THE UNIVERSITY OF MANITOBA

AN ANALYSIS
of the
ANTHROPOMETRIC, FLEXIBILITY
and
STRENGTH MEASUREMENTS
RELATED TO
HAMSTRING STRAINS
IN
ATHLETES

by

Debra Bruce

submitted to
The Faculty of Graduate Studies
in Partial Fulfillment
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AN ANALYSIS OF THE ANTHROPOMETRIC, FLEXIBILITY AND STRENGTH MEASUREMENTS RELATED TO HAMSTRING STRAINS IN ATHLETES

BY DEBRA BRUCE

A thesis submitted to the Faculty of Graduate Studies of
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MASTER OF PHYSICAL EDUCATION

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Abstract

An analysis of anthropometric, flexibility and strength measurements related to hamstring strains in athletes.
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The purpose of this study was to determine the relationships between selected anthropometric, strength and flexibility variables and hamstring strains in athletes. The subjects included nineteen male athletes who had experienced a hamstring strain in the past, who had been rehabilitated and were competing again, and twenty male athletes who had never experienced a hamstring strain. The athletes were recruited primarily from university football, hockey and track and field athletes. The testing protocol for each subject included: weight, height, biiliac breadth, bitrochanteric breadth, thigh length, calf length, hamstring flexibility, flexibility of the hip flexors, hip extensors, hip internal rotators and hip external rotators, Q angle, and the eccentric and concentric strength of the quadriceps, hamstrings, hip flexors and hip extensors. The analyses of the data included a principal component analysis which identified eight facts which accounted for 84% of the total variance. These eight principal components were then entered into a discriminant analysis, and they were able to predict the injured subjects with 82% accuracy and the non-injured subjects with 76% accuracy. Stepwise discriminant analysis indicated that the combination of the principal components yielded these classification results rather than any specific components. Two of the components (lack of hip flexibility, injured>non-injured; hip strength, non-injured>injured) were selected, but did not reach the .05 level of confidence.

Acknowledgements

The author would like to thank her thesis committee, Dr. M. Alexander, Dr. J. Cooper, Dr. K. Lindner and Professor Glen Bergeron for their assistance and guidance while working on this paper. Special thanks to Dr. Alexander, my advisor, for help given throughout my entire Master's program.

Acknowledgement is extended to all those faculty members and as well as the subjects who participated in my study who have contributed towards the completion of this study. Special thanks to Lisa and Rick for their help during the collection of the data and for moral support that they gave.

Dedication

I dedicate my thesis to my family, especially my mom and dad who have stood behind me and supported me throughout my school years and to a very special friend, Charlie, who believed in me when I didn't. Thank you all so much.

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Chapter 1

Introduction

Of all the muscle groups subject to frequent muscle strains, the hamstring muscle group ranks the highest of all the muscles of the thigh (Sutton, 1984; Coole & Gieck,1987). Bailey and Bremiller (1981) as reported by Sutton (1984) found that the hurdles, 200 meter sprint, jumping events and contact sports such as football were types of sports found to be most often associated with high rates of hamstring injury. Injuries to the hamstrings of athletes can be devastating because they heal slowly, impeding the athlete's return to competition and they also have the tendency to recur (Agre, 1985). The majority of injuries to the hamstring muscles occur as soon as the speed of an athletic event increases (Garret, Califf & Bassett, 1984). Many etiologies of hamstring strains have been proposed. Suggested mechanisms include muscle strength imbalances between the quadriceps and hamstring muscle groups, strength imbalances between the left and right hamstring muscle groups and asymmetry of flexibility in the hamstring muscles (Coole & Gieck,1987; Klein & Roberts, 1976; Heiser, Weber, Sullivan, Clare & Jacobs, 1984; Sutton, 1984; Liemohn, 1978; Burkett, 1970; Bailey

& Bremiller, 1981). The effects of the hamstring-quadriceps strength ratio and lack of flexibility on hamstring muscles strain have been well documented (Heiser, Weber, Sullivan, Clare & Jacobs,1984; Liemohn, 1978; Burkett, 1970; Hage, 1983; Capiau, 1981; Stephens & Reid, 1988; Bailey & Bremiller, 1981). However, there has been no attempt to establish interrelationships among these predisposing factors for hamstring strains or which of these factors would best characterize an athlete's predispostion to a hamstring strain. Also, previous studies involving anthropometric variables as related to hamstring strains are very limited. The anthropometric variables in this study were included as possible variables involved in hamstring strains.

Statement of the Problem

The purpose of this study was to determine which strength, anthropometric and flexibility factors may be implicated in hamstring strains. A further purpose of this investigation was to determine if there are any interrelationships among strength measures, flexibility of hamstrings and other muscle groups associated with hamstring function and anthropometric variables such as leg length, calf length, biiliac breadth and bitrochanteric breadth that might be used to develop tests to screen an athlete believed to be predisposed to hamstring injuries.

Purpose of the Study

Several questions could be answered by a study of this type. Such questions include:

1. What is the relationship between strength of the hamstrings, quadriceps, hip flexors and hip extensors to incidence of hamstring injury? For example, if there is an imbalance between opposing muscles of the same limb such as the hamstrings and quadriceps (agonist-antagonist) or if there is a difference between concentric and eccentric muscle force exerted by one particular muscle group, there may be an increased chance for an injury to occur.

