Torque		Angle	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
.52r/s	136.02	26.18	31.73	8.05	200.40	37.87	77.63	7.74
1.05r/s	129.67	23.76	35.28	6.64	192.81	31.17	75.38	6.86
2.09r/s	119.21	19.95	40.49	7.54	163.99	26.25	71.87	6.59
3.14r/s	104.59	18.51	44.46	8.43	137.81	23.61	71.49	5.49
4.19r/s	92.94	17.19	45.41	10.24	111.61	22.10	70.57	7.47

Torque is in Nm
Angles are in Degrees

muscle group becomes stronger while the other becomes weaker. Therefore, it is expected that the F:E ratio would favour the flexors at one end of the range of motion, become neutral in mid-range, and finally favour the extensors at the opposite end of the range of motion.

Figure 12 compares the absolute torque output between the flexors and extensors at each of the five test angles. The changing relationship between the flexors and extensors is very apparent. Some notable features found in Figure 12 include:

1. At a position of 45°, torque of the flexors and extensors is approximately equal; the F:E ratio is approximately 100%.
2. At all positions, the decrease in torque of the two muscle groups is approximately parallel from 2.09r/s (120°/s) to 4.19r/s (240°/s). As the leg moves towards extension, there is also a tendency for the decrease in torque from .52r/s (30°/s) to 2.09r/s (120°/s) to become more parallel.

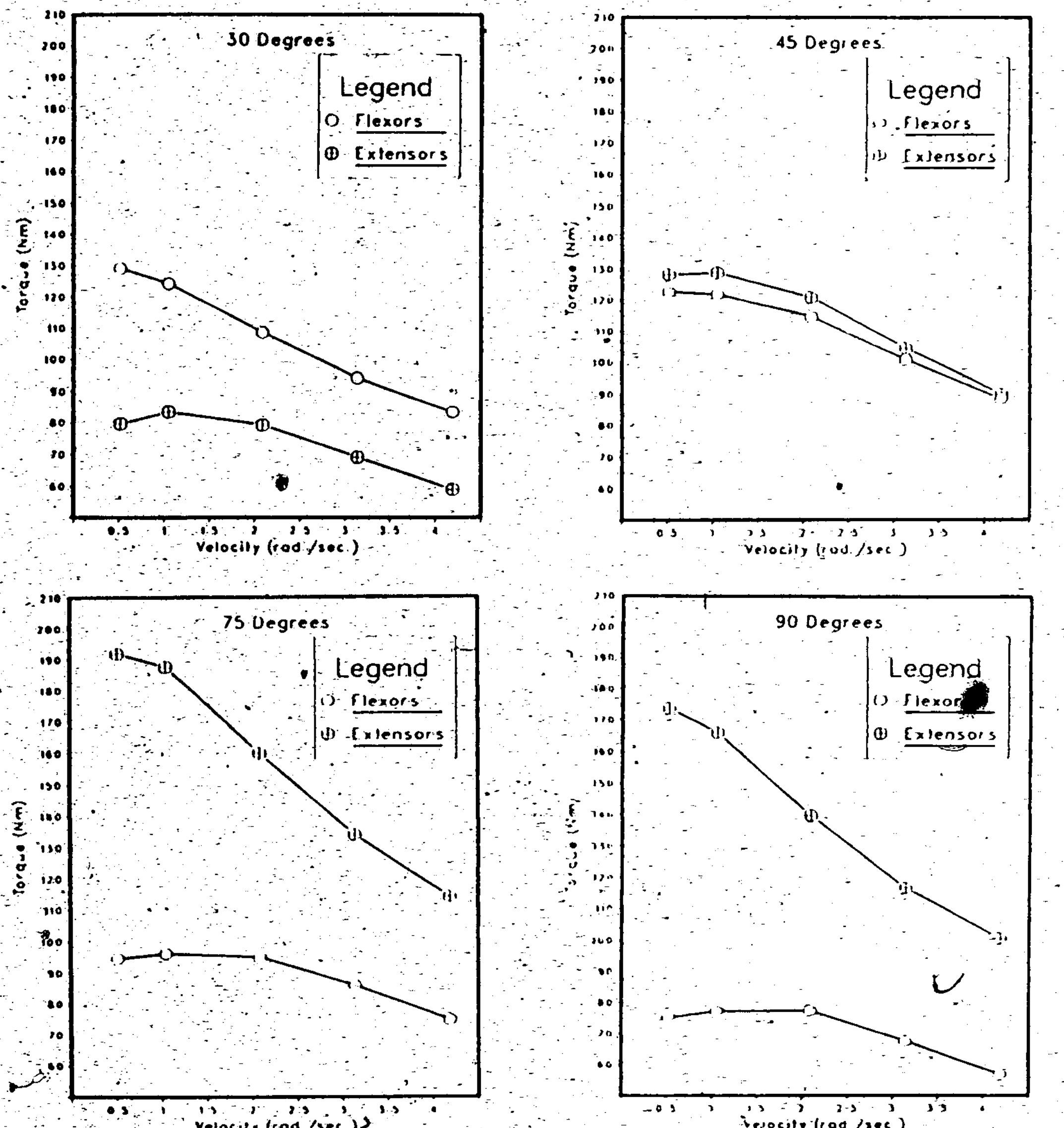

Figure 12:
Comparison of Angle-specific
Flexor and Extensor Torque

3. The effect increasing velocity has on torque appears to be angle-specific, especially for the knee extensors. In general, the greater decreases are seen at those angles producing the greatest torque.
4. As suggested earlier, the relationship between the flexors and extensors favours the flexors in the most extended position, becomes neutral near the middle of the range of motion (45°), and finally favours the extensors at the positions of greatest flexion.

Although the preceding results indicate that both position and velocity act to influence the torque of both the flexors and extensors, it appears that position plays a greater role in producing differences in the F:E ratio. The changes in the relationship between the muscle groups as the leg moves through the range of motion are easily seen upon examination of Figure 12. Although changes in the relationship between the muscle groups do occur as the velocity is increased, they are not as distinct and it is questionable as to whether or not the differences are significant and would produce changes in the F:E ratio.

Angle-specific Flexor:Extensor (F:E) Ratios

In general, it can be said that the F:E ratio increased as the knee moved from flexion to extension, for all velocities evaluated. Further, with the exception of 30°, there was a general trend for angle-specific F:E ratios to gradually increase as movement velocity was increased. At 30°, however, the F:E ratio was largest at the lowest velocity and then decreased with successive velocities, reaching a minimum at 3.14r/s (180°/s) before rising to a second peak at 4.19r/s (240°/s). The aforementioned trends can be recognized in Figure 13. Table 6 summarizes the means and standard deviations of the data.