2. What is the relationship between flexibility of the hamstrings and hips and the incidence of hamstring injury? Lack of flexibility has been cited as a factor involved in injuries such as hamstring strains (Klein & Roberts, 1976; Liemohn,1978; Cantu & Gillespie, 1982).

3. Is the leg that has sustained a hamstring injury less flexible and weaker than the leg that did not sustain a hamstring injury? Decreased flexibility and muscle strength would lead to the injured leg becoming fatigued faster because it would have to work harder than the limb that is stronger and more flexible.

4. Which of the above mentioned are most important in determining the predisposition of an athlete to hamstring strains if there is an imbalance or deficit in one of the variables as compared to normal values? If certain variables are determined as being the most important in differentiating athletes predisposed to hamstring injuries from athletes who are not, a battery of tests could be designed to test an athlete who may be predisposed to hamstring strains.

5. Are the non-injured athletes symmetrical as compared to previously injured athletes regarding the flexibility, anthropometric and strength measurement data? If they are not symmetrical, then these variables will not be able to differentiate an injured limb from a healthy limb.

Hypothesis

The null hypothesis of this study was that there are no anthropometric, strength or flexibility differences between an athlete who has never had a hamstring injury and an athlete who has experienced a hamstring injury and has been fully rehabilitated and returned to full pain free activity. Significance was accepted at $p<.05$.

Rationale of the Study

The ability to identify an athlete's predisposition to hamstring strain may help prevent an injury from occurring and decrease the time the athlete has to spend away from training and competition. It may also be useful in pre-season and off-season testing because coaches may be able to design training programs to effectively develop an athlete's identified weakness as a preventative measure.

Limitations and Delimitations

1. The subjects in the experimental group were athletes who had been diagnosed by a physiotherapist/certified athletic therapist as having a hamstring muscle strain and were fully rehabilitated to the extent of returning to their activity.

2. The experimental group subjects were chosen from several sporting fields. This was a less than ideal situation because of decreased homogeneity within the experimental and control group as well as decreasing the ability to generalize the results of this particular study to a specific sport area. However, the experimental and control group were kept as homogeneous as possible within this experiment.

3. The ages of the subjects ranged from 18 to 45 years old. It was felt that athletes in this age category would be more likely to be involved more often in sports that required high velocities of movement. Previous studies have included athletes ranging in age from 18 years to 33 years of age (Stephens & Reid,1988; Gajdosik & Lusin, 1983, Hageman et al., 1988, Housh et al., 1988; Capiau et al., 1981).

4. Each subject was measured by the same investigator with the same instruments. The measurements of each subject were performed all in one session.

5. The strength testing was performed using a velocity of 30 degrees per second instead of using a higher or lower velocity in order to reduce any chances of re-injury to the previously injured subjects as well as reducing chances of an injury to any of the control subjects. Previous studies have used velocities of 30 degrees, 60 degrees, 180 degrees and 300 degrees

per second (Stephens & Reid, 1988; Hageman et al., 1988; Housh et al., 1988; Agre & Baxter, 1987; Capiau et al., 1981).

6. It was noted that the flexibility and strength tests might not be measuring the true capacity of the athletes . The flexibility tests were performed under static conditions to reduce the risk of re-injury to the experimental group. The strength testing was also performed at a lower velocity for the same reason.

7. Three trials were used during the testing of the athletes and the average of the three was recorded as the final measurement.

Definitions

Muscle Imbalance As used in this paper, muscle imbalance is a difference in strength or flexibility present between opposing muscles of the same limb (agonist-antagonist) (Grace, 1985). It is also referred to as a difference between the concentric and eccentric muscle force exerted by one particular muscle group.

Hamstring Injury As used in this paper, hamstring injury refers to any stress causing an overextension of the normal range of motion of the hamstring muscle group resulting in a first, second or third degree strain.

Flexibility As used in this paper, flexibility is a static measure specific to a joint and joint action. Flexibility is measured as the range of motion at a single joint or a series of joints (MacDougall et al., 1982) measured by the Leighton flexometer.

Strength As used in this paper, strength is the peak torque/force developed during a maximal voluntary contraction (MacDougall et al., 1982). Strength is measured in units of peak force (Newtons) or torque (Newton-metres) which is developed during maximal contraction (MacDougall et al., 1982). Strength is measured by use of an isokinetic dynamometer.

Concentric contraction As used in this paper, concentric contraction is a muscle contraction in which the muscle shortens while producing tension.

Eccentric contraction As used in this paper, an eccentric contraction is a muscle contraction in which the muscle lengthens while producing tension.

Chapter 2

Review of Related Literature

Introduction

This chapter is devoted to a literature review of pertinent hamstring injury articles that include studies involving suggested mechanisms of hamstring injuries. For the purpose of clarity, the literature review will contain (1) anatomy of the hamstring muscles and quadriceps muscles, (2) proposed causative factors of hamstring injuries as reported from previous studies, (3) activity of the hamstrings during running, (4) EMG activity of the hamstrings during running, and (5) the common sites of hamstring strains.

There are many muscles involved in the production of force in sprinting activities. The hamstrings flex the knee joint and extend the hip while the quadriceps oppose the action of the hamstrings through flexion of the hip and extension of the knee. The quadriceps muscles also assist in flexing the hip. These two muscle groups will be discussed in anatomical detail because their involvement in the mechanism of hamstring strains have been implicated in other studies (Liemohn, 1984; Sutton, 1984; Heiser et al., 1984; Burkett, 1970; Wyatt, 1981; Hageman et al., 1988; Agre, 1987). Muscles such as the gluteal muscles, the tensor fasciae latae, articularis genus, sartorius and the iliopsoas may also be involved in the mechanics of sprinting because they cross the hip and knee joint. The adductor muscles such as the gracilis, adductor longus, adductor brevis and adductor magnus are involved in adduction of the thigh. Lateral rotators of the thigh include the piriformis, obturator internus, gemelli muscles, quadratus femoris and the obturator externus. These are all actions that occur during sprinting. However they have not been cited as muscles that are involved in the actual occurrence of hamstring strain and therefore they will not be described in the anatomy section.

Anatomy of the Hamstring Muscle Group

The hamstring muscles make up the posterior thigh muscle group (Figure 1). The muscles included in this group are the semitendinosus, the biceps femoris and the semimembranosus as well as the posterior portion of the adductor magnus (Romanes, 1981; Clemente, 1985). All of these muscles cross both the hip and knee joint with the exception of the adductor magnus which crosses only the hip joint. The posterior thigh group, if traced downwards from its origin, may be divided into a lateral compartment containing the biceps femoris and a medial compartment containing the semimembranosus, semitendinosus and the adductor magnus.

Semitendinosus

The semitendinosus originates by a short tendon in common with the long head of the biceps femoris from the ischial tuberosity. The long, round tendon of insertion of the semitendinosus begins approximately two thirds of the way down the posterior thigh and runs as a cord in a furrow created by the semimembranosus muscle. The long cord of insertion of the semitendinosus spreads out to form a flattened aponeurosis on the medial side of the posterior thigh to insert into the upper part of the medial surface of the body of the tibia behind the insertions of the gracilis and the sartorius muscles.

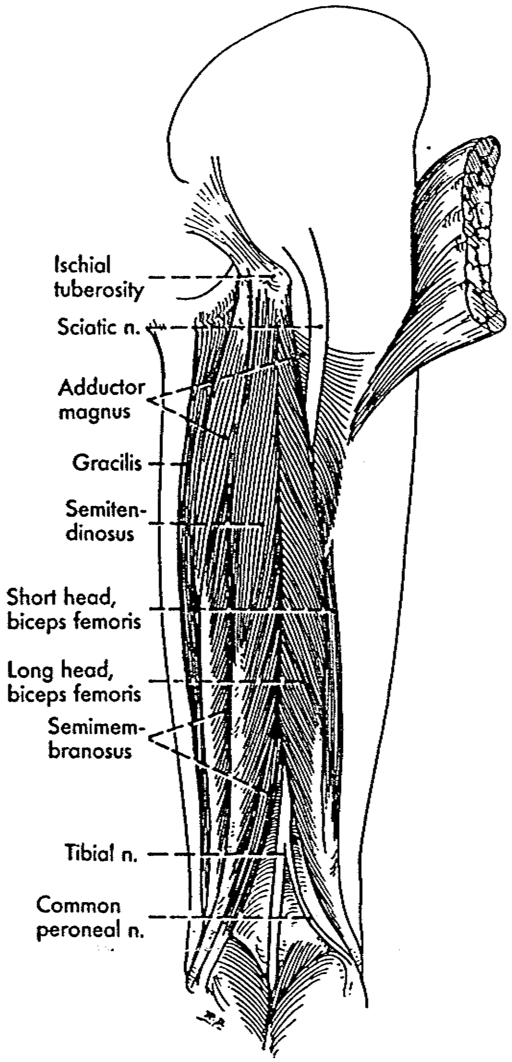

Figure 1. The Hamstring Muscles. (Taken from: Textbook of Anatomy. Fourth Edition. H.W. Hollinshead & C. Rosse (1985). Philadelphia P.A. Harper & Row Publisher Inc. Page 390).

The semitendinosus acts as an extensor of the hip joint. It is also important in eccentrically controlling hip flexion when the body is bent forwards from an erect position. The semitendinosus is also involved in flexion at the knee joint. It is a medial rotator of the tibia on the femur particularly when the knee is flexed. If the foot is on the ground, it is a lateral rotator of the pelvis and femur on the tibia. The semitendinosus is restricted in its simultaneous action on both the hip and knee joints. This muscle is so shortened when the knee is flexed that it cannot contract further and act on the hip (Romanes, 1981). Conversely, if the semitendinosus is initially stretched with the hip in a fully flexed position, simultaneous knee flexion will be restricted unless the muscle is specially trained (Romanes, 1981).

Semimembranosus

The semimembranosus arises from the lateral facet of the ischial tuberosity by means of a strong membranous tendon. This tendon continues downward along the lateral margin of the muscle. The fleshy belly of the semimembranosus lies medial to the tendon and is deep to the semitendinosus and long head of the biceps femoris. It runs downwards and medially. The semitendinosus is situated in a groove on its superficial surface. The semimembranosus inserts at the back of the knee via a tendon which is inserted into a horizontal groove on the posteromedial surface of the medial condyle of the tibia. A fascial band from the tendon of insertion runs to join the posterior border of the tibial collateral ligament of the knee joint. Another fascial band running downwards, laterally and posteriorly forms the fascia covering of the popliteus muscle and is attached to the soleal line of the tibia. Another strong fascial band from the tendon of insertion extends upwards and laterally to the back of the lateral condyle of the femur and forms the oblique popliteal ligament of the knee joint (Romanes, 1981).