The RMANOVA of the data revealed that there were significant main effects as well as significant interaction effects ($P \leq 0.05$). When considering velocity main effects, Scheffe's method of multiple contrasts revealed 1.05r/s (60°/s) and 4.19r/s (240°/s) to differ significantly ($P \leq 0.05$). Multiple contrasts of position main effects revealed all but one of the

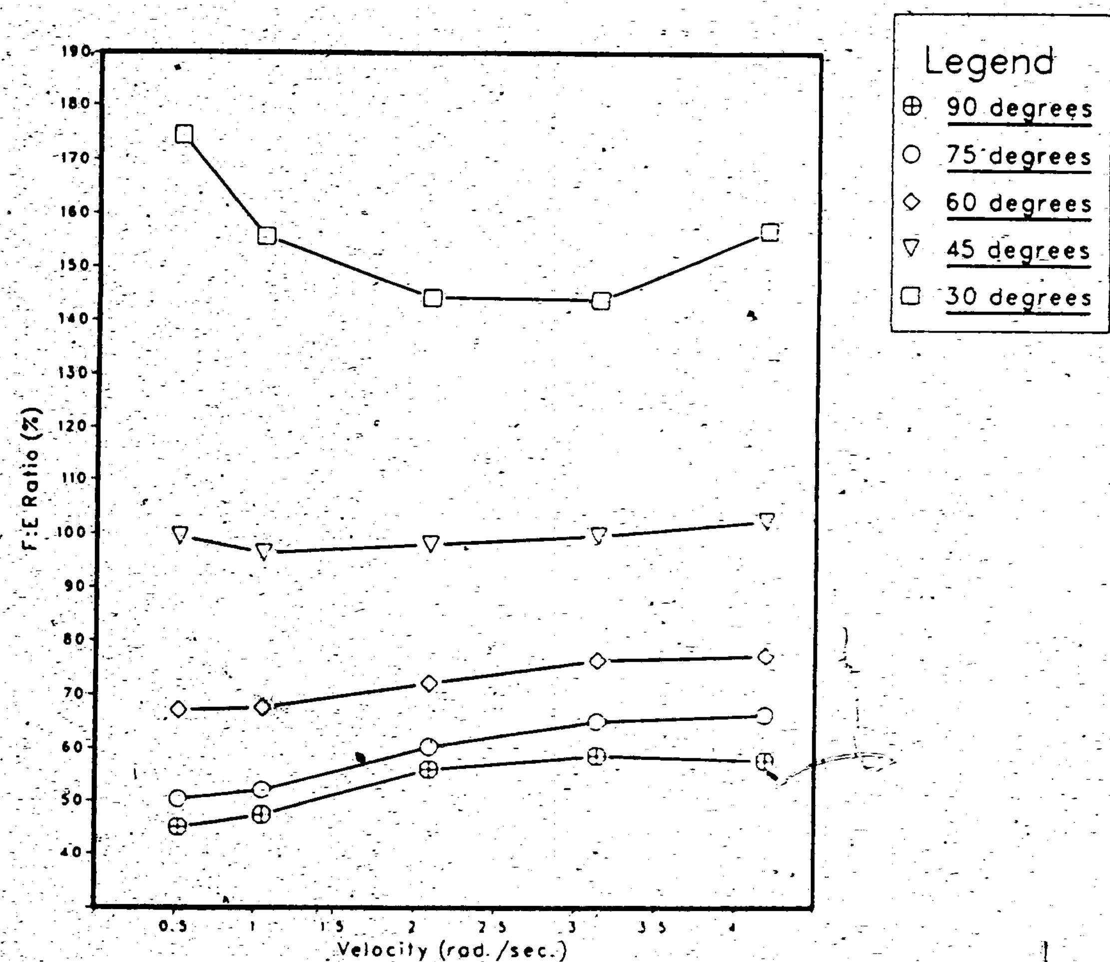

Figure 13: Angle-specific Flexor:Extensor (F:E) Ratios

Table 6

Means and Standard Deviations of the Flexor:Extenor (F:E) Ratio

Velocity (r/s)	Position (Deg.)	F:E Ratio Mean	SD
	30	174.46	49.18
	45	99.45	19.26
.52	60	67.17	13.63
	75	50.38	9.68
	90	45.16	10.84
	30	155.56	34.90
	45	96.37	16.70
1.05	60	67.62	11.21
	75	52.12	8.38
	90	47.43	8.41
	30	144.14	39.98
	45	98.03	19.48
2.09	60	72.12	11.64
	75	60.29	9.00
	90	56.10	8.36
	30	143.83	36.47
	45	99.74	19.86
3.14	60	76.49	12.08
	75	65.12	9.16
	90	58.70	11.40
	30	156.88	54.93
	45	102.56	23.29
4.19	60	77.30	11.73
	75	66.32	10.47
	90	57.75	16.78

n=30

possible contrasts to be significant - 90° was *not* different from 75°.

Interaction effects produced a large number of multiple contrasts, the results of which are presented in Table 7. Some of the more notable contrasts, which are suggested through examination of Figure 13, can be summarized as follows:

1. Regardless of velocity, 30° is significantly different from the remaining

Table 1

Contrasts of E-F Ratios at Selected Joint Angles and Angular Velocities†

Pos.		30				45					60					75					90				
Pos.	Vel.	1.05	2.09	3.14	4.19	.52	1.05	2.09	3.14	4.19	.52	1.05	2.09	3.14	4.19	.52	1.05	2.09	3.14	4.19	.52	1.05	2.09	3.14	4.19
	.52		*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	1.05					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30	2.09					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	3.14					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	4.19					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	.52										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	1.05										*	*	*			*	*	*	*	*	*	*	*	*	*
45	2.09										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	3.14										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	4.19										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	.52																				*				
	1.05																				*				
60	2.09															*					*	*			
	3.14															*	*				*	*	*		
	4.19															*	*				*	*	*		
	.52																								
	1.05																								
75	2.09																								
	3.14																								
	4.19																				*				
	.52																								
	1.05																								
90	2.09																								
	3.14																								

† Velocities are in radians per second
*Significant difference ($P \leq 0.05$)

four positions at all five velocities. With a few exceptions, 45° is also significantly different from all other positions at all velocities.

2. Only 30° demonstrates any difference with velocity - .52r/s (30°/s) is different from 2.09r/s (120°/s) and 3.19r/s (180°/s).
3. When contrasting 75° with 90°, only one contrast (75° at 4.19r/s or 240°/s vs. 90° at .52r/s or 30°/s) is significant.

Figure 13 illustrates that changing joint positions produces distinct changes in the F:E ratio. In contrast, changes in velocity produced insignificant changes in the F:E ratio at all positions except 30°. It is interesting, therefore, that very few studies report on the relationship between position and the F:E ratio; most deal only with the effects of velocity on F:E ratios which have been determined using peak torque.

Houtz, Lebow, and Beyer (39) are one of the few research teams that have considered position (both hip and knee) when evaluating the F:E ratio. Three postures (seated, supine, and prone) and seven knee positions (15, 30, 45, 60, 75, 90, and 105°) were examined. In general, the trend for all three postures was for the F:E ratio to increase as the knee moved from a position of flexion to that of extension. Figure 14 compares the results of Houtz et al(39) with the results observed at .52r/s (30°/s) of the present investigation.