The actions of the semimembranosus are the same as those of the semitendinosus muscle, an extensor of the hip joint and a flexor of the knee joint. It is also a medial rotator of the tibia on the femur. In contrast to the semitendinosus, however, the rotary action of the semimembranosus on the knee joint only operates when the knee joint is flexed (Romanes, 1981).

Biceps Femoris

The biceps femoris is a two-headed muscle. The long head arises with the semitendinosus from the medial impression of the ischial tuberosity and from the sacrotuberous ligament. The fleshy belly of the long head of the biceps femoris becomes tendinous at the distal third of the posterior thigh and is then joined by the short head of the biceps femoris. The short head arises separately from the lateral lip of the linea aspera and the upper half of the lateral supracondylar ridge of the femur. Some of its fibres come from the lateral intermuscular septum (Romanes, 1981). The distal attachment of the biceps femoris is the proximal, posterior area of the fibular head.

The long head of the biceps femoris assists the semitendinosus, semimembranosus and the gluteus maximus to extend the hip joint. Both heads of the biceps femoris flex the knee joint. When the knee joint is flexed, both heads also rotate the leg laterally on the thigh. If the hip is flexed, the biceps femoris rotates the thigh laterally and pelvis medially (Romanes, 1981).

Adductor Magnus

The adductor magnus is the largest muscle of the adductor group (Figure 2). It is a composite muscle because it functions as a hamstring during extension of the hip as well as an adductor muscle. The adductor magnus arises from the femoral aspect of the conjoint rami of the ischium and pubis and from the lateral part of the inferior surface of the ischial tuberosity. It inserts linearly along the whole length of the posterior aspect of the femur from the insertion of the quadratus femoris to the adductor tubercle including the linea aspera and the medial supracondylar line (Romanes, 1981).

The proximal portion of the adductor magnus acts with the adductor longus and adductor brevis in adduction, medial

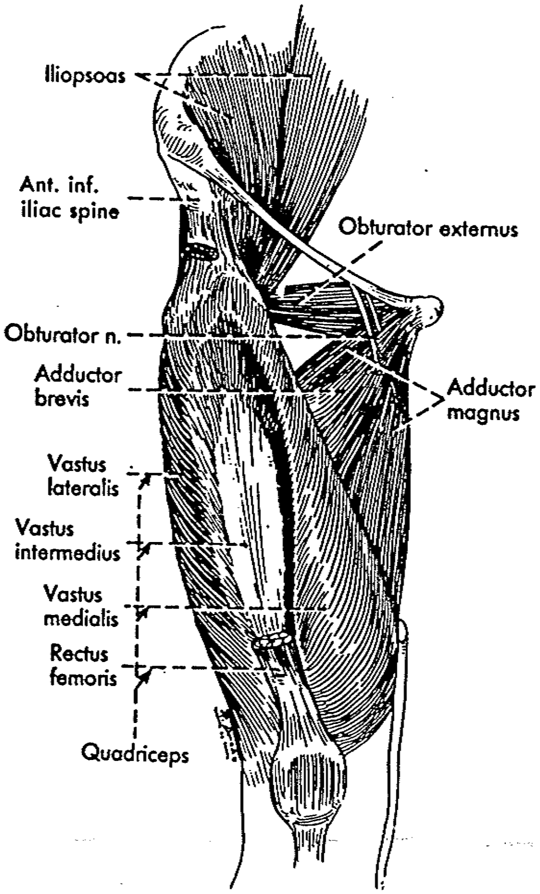

Figure 2. The Quadriceps Muscles. (Taken from: Textbook of Anatomy. Fourth Edition. H.W. Hollinshead & C. Rosse (1985). Philadelphia, Pa. Harper and Row Publishers Inc. Page 390).

rotation of the thigh and in preventing lateral overbalancing at the hip during walking (Romanes, 1981). The vertical fibres of the ischial portion of the adductor magnus act as weak extensors of the hip joint.

The Quadriceps Muscle Group

The quadriceps femoris or anterior thigh muscle group is a composite muscle made up of the rectus femoris, vastus intermedius, vastus lateralis and vastus medialis muscles (Figure 2). The **rectus femoris** is a spindle-shaped bipennate muscle described as having two heads of origin although they are continuous with each other (Romanes, 1981). The straight head of the muscle arises from the anterior inferior iliac spine and the reflected head from the rough groove on the ilium immediately above the acetabulum. A single tendon from the continuous origin descends to a fleshy belly. A tendon runs from the lower end of the belly into the upper border of the patella.

Vastus Lateralis

The vastus lateralis has a linear origin from the capsule of the hip joint, upper part of the intertrochanteric line, lower border of the greater trochanter, lateral margin of the gluteal tuberosity and upper one-half of the linea aspera as well as from the fascia lata and lateral intermuscular septum. The muscle fibres run downwards and forwards giving way to a broad tendon which inserts into the lower part of the tendon of the rectus femoris, the lateral border of the patella and the front of the lateral condyle of the tibia, blending with the iliotibial tract and to a large extent replacing the capsule of the knee joint in this region (Romanes, 1981).

Vastus Medialis

The vastus medialis is a larger, heavier muscle compared to the vastus lateralis. The origin of the vastus medialis is long, starting from the lower one-half of the intertrochanteric line, linea aspera, upper two-thirds of the medial supracondylar line, medial intermuscular septum and the tendon of the adductor magnus. It inserts into the medial aspect of the tendon of insertion of the rectus femoris, the upper and medial borders of the patella and the front of the medial condyle of the tibia reinforcing the anteromedial portion of the capsule of the knee joint (Romanes, 1981).

Vastus Intermedius

The deepest portion of the quadriceps muscle, the vastus intermedius, arises as fleshy fibres from the upper two-thirds of the body of the femur on its anterior and lateral surfaces and from the lower half of the lateral lip of the linea aspera and upper part of the lateral supracondylar line as well as from the intramuscular septum. The vastus intermedius has a membranous tendon on its anterior surface separating it from the deep surface of the rectus femoris. This membranous tendon allows movement between the rectus femoris and vastus intermedius. The vastus intermedius inserts into the deep surface of the tendons of the rectus femoris, vastus lateralis and the vastus medialis.

The true insertion of the rectus femoris is via the patellar ligament which is a strong band which attaches the inferior angle and margins of the patella to the tuberosity of the tibia. The patella is a sesamoid bone located in the tendons of the rectus femoris and vastus intermedius. The patella receives fibres of insertion from the vastus lateralis and medialis on its lateral and medial border respectively.

All four of the quadriceps muscles extend the knee joint. The rectus femoris is also a strong flexor at the hip joint as well as an assistant to the iliopsoas muscle during flexion of the trunk on the thigh when the thigh is fixed.

Proposed Causal Factors of Hamstring Injuries

Strength

The proposed mechanism of hamstring strains that has been studied most often is an imbalance in muscle strength ratios. It is logically assumed that there is a relationship between muscle imbalance and injury. Grace (1985) stated that the weaker or more imbalanced an extremity muscle is compared to the normal muscle condition, the more prone it would be to joint or soft tissue injury. Housh et al. (1988) stated that the demands of a particular sport or the requirements of a conditioning program may be responsible for dissimilarities in muscular strength characteristics between athletes who compete in different sports. Burkett (1970) found that weak hamstring muscles were found to increase the risk of hamstring strain injuries. A discrepancy of ten percent has been accepted as a significant imbalance in strength (Burkett, 1970; Grace, 1985; Heiser et al., 1984; Sutton, 1984). One muscle group imbalance that is most commonly studied is the hamstring-quadriceps strength ratio. A balanced hamstring-quadriceps ratio has been suggested as being .50-.60 (Liemohn, 1984; Sutton, 1984; Heiser et al., 1984). Heiser et al. (1984) stated that in his study an athlete with a ratio of .50 or less was felt to have an increased likelihood of sustaining a muscle injury. A ratio of .50 or less indicated that the hamstrings were especially weak. Burkett (1970) found a significant difference between the hamstring-quadriceps strength ratio in a study he conducted involving thirty track athletes and thirty-seven football players. Liemohn (1978) however, found that the athletes in his study approximated the .60 hamstring-quadriceps ratio. Hageman et al. (1988) found hamstring-quadriceps strength ratios to range from .76 to .88 in their study. Wyatt and Edwards (1981) reported that athletes in their study were found to have hamstring-quadriceps strength ratios as high as .72. Stephens and Reid (1988) contradicted these studies. The concentric knee flexion-extension peak torque ratio was found to be .40 for the non-injured athletes and .48 for the injured subjects. Wyatt and Edwards (1981) also found that the difference in the hamstring-quadriceps ratios decreased as speed of exercise increased and suggested that the hamstring torque might exceed the quadriceps torque at higher velocities to eventually change the hamstring-quadriceps ratio to 1.00. Appen and Duncan (1986) suggested that there is no standard ratio of hamstrings-quadriceps strength at all velocities that would be appropriate for most competitors in a sport because there may be a difference in strengths due to training requirements of a sport or due to distinct fiber composition.

Bilateral strength differences have also been measured. Liemohn (1978) found that, as a group, the athletes in his study (whether injured or non-injured) had a greater hamstring-quadriceps strength ratio on the right limb than on the left limb. The injured groups tended to be show a greater strength ratio difference between the two legs. The left leg hamstrings were proportionately stronger than the right relative to the extensors in those athletes tested. The imbalance was greater in the injured group as compared to the non-injured group. Agre and Baxter (1987) found no significant leg strength imbalances in a study conducted on 25 male college soccer players.

Flexibility

Burkett (1970) stated that muscle strength imbalance may not be the only predisposing factor in hamstring injuries. Not every person with a muscle imbalance will sustain a hamstring injury. A deficiency in the flexibility of the hamstrings or hip muscles has been suggested as a possible cause of hamstring strains.

Flexibility of a muscle below a certain level is suspected to predispose that muscle to injury when stressed (Cantu & Gillespie, 1982). The definition of "certain level" was not stated in this study. The degree of flexibility present in the thigh and hip region may be involved in the mechanism of hamstring injuries. Liemohn (1978) measured hip joint flexibility of twenty-seven athletes in a study and proposed that the normal hip-joint flexibility is between 80 to 85 degrees of flexion. He found that the injured group were (1) always less flexible than non-injured group and (2) and showed a greater left/right discrepancy. The data did not indicate that the least flexible limb was the one usually injured.