As the present study employed a seated posture, one would expect the results to most closely resemble the seated posture of Houtz et al (39). However, as Figure 14 demonstrates, the results from the two studies were not similar. However, the results from the present study resemble those of the prone posture of Houtz et al (39). Differences in sample characteristics as well as testing procedures may be responsible for the differences observed between the seated posture of Houtz et al (39) and the results of the present investigation. Particularily, the different results for the seated postures may be related to two factors:

1. Different velocities were used in the two studies - Houtz et al (39) used isometric testing (0r/s) and the present study used a velocity of .52r/s (30°/s). Velocity effects the shape of the torque curves for both the

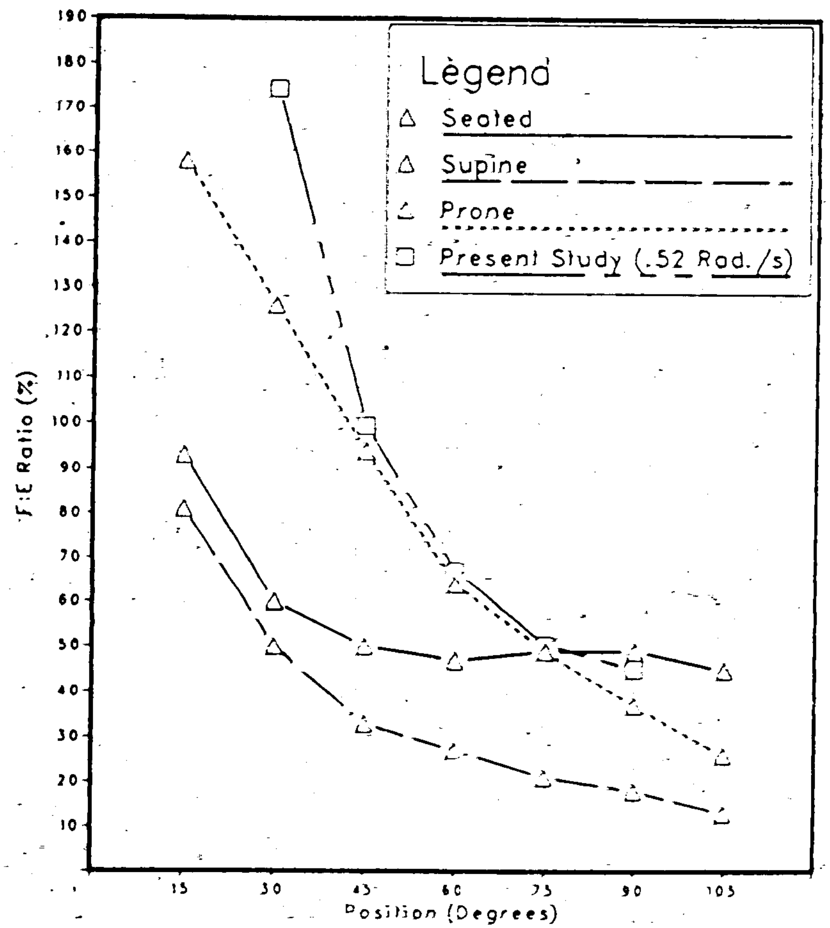

Figure 14: Comparison of F:E Ratios

Adapted from Houtz, Lebow, and Beyer (39) flexors and extensors (72, 73, 79, 83, 92, 95) and, therefore, these differences may be reflected in the F:E ratio.

2. Although both studies used seated postures, the hip angle was not reported in the study by Houtz et al (39). Therefore, different hip angles may have been used, which may be responsible for producing different results.

Two additional studies, one by Patricia Murray et al (66) and the other by Sarah Murray et al (68), examined the effect of velocity on angle-specific (30° and 60°) F:E ratios. Although the F:E ratios of the two studies were considerably smaller than those reported for the present study, particularily at 30°, similar trends were observed for all three studies. In the present study, as well as that by Sarah Murray et al (68), a small, but insignificant, increase in the F:E ratio at 60° was observed with increases in velocity. Patricia Murray et al (66) did not indicate if the increases observed in their study were significant or not. At 30°, the present study and that of Patricia Murray et al (66) both reported a decrease in the F:E ratio as velocity increased. In contrast, Sarah Murray et al (68) reported the F:E ratio increased as velocity increased.

Although a number of variables may be responsible for the discrepencies between the three studies, one of the more important considerations, particularily with respect to the magnitude of the F:E ratio, may be that the results of the present investigation were *not* corrected for the effects of gravity. Recent evidence has shown that gravity correction significantly alters the magnitude of the F:E ratio (2, 23, 80, 82, 101), as a result of extensor torque being underestimated and flexor torque being overestimated. Furthermore, the degree to which gravity correction effects the F:E ratio is dependent on the position being considered (23, 41, 101), which may also explain why the differences between the studies were relatively small at 60° and extremely large at 30°. Table 8 demonstrates the differences between corrected and uncorrected flexor and extensor torque, as well as the associated F:E ratios.

Table 8

Comparison of Gravity Corrected (GC)
and Nongravity Corrected (NGC)
Peak Torques• and Flexor:Extensor (F:E) Ratios†

Velocity	Flexors‡		Extensors‡		F:E Ratio‡	
	GC	NGC	GC	NGC	GC	NGC
1.05r/s	83±19	95±20	156±29	149±28	54±10	64±20
3.14r/s	63±12	73±12	105±17	94±16	60±10	79±13
4.19r/s	54±12	63±12	89±16	77±14	61±10	84±13
5.24r/s	48±14	57±12	78±13	67±11	60±13	84±20

•ft-lbs
†Adapted from Appen and Duncan (2)
‡Mean ±SD

Of the three studies, only that of Sarah Murray et al(68) reported the F:E ratio at 30° to increase as velocity increased. As the information base regarding the effect of velocity on angle-specific F:E ratios is extremely limited, it is impossible to determine if the F:E ratio would be expected to increase or decrease as velocity is increased. However, it is interesting to note that, of the five positions evaluated in the present study, 30° is the only one in which there was a trend for the F:E ratio to *decrease* as the velocity increased. The question, therefore, can be raised as to whether or not the observed results at 30° are truly reflective of the relationship between the muscles as velocity is increased, or if experimental error has influenced the results.

Two observations, made at the time of testing, indicate that experimental error may have, in fact, influenced the results. Firstly, at the slowest velocities, particularily .52r/s (30°/s), subjects had difficulty reaching full extension, and, thus, may not have been working maximally due to discomfort. If such were the case, the maximal capability of the extensors would not have been reflected in the F:E ratio and the F:E ratio would have been overestimated. Secondly, at the higher velocities (2.09r/s to 4.19r/s; 120°/s to 240°/s), some subjects had difficulty keeping up to the lever arm of the test apparatus during the flexion movement, particularily at the beginning of the movement. Therefore, instead of the subject using his own muscular effort to pull the lever arm down, he subconsciously would allow the lever arm to be pushed down by the force of gravity. Assuming that the subject was allowing gravity to move the lever arm during flexion at the higher velocities, the torque value produced at the position of 30° may reflect the effects of gravity only and not the effects of both gravity and muscular effort as seen at the other positions. Thus, the maximal capability of the flexors would not be reflected in the F:E ratio and the F:E ratio would have been underestimated. If in fact the slower velocities overestimated the F:E ratio, and the higher velocities underestimated the F:E ratio, then it may be that the actual values of the F:E ratio at 30° gradually increase with increasing velocity as seen with the other positions, as well as with other studies.

The limited number of investigations discussing the effects of position and velocity on the F:E ratio make it difficult to ascertain if the results of the present investigation verify the results of previous investigations. However, on the basis of what research was available, it appears the F:E ratio is significantly altered by the position of the joint and, to a lesser degree, the velocity of the movement. As well, the effect of velocity appears to be dependent on the position of the joint. Only further research using standardized methods, however, can determine with any degree of certainty the relative effects of position and velocity on the F:E ratio.

Peak F:E Ratios

In contrast to the paucity of information available on angle-specific F:E ratios, in the last three to five years considerable information regarding peak F:E ratios has been made available. Although the author does not believe the use of peak F:E ratios to be appropriate, it is thought the prevalent use of peak data necessitates a discussion of the effects of velocity on peak F:E ratios.

Repeated measures analysis of variance (RMANOVA) of the peak F:E ratio data revealed that significant differences between velocities exist. Scheffe's method of multiple contrasts revealed .52r/s and 1.05r/s (30°/s and 60°/s) to be different from 2.09, 3.14, and 4.19r/s (120, 180, and 240°/s). Additionally, 2.09r/s (120°/s) was different from 4.19r/s (240°/s). With one exception (1.05 r/s vs 2.09r/s; 60°/s vs 120°/s), adjacent velocities were *not* significantly different, perhaps indicating that an increment of 1.05r/s (60°/s) or less is not sufficient to produce significant differences in the F:E ratio. It may be possible that the same increment between 1.05r/s and 2.09r/s (60°/s and 120°/s) was significant as it represented a distinct shift from those velocities considered to be slow to those considered to be fast.

In the present investigation, the use of peak torques to determine the F:E ratio produced results almost identical to those obtained at 60° (Figure 15). The angles of peak flexor torque ranged from approximately 32° to 45°, depending on the velocity. In contrast, the angles of peak extensor torque ranged from approximately 71° to 78°, again depending on velocity. Therefore, it is very difficult to explain how peak F:E ratios can duplicate angle-specific F:E ratios so accurately. Further investigation of the results, however, revealed that at velocities of 2.09r/s to 4.19r/s (120°/s to 240°/s), the torque of both the knee flexors and extensors at 60° did not differ significantly from those angle-specific torques most similar to the angles of peak torque for each of the muscle groups (30° and 45° for the knee flexors; 75° for the knee extensors). At .52r/s and 1.05r/s (30°/s and 60°/s), the similarity between the peak F:E ratio and the F:E ratio at 60° can only be explained as a coincidence, which may also be the actual explanation for the similarities observed at the three highest velocities.

As already mentioned, a vast number of studies exist which have investigated the effect of velocity on the peak F:E ratio. The results of several studies investigating peak F:E ratios have been summarized in Table 9. Only those investigations which used a minimum of two of the velocities utilized in the present investigation have been included.