The flexibility of the hip flexors during extension may also be a mechanism involved in hamstring strains. Klein and

Roberts (1976) stated that tight hip flexor muscles could account for early hamstring muscle fatigue and this could be one of the fundamental causes of hamstring injuries. When the hip flexors (iliopsoas and rectus femoris) are tight, they tend to tip the pelvis forward due to the anatomical insertion points of the muscles. Anterior rotation of the pelvis places the hamstrings in a state of overstretch because the origin of the hamstrings, the ischial tuberosity, migrates superiorly and posteriorly and thus the normal distance between the origin and insertion of the hamstring muscle group is lengthened. Pre-lengthening of the hamstrings could account for early fatigue and therefore could be included in the fundamental causes of hamstring injuries (Klein, 1976). Capiau (1981) also found that athletes with decreased hip flexibility seemed to be more susceptible to hamstring injuries. Bailey and Bremiller (1981) as reported by Sutton (1984) found that decreased hip joint flexibility was a major factor in occurrence of hamstring strains and that the less flexible limb tended to be the extremity most often injured.

The degree of hamstring flexibility must also be considered as a potential mechanism for injury. Agre (1985) stated that if the hamstring musculotendinous unit is tight and lacking in flexibility, the unit may be vulnerable to being stretched beyond its capability. This situation is most likely to occur during sprinting because the requirement for flexibility is greatest due to the combined range of motion at the hip and knee joint being the largest of almost any other activity. Burkett (1970) however, found the correlation between decreased flexibility and hamstring injury was not significant. Stephens and Reid (1988) also found in their study that their injured group of football players in positions involving sprinting was not significantly different than the group of non-injured players of similar positions in flexibility ($p <.01$). Lysens et al. (1984) found no statistical evidence to support the belief that muscle tightness was associated with muscle strains. They also found that an increase in the extent of flexibility and ligamentous laxity seemed to predispose athletes to injury.

Sutton (1984) stated that due to variable methods of measuring flexibility of the hamstrings, decreased flexibility proved to be a significant indicator of hamstring injuries in some studies and insignificant in other studies. The problem associated with the parameter of flexibility is in determining the acceptable range of motion (Coole & Gieck, 1987) . Common standards use the "Well's sit-and-reach" flexibility test which, although simple, is widely criticized for its inability to isolate the hamstrings as the component being evaluated. It involves overall trunk flexibility which includes multiple joints and associated soft tissue in that area and it does not take into consideration the relative lengths of body segments nor does it isolate each leg. Sutton (1984) stated that decreased flexibility is demonstrated by the number of degrees that the athlete lacks from completing full extension of the knee when lying supine with the hip joint flexed to 90 degrees. The hip joint of the leg to be measured is stabilized in this position and the subject attempts to perform knee extension.

Injury Mechanisms

Sutton (1984) proposed a possible mechanism of hamstring injury. He hypothesized that the injuries are created by violent stretching of a muscle or rapid contraction of a muscle group. He suggested that the ability of the hamstring muscles to contract at high velocities when the muscle is eccentrically contracted and stretched to the limits of its length may be a factor which could promote injury. Such a position would occur during the late swing phase when a runner is attempting to decelerate his limb and preparing for the stance phase. Garret, Califf and Bassett (1984) proposed a theory similar to that of Sutton which involved histochemical characteristics of the hamstring muscles. The hamstring muscle group have a relatively high proportion of Type II fibres which are involved with exercise of high intensity and force production. Hamstring muscles in their study were found to have a range of 55.2 % ± 7.0 to 60.4% ± 12.1 Type II fibres in ten subjects that volunteered muscle biopsies. Type II fibres are increasingly recruited for neuromuscular activity as exercise intensity increases. The high intensity exercise associated with hamstring injuries therefore involves larger proportions of Type II fibres with corresponding higher intrinsic force production within the muscles (Garrett et al., 1984).

Some degree of leg length asymmetry is present in every human being (Friberg, 1983). The effect of lower limb length discrepancy and the Q angle on hamstring injuries is not well documented. These two variables are proposed as mechanisms because of the effect that they may have on the functional capabilities of the hamstrings during flexion of the hip and knee. Lower limb length imbalance may cause pelvic rotation which in turn may cause one hamstring muscle group to be prestretched and therefore more likely to experience early fatigue.

History of previous hamstring injury occurrences may be a predictor because it is known that hamstring strains tend to recur in an individual that has already experienced one. Sutton (1984) stated that, in a study done by Bailey and Bremiller (1981), 77% of all the injured athletes had previously sustained a hamstring strain to the same leg that was reported in the study.

Another predisposing factor may be the intensity of the sport in which the athlete is involved. Brubaker and James (1984) stated that strains of the hamstrings accounted for 50% of the strain injuries in sprinters. Lysholm and Wiklander (1987) found, in a study of sixty runners, that hamstring strains were significantly more common in sprinters than in middle-distance and long-distance runners (p<.001). Sutton (1984) stated that hurdling, the 200 meter sprint and jumping events such as the triple jump were activities found to be most often associated with a high rate of hamstring injuries. All of the events involve an increase in the speed and the force output at which the hamstrings must function. Agre and Baxter (1987) stated that as gait increases from walking to running, the total range of motionin the hip and knee is increased in magnitude but the time in which the increased range of motion occurs is not increased and therefore the requirement for flexibility is greatest because the range and speed of motion of the limbs is greatest.

There are many other factors which may contribute to the mechanisms of hamstring strains such as the lead leg used by the athletes in a particular sport, femoral torsion, the amount of pronation that occurs in the ankle and knee during the activity, age of the competitor and number of years active in that sport. However, the main variables of hamstring strains discussed thus far involve the flexibility of the hamstrings, the strength ratio differences between the hamstring and quadriceps muscles as well the strength of the eccentric contraction of the hamstring muscles unilaterally.