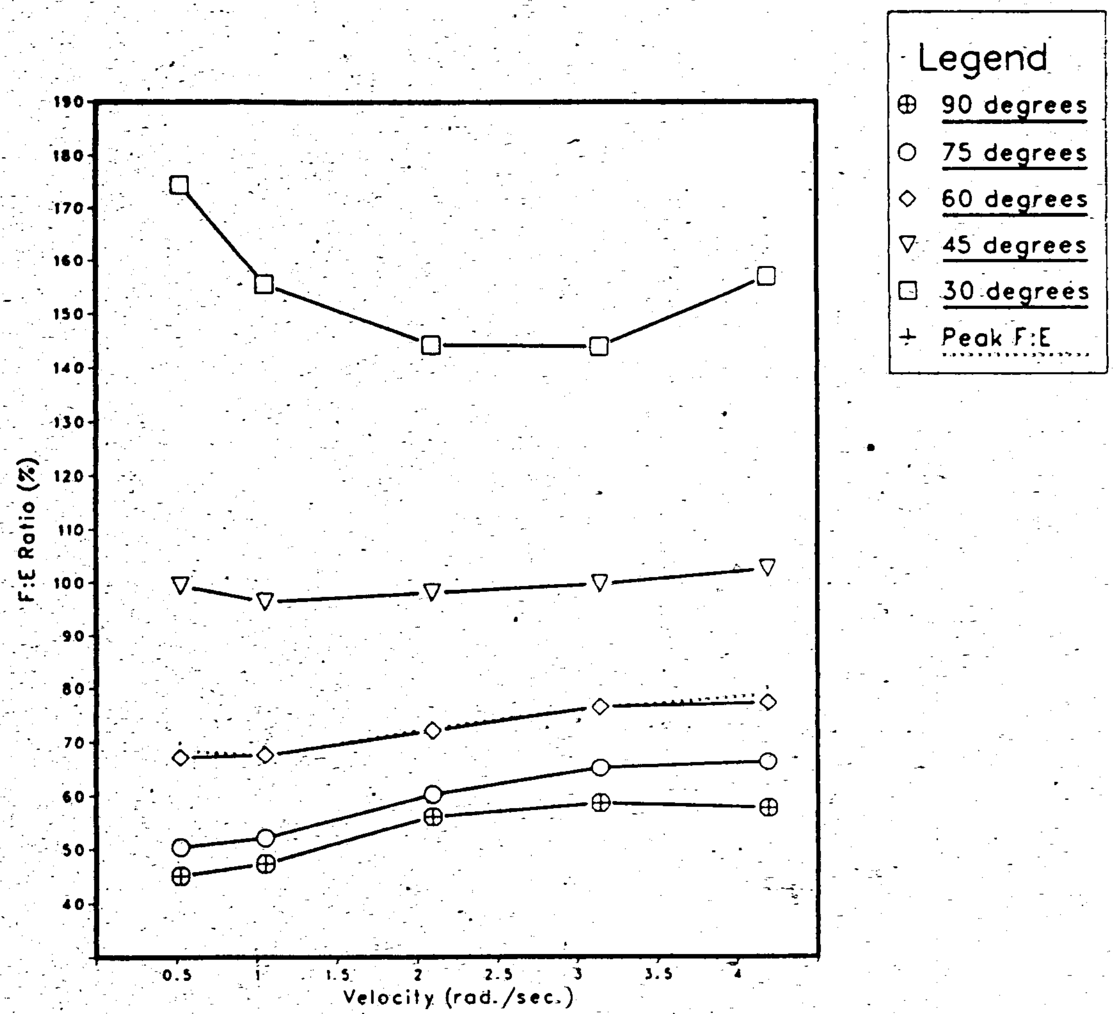

Figure 15: Angle-specific and Peak F:E Ratios

Table 9

Comparison of Peak F:E Ratios

Authors	Subjects	Velocity (r/s)				
		.52	1.05	2.09	3.14	4.19
Golemblaski	Athletes	66.46	67.49	72.54	76.35	78.89
Appen and Duncan (2)	Sprint/Dist. run		64.00		79.00	84.00
	Sprint/Dist. run (GC)		54.00		60.00	61.00
Berg et al (5)	College Basketball (F)		65.00	69.00	73.00	77.50
Campbell and Glenn (8)	Ligament repairs (NI)	70.00			82.00	
	Meniscectomy (NI)	68.00			71.00	
	Chondromalacia (NI)	67.00			81.00	
Capiau (11)	College Track		59.91		72.39	
Costain and Williams (17)	HS Soccer (F)	61.00			[illegible]	
Fillyaw et al (23)	Soccer (F)		67.00			79.00
	Soccer (F) (GC)		54.00			51.00
Gilliam et al (26)	HS Ftbl - Backs, Rec	59.00			77.00	
	HS Ftbl - Linemen	65.00			80.00	
Grace et al (31)	HS Football		60.20			71.60
Hagerman and Staron (34)*	Olympic Rowers	68.92	71.53	74.52	82.48	91.94
Holmes and Alderink(38)	HS Students (F)		55.00		68.00	
	HS Students		58.00		70.00	
Imwold et al (40)	Basketball (F)	55.00			80.00	
	Track (F)	48.00			85.00	
Morris et al (65)	Big Ten X-Country	63.00	65.00		76.00	83.00
Rankin and Thompson (78)	Athletes (M/F) (min)		56.68		64.79	
	Athletes (M/F) (max)		69.84		84.38	
Richards (79)	Healthy women (GC)	47.00			60.00	
Schlinkman (82)	HS Football (GC)		54.00			66.00
Smith et al (88)	Elite Amateur Hockey	59.00			76.00	
	Edmonton Oilers	66.00			87.00	
Thomas (94)	Healthy women		59.70			81.30
Watkins et al (98)	Patellectomy (NI)	57.00			79.00	
	Controls	58.00			84.00	
Wyatt and Edwards (103)	Normal Men		72.00		78.00	
	Normal Women		71.00		79.00	

GC - Gravity corrected
F - Females
NI - Non-injured limb
*Actual velocities were: .5r/s, 1.1r/s, 2.1r/s, 3.2r/s, and 4.2r/s

As can be seen from Table 9, considerable variation exists at each test velocity, with the exception of 2.09r/s (120°/s). The results of the present investigation are in the mid to upper range of the results presented. The smaller range of values observed at 2.09r/s (120°/s) is likely related to the comparatively small number of studies which used 2.09r/s (120°/s) to evaluate the F:E ratio. The largest range of values - 51% to 91.94%, is found at the highest velocity (4.19r/s; 240°/s).

Gravity correction was used in at least one study at all velocities except 2.09r/s (120°/s). In all instances in which gravity correction was used, the lower limit of the range was a gravity corrected value. At .52, 1.05, and 3.14r/s (30, 60, and 180°/s), the range was not dramatically influenced by the use of gravity correction. However, at 4.19r/s (240°/s), the lower limit of the range increased from 51% to 66% when gravity corrected values were not included, thereby reducing the overall range of values.

The influence of gravity correction on the F:E ratio is only one example of the many variables which can act to obscure the meaning of any comparison of the various results summarized in Table 9. Apparently similar results may actually be very different. Therefore, one must be careful not to draw steadfast conclusions based on the results of different investigations. However some of the similarities and/or differences between the studies are noteworthy and may provide insights for future research.

With the exception of the data of Fillyaw and associates (23), the F:E ratio increased as velocity increased. Although the significance of a large proportion of the data was not reported, the consistent finding of an increase in the F:E ratio with increasing velocity is enough to suggest that the F:E ratio is not a fixed value. Further research using standardized methods, however, is necessary to confirm this finding as well as to allow for an enhanced understanding of the meaning of this finding.

It is interesting that only the data of Fillyaw and associates (23) demonstrates a decrease in the F:E ratio as velocity is increased. Because Fillyaw and associates (23) used gravity correction in their investigation, it is tempting to suggest that gravity correction may be responsible for the opposing trend of their results. However, Appen and Duncan (2), Richards (79), and Schlinkman (82) also used gravity correction and, with the exception of magnitude, did not generate results different from those studies that did not use gravity correction. Subject differences as well as differences in the velocites selected for evaluation may be responsible for the discrepencies between the various studies using gravity correction.

Considering the investigations summarized in Table 9 used subjects of different ages, gender, and activity groups, the results of the various studies are remarkably similar. The similarity of the results may be explained, in part, by the consistent use of the Cybex II as the measurement apparatus. Further standardization of test procedures (ie: velocities assessed, hip and knee positions assessed, use of gravity correction, limb evaluated), however, is necessary in order to determine the actual effects of such variables as age, gender, velocity, and sport/activity on the magnitude of peak F:E ratios.

Chapter V

SUMMARY AND CONCLUSIONS

The role of the knee flexors and, in particular, the knee extensors in preventing injuries to the knee has been the object of considerable research in the past. Recently, however, attention has been focused more on the role of the *relative* strength of these muscles in preventing injuries to the knee joint and its supporting musculature.

The earliest research to examine the role of the flexor:extensor (F:E) ratio in injury prevention indicated that the flexors must be 60% as strong as the knee extensors to ensure injury did not occur (45). Further attempts to correlate deviations from the recommended F:E ratio with the occurrence of injury have produced mixed results (6, 11, 21, 24, 31, 45, 102). The lack of consensus regarding the relationship between the F:E ratio and injury may indicate that such a relationship does not exist or cannot be demonstrated consistently as a result of the influence of confounding variables. Another possible explanation for the lack of consistent findings is that the methods used to evaluate the F:E ratio may not be appropriate and, therefore, unreliable.

The present investigation was prompted by the author's contention that past research procedures were inappropriate and unreliable as they used evaluation procedures which did not adhere to the principle of "specificity of testing". Initially, research utilized static measurement techniques and assessed each muscle group at different joint positions, with the extensors usually being evaluated at a position of 65° as opposed to 15° for the flexors. However, during functional activities, the muscles of the knee function at the same position at any given time and are required to move through a range of motion. Furthermore, the dynamic nature of sports requires the knee to move at a variety of velocities. Therefore, previous evaluation procedures do not reflect the functional requirements of activity.

The introduction of isokinetic testing has enabled researchers to regulate velocity and, therefore, allow them to assess the F:E ratio at more functional velocities. However, most researchers evaluate function of the knee muscles using peak torques. As peak torque occurs at different joint positions for the two muscle groups, evaluation procedures still do not assess the F:E ratio at positions which reflect the function of the knee. Therefore, it was the purpose of this investigation to examine the effects of both velocity and knee position on the F:E ratio. In order to compare results with the literature, the F:E ratio was also evaluated using peak torques. The effects of velocity and position on each of the muscle groups which comprise the F:E ratio was also studied to acquire a more complete understanding of the factors which effect the F:E ratio.

The right knee of thirty male athletes was assessed to determine the effect of joint position and movement velocity on the torque output of the flexor and extensor muscles, and the associated F:E ratios. Five joint positions (30, 45, 60, 75, and 90°) were assessed at five pre-selected, randomly assigned velocities - .52, 1.05, 2.09, 3.14, and 4.19r/s (30, 60, 120, 180, and 240°/s). Peak torque of the flexors and extensors, the associated F:E ratio, and angles of peak torque were also recorded. Repeated measures analysis of variance (RMANOVA) was administered on all variables ($P \leq 0.05$). Multiple contrasts were performed using the method of Scheffe ($P \leq 0.05$).

The results of the RMANOVA revealed the following:

1. The angle-specific F:E ratio changes through the range of motion. As the knee moves from flexion to extension the F:E ratio becomes significantly larger.
2. Using angle-specific F:E ratios, the only significant difference between velocities occurred between 1.05r/s and 4.19r/s (60°/s and 240°/s).
3. The angle-specific F:E ratio demonstrated significant interaction between velocity and position.
4. The peak F:E ratio significantly increased as velocity was increased. All of the *non*significant contrasts were between adjacent velocities - .52r/s vs. 1.05r/s, 2.09r/s vs. 3.14r/s, and 3.14r/s vs. 4.19r/s (30°/s vs. 60°/s, 120°/s vs. 180°/s, and 180°/s vs. 240°/s), perhaps indicating that an

increment of 1.05r/s (60°/s) or less was not sufficient to produce significant differences in the F:E ratio.

5. An inverse relationship exists between velocity and torque (angle-specific and peak) for both the flexors and extensors. With the exception of the comparison between .52r/s and 1.05r/s (30°/s and 60°/s), torque of both the flexors and extensors decreased as the velocity was increased.
6. Changes in position produced significant differences in the torque of the flexors. Multiple contrasts between positions of the flexors indicated all but one comparison to be significant - 30° was *not* different from 45°.
7. The extensors also demonstrated only one *non*significant comparison - 60° was not different from 90°.
8. Both the flexors ands extensors demonstrated significant interaction between position and velocity.
9. As velocity increased, the angle of peak flexor torque increased significantly.
10. The angle of peak extensor torque significantly decreased as velocity increased.

The results of the present investigation regarding flexor and extensor torque demonstrated the interaction between angle of pull, length-tension, and angular velocity. The flexor and extensor data revealed the pattern of torque production was different for each muscle group. Therefore, it was concluded that the relationship between the muscle groups would also be dependent on the position of the joint and the velocity of movement. The results of the present investigation confirm this conclusion, as they indicate that the F:E ratio increases as the leg moves from flexion to extension. The same trend was found in the study conducted by Houtz et al (39), although the magnitude of the F:E ratio at any given position was greater in the present study. The only other studies which investigated angle-specific F:E ratios, only reported results for two positions and used gravity corrected values (66, 68), which made comparisons with these studies less meaningful. However, with the exception of the results of Sarah Murray et al (68) at 30°, similar trends were demonstrated between studies (68, 69).

For peak F:E ratios, the results of the present investigation were in the mid to upper range of those reported by other researchers (2, 5, 8, 11, 17, 23, 26, 31, 34, 38, 40, 65, 78, 82, 88, 94, 98, 103). The number of significant contrasts between velocities was increased considerably when the F:E ratio was assessed using peak torque rather than angle-specific torque. Some researchers have attributed the increase in the peak F:E ratio (with increasing velocity) to differences in the ability of the flexors and extensors to produce torque at higher velocities (5, 65) due to biochemical/physiological differences between the two muscle groups. When angle-specific flexor and extensor torque was compared at higher velocities, however, the decreases in torque in the two muscle groups appeared to parallel each other. However, the magnitude of the decrease appeared to be dependent on the angle being considered (ie: the decrease at 60° appeared to be larger than that at 30°. Therefore, the increase of the peak F:E ratio as velocity increases may be more a function of the changes in the angles of peak torque of the flexors and extensors, rather than biochemical/physiological differences of the two muscle groups.

Implications and Recommendations

Although the present investigation is not the first to examine the effect of velocity on the F:E ratio of the knee, it is the first to use angle-specific ratios to do so. Therefore, the results of the present study have contributed to the general body of knowledge in the area of F:E ratios of the knee.

The results of the present investigation indicate that both position and velocity are important considerations when evaluating the F:E ratio. Changes in the F:E ratio, as a result of using different joint positions, were greater than those observed as a result of increasing velocity. Ideally, further attempts to predict the likelihood of injury using the F:E ratio should use joint positions and velocities similar to those at which injuries occur. If a consistent relationship between the F:E ratio and injury could then be established, training and rehabilitation programs could then be designed which would establish F:E ratios that promote injury prevention. Unfortunately, present technology makes it difficult, if not impossible, to determine the positions and velocities at which injuries occur. Until such technology becomes available, the author recommends that any evaluations of the F:E ratio use angle-specific torques, rather than peak torques, and that several velocities be used for the evaluation. As the results of the present investigation revealed that the F:E ratio at 45° was approximately 100%, at all velocities, it is suggested that, particularily when time is a consideration, the position of 45°, rather than peak tor[illegible] be used to evaluate the F:E ratio. Because the F:E ratio at 45° approximates 100%, calculations would not usually be necessary, allowing for even more effective use of time.

Although the present investigation evaluated the F:E ratio under conditions that simulated functional activities more closely than past research, further improvements in methodology are necessary in order to gain a complete understanding of the relationship between the F:E ratio and injury. For instance, the nature of isokinetic testing requires that the knee flexors and extensors are evaluated in isolation. However, during functional acitivities both muscle groups function together - one as the prime mover and the other as the antagonist, which serves to control the movement of the prime mover. Therefore, while the prime mover may be functioning at or near its maximal capability, the antagonist is likely to be functioning at a submaximal level, thereby changing the relationship between the two muscle groups. As well, isokinetic testing does not allow for the muscles to be assessed using eccentric (lengthening) contractions, which are prevalent in sports. Would the relationship between the two muscle groups be altered if eccentric evaluation was possible? Furthermore, isokinetic testing also dictates that the muscles are evaluated at a constant velocity, whereas the velocity of movement during activity is variable. What effect does a sudden change in velocity have on the F:E ratio? Is injury more likely to occur with acceleration or deceleration of the limb? Another notable difference between isokinetic testing and functional activities is that most functional activities are weightbearing, whereas isokinetic evaluation is non-weightbearing. Would evaluating the F:E ratio under weightbearing conditions produce different results? Further research is needed to answer these questions and provide a clear picture of the relationship between the F:E ratio and injury.