Activity of the Hamstrings During Running

The period of activity of muscles changes as speed increases from jogging to running. The total range of motion of the hip, knee and ankle is also increased (Agre and Baxter, 1987). The precise actions produced by the hamstrings depend extensively on the position of the knee and hip at the time of muscle contraction as well as the relative stability of each of the joints involved (Coole & Gieck,1987). The hamstrings can act at the hip and knee simultaneously to produce concurrent or countercurrent motion. Concurrent motion occurs when there is a shortening of a muscle at one end and a concomitant lengthening at the opposite end (Coole and Gieck, 1987). The relative lengths of the muscle remains constant and therefore the ability of the muscle to do work remains constant. Concurrent motion occurs during such actions as hip flexion occurring with knee flexion. Counter-current motion occurs when opposite movements occur simultaneously (Coole and Gieck, 1987). Counter-current motion occurs when the hip is extended while the knee is flexed or when the knee is extended and the hip is flexed. These two conditions create passive or active insufficiency. Passive insufficiency occurs when active range of motion is limited at the two involved joints due to their biarticular stretch. This situation would occur in the late recovery phase of the running gait. Active insufficiency occurs when the muscles shorten to a degree that active contraction is negligible. For example, during the early recovery phase of running, the knee is flexed and the hip is extended so that active insufficiency is occurring at the two joints involved.

During the first half of the swing phase of running, the length of the hamstring musculotendinous unit remains essentially unchanged (Agre, 1985) (Figure 3). The hip and knee rapidly flex but the knee flexion is passive resulting from the rapid forward acceleration of the thigh caused by hip flexion. The knee begins to rapidly extend while hip flexion continues midway through the swing phase. There is a predominance of eccentric muscle activity in the hamstrings before foot strike and to a lesser extent in the quadriceps during midsupport (Coole and Gieck, 1987).

During the last 25% of the swing phase, the hamstring muscles undergo eccentric contractions to assist in hip extension while decelerating knee extension (Agre, 1985). During the late forward swing phase (Figure 4), the hamstrings are at their greatest length generating maximum tension while eccentrically contracting. This strong eccentric contraction of the hamstrings is accompanied by a relaxation of the quadriceps (Coole & Gieck,1987). The eccentric contraction is followed by a brief concentric contraction of the hamstring muscles which flex the knee and extends the hip in preparation for the support phase.

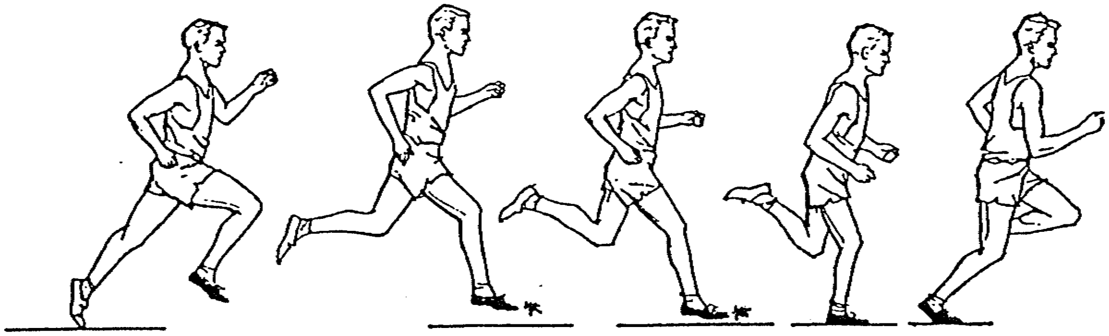

Figure 3. First Half of Swing Phase Demonstrating Left Lower Limb. (Taken from: The Mechanics of Athletics. G. Dyson (1973) London, England. University of London Press Ltd. Page 122).

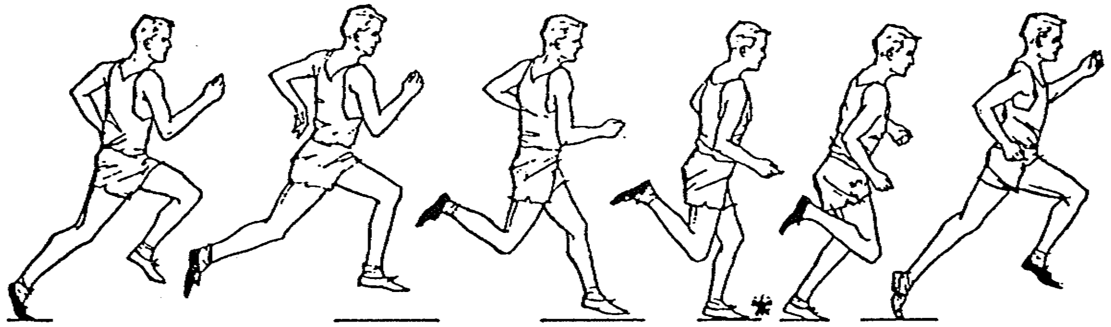

Figure 4. Late Forward Swing Phase Demonstrating Left Lower Limb.
(Taken from: The Mechanics of Athletics. G. Dyson (1973)
London, England. University of London Press Ltd.
Page 123).