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Appendices

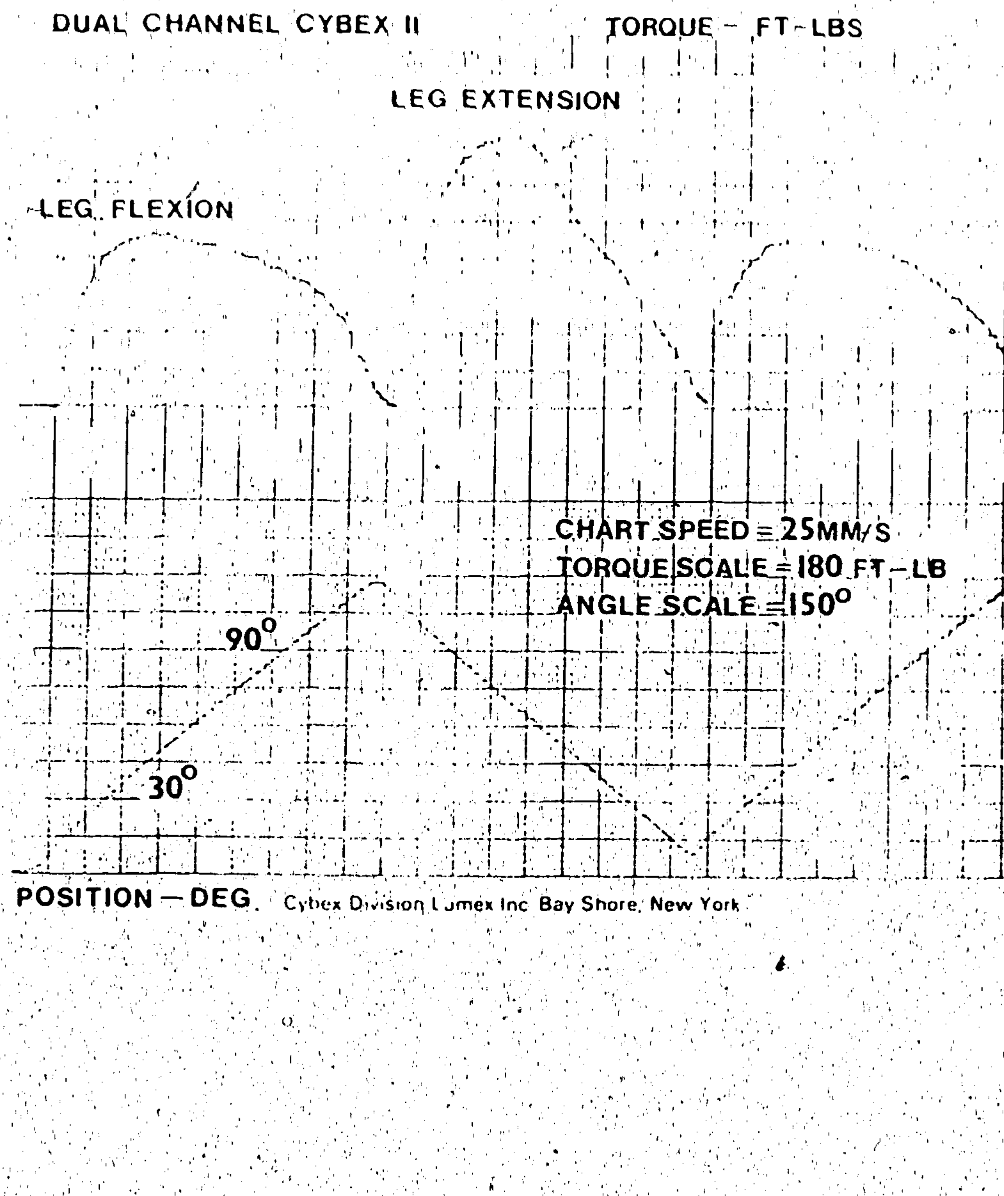
Appendix A

Age and Sport/Activity Characteristics of the Sample

Subject	Age (Years)	Sport/Activity
1	24	Rugby
2	24	Distance Runner
3	24	Hockey
4	26	Basketball
5	19	Speedskating
6	26	Sprint Runner
7	24	General Fitness
8	24	Hockey - Goal
9	22	X-country Skiing
10	18	Hockey
11	30	Distance Runner
12	25	Hockey
13	19	Sprint Runner
14	26	Soccer
15	22	General Fitness
16	23	Volleyball/Golf
17	22	Basketball
18	23	General Fitness
19	18	Track - High Jump
20	21	Volleyball
21	27	Track - Pentathlete
22	25	Gymnastics
23	23	Soccer
24	21	General Fitness
25	30	Distance Runner
26	26	Basketball
27	25	Cycling
28	21	Wrestling
29	21	Football - Receiver
30	26	Hockey/Fitness

Appendix B

Example of Cybex II Leg Extension/Flexion Printout



Appendix C

Cybex II Torque Channel Calibration

Calibration Procedure

1. Turn on power and allow for five minutes warm-up.
2. "Zero" or "null out" the baseline using the following procedure:
   a. With no load on the dynamometer, set damping control at zero, chart paper at 5mm/sec and speed selector at 30°/s.
   b. Set foot-pound scale on 180 and zero recorder stylus on baseline using the "zero adjust" control.
   c. Check to ensure baseline does not shift any more than 1/2 minor division when the foot-pound scale is changed from 180 to 30. If the stylus does shift, adjustments can be made using the "zero null" potentiometer.
3. Select appropriate scale to be calibrated (360 ft./lb.) and set the damping control at 3.
4. With no load on the dynamometer, set speed selector at 30°/s and zero baseline using "zero adjust" control.
5. Add appropriate amount of disk weights to the T-bar, which is set at the input arm length for the scale being calibrated (see chart).
6. Chart paper speed is set at 5mm/sec.
7. Lift the weighted T-bar to the vertical position and then allow gravity to swing the bar down until the weights contact the floor. The maximal point on the curve occurs when the weighted bar is horizontal and sholud be five major divisions above the baseline.
8. If the chart recording is above or below five major divisions, the potentiometer for the particular ft/lb scale should be adjusted using a small screwdriver. Turning the potentiometer clockwise increases the torque reading and counter-clockwise decreases it.
9. Once the torque value is correct, re-check twice to ensure the reading is consistent.

Cybex II Torque Channel Calibration Specifications Chart

Scale Selector (ft/lb)	Lever Arm* (in)	Weight (lb)	Graph Reading Peak
360	30	70.0	5 major divisions
180	31	32.5	5 major divisions
30	33	5.0	20 minor divisions

*Measures distance from center of dynamometer input shaft to center of calibration T-bar cross-tube.

Appendix D

Cybex II Position Angle Calibration

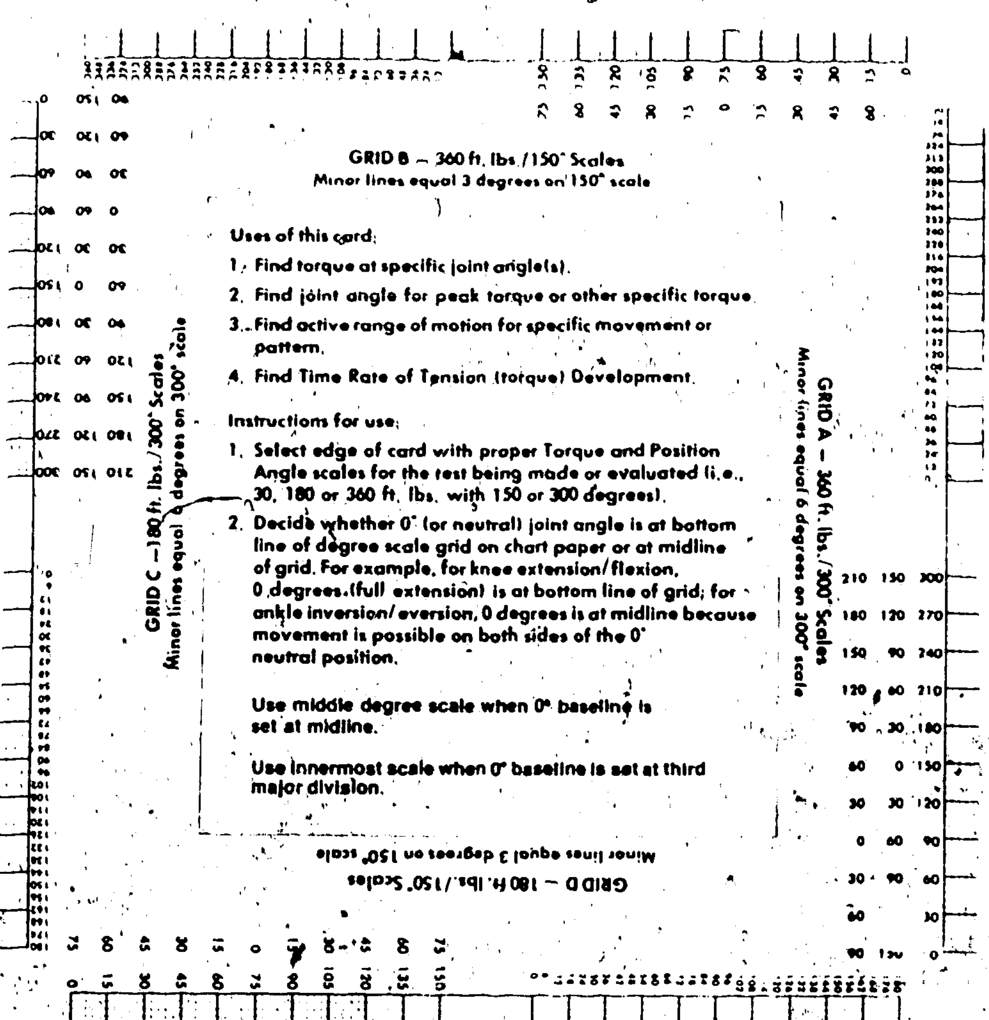
Two scale settings are available (150° and 300°). Because the range of motion at the knee does not exceed 150°, the 150° scale was selected.

Calibration Procedure

1. Turn on power and allow apparatus to warm up for five minutes.
2. Select degree scale (150°) and set chart speed at 5mm/sec.
3. Set the "Input Direction" switch to clockwise (CW).
4. Turn the goniometer dial clockwise until the stylus moves to the chart baseline.
5. Using the white line under the goniometer as a reference point, rotate the dial clockwise 150°. The stylus should trace a line on the topline of the graph. If not, proceed to step 6 to make the necessary adjustment.
6. Locate and adjust the "Deg. Cal." screw on the recorder by loosening the locking nut and turning the adjusting screw until the stylus is at the top of the chart. While using the screwdriver to maintain the position of the "Deg. Cal." screw, tighten the locking nut.
7. Repeat procedure to ensure the setting is correct.
8. Set the "Input Direction" switch to counter-clockwise (CCW) and repeat steps 4 through 7, turning the goniometer dial counter-clockwise instead of clockwise in steps 4 and 5.

Appendix E

Cybex II Chart Data Card



Appendix F

Data Record Sheet

NAME:
AGE:
SPORT/ACTIVITY:

Velocity: .52r/s

Pos	Trial 1			Trial 2			Trial 3			Trial 4			Trial 5			Mean		
	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E
30																		
45																		
60																		
75																		
90																		

Velocity: 1.05r/s

	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E
30																		
45																		
60																		
75																		
90																		

Velocity: 2.09r/s

	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E
30																		
45																		
60																		
75																		
90																		

Velocity: 3.14r/s

	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E
30																		
45																		
60																		
75																		
90																		

Velocity: 4.19r/s

	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E	F	E	F:E
30																		
45																		
60																		
75																		
90																		

Appendix G

Peak Data Record Sheet

NAME:
AGE:
SPORT/ACTIVITY:

Trial	Velocity	Peak F Torque	Peak F Angle	Peak E Torque	Peak E Angle	Peak F:E
1						
2						
3	.52r/s					
4						
5						
1						
2						
3	1.05r/s					
4						
5						
1						
2						
3	2.09r/s					
4						
5						
1						
2						
3	3.14r/s					
4						
5						
1						
2						
3	4.19r/s					
4						
5						

Appendix H

Means and Standard Deviations for the GANOVA Data

Pos. (Deg)	Vel. (r/s)	Flexors Mean	Flexors SD	Extensors Mean	Extensors SD	F:E Ratio Mean	F:E Ratio SD
	.52	73.13	18.40	166.65	48.68	46.30	12.09
	1.05	76.25	17.86	164.44	38.39	47.21	9.62
90	2.09	76.21	17.89	143.15	32.94	53.93	7.63
	3.14	65.54	11.77	119.87	29.38	56.04	8.89
	4.19	56.91	11.51	96.55	22.01	59.99	9.40
	.52	101.61	12.96	205.75	29.37	49.92	6.20
	1.05	100.21	18.18	201.50	34.59	50.59	9.67
75	2.09	99.71	19.59	171.40	31.69	59.04	11.21
	3.14	92.48	17.59	146.54	18.71	63.10	9.07
	4.19	80.51	19.27	126.01	19.54	63.97	12.21
	.52	114.13	15.51	155.80	39.64	77.62	21.54
	1.05	117.16	16.94	156.35	34.06	76.59	11.43
60	2.09	112.41	17.25	148.08	29.00	77.45	12.39
	3.14	100.03	13.90	122.54	29.74	83.41	10.39
	4.19	86.47	15.32	107.53	25.64	81.13	11.95
	.52	127.87	17.09	125.61	26.94	104.95	17.45
	1.05	124.21	15.00	126.01	27.47	101.63	17.13
45	2.09	112.51	11.54	117.74	24.64	98.46	16.96
	3.14	104.78	13.61	106.31	27.66	101.94	17.60
	4.19	87.37	14.13	87.87	28.86	105.18	21.94
	.52	122.89	19.63	78.88	27.95	182.63	81.49
	1.05	118.28	18.24	86.96	17.37	140.66	33.90
30	2.09	98.99	19.49	80.72	20.20	126.47	31.13
	3.14	83.94	22.70	73.32	23.62	120.27	39.12
	4.19	79.50	15.11	60.03	20.80	142.90	44.70