At footstrike, the hamstrings extend the hip and stabilize the knee. The hamstrings remain active during the first half of the support phase producing hip extension while resisting knee extension by concentrically contracting (Agre, 1985). This action controls the momentum of the leg as well as preparing the leg for an efficient foot strike. The quadriceps are also active eccentrically during the first half of the support phase to decelerate and control knee flexion at foot contact and during the period of flexion which follows (Agre, 1985). There is a dominance of hamstring activity early in the support phase (Wood, 1988). This is generally caused by an attempt by the sprinter to minimize breaking action at touchdown by pulling the body forward and over the touchdown point during initial ground contact by hip extension.

Two points during running have been cited as the actual positions at which hamstring injury may occur. These are the late forward swing phase during the recovery segment and the takeoff segment of the support phase (Coole & Gieck, 1987). These two phases are implicated because of the sudden change in the function of the hamstrings. In the later stage of the swing phase, the hamstrings act as a stabilizing flexor to decelerate knee extension while during that toe-off phase, they become an active extensor of the hip joint (Agre, 1985).

During the late forward swing phase, the hamstrings are at their greatest length therefore generating the maximum potential tension (countercurrent position). The hamstrings are eccentrically contracted to decelerate flexion of the thigh at the hip and extension of the lower leg at the knee. The strong eccentric contraction of the hamstrings coincides with relaxation of the quadriceps. Sutton (1984) proposed that an alteration of this reciprocal action between the quadriceps and hamstring muscles might cause a hamstring injury. The injury could be caused due to excessive antagonistic force from the quadriceps being placed on the eccentrically lengthening hamstring. This antagonistic force may cause overstretching which in turn may be increased if the quadriceps are excessively stronger than the hamstrings of one limb or of both. As the hamstrings are stretched and fully elongated, the muscle responds to the stretching with a rapid and excessive protective contraction which is opposed by muscle spindle. If the quadriceps are stronger than the hamstrings, the hamstrings may not be able to counteract the greater force generated by quadriceps contraction as efficiently as they should due to imbalance or weakness. The semitendinosus sustains the greatest rate of lengthening while the long head of the biceps femoris is stretched the most due to it having the shortest fibres per muscle length (Wood, 1988).

The second position cited as a potential injury position is the takeoff segment of the support phase (Coole & Gieck, 1987). At toe-off , the hamstrings contract concentrically, extending the hip as a propulsive mechanism to accelerate forward motion. During the follow-through, the knee flexion is passive and results from prior contractions of the hip flexors. The function of the hamstrings changes from stabilizing the knee to powerfully flexing the knee and extending the hip. The magnitude of hip and knee power requirements indicate that hamstrings are under considerable stress (Wood, 1988). This is compounded by the athlete's attempts to minimize the retarding forces at foot strike by prolonging the hip extension/knee flexion phase.

EMG Activity of the Hamstrings During Running

During footstrike, the biceps femoris and semimembranosus each contract concurrently to aid in knee stabilization (Coole & Gieck, 1987). The semitendinosus muscle fires during midsupport to assist the other hamstring muscles in providing for knee stability and continued hip extension. When the heel has lifted and just prior to toe-off, the biceps femoris muscle elicits maximum spikes on the EMG with the semimembranosus and semitendinosus also creating high spikes. This finding indicates that the hamstring muscles reach their peak EMG activity at a time when their respective lengths are just greater than resting length (Wood, 1988). It is at this stage that the greatest force potential is physiologically the greatest (Figure 5). During the follow-through, the hamstring muscles are largely passive due to the transfer of inertial forces. The hamstring muscles are relatively quiet during the recovery phase until the forward swing segment of the running gait when the semimembranosus shows increased activity. This activity results in eccentric contractions producing deceleration of the flexion of the thigh. The direction reversal of the thigh (or deceleration) and the end of the knee extension phase is due to an increase in semimembranosus and semitendinosus activity although the biceps femoris dominates the EMG recordings. EMG recordings may relate to hamstring strains because if it is known precisely when the maximum force output of the muscle is occurring, it may be possible to pinpoint when the muscle is being forced beyond its capabilities.

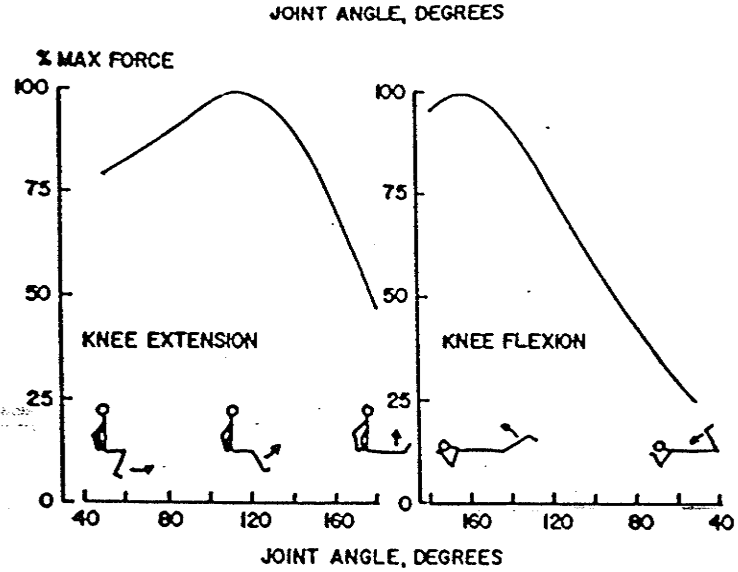

Figure 5. Length Tension Curve of Hamstring Muscle Group. (Taken from: Physiological Testing of the Elite Athlete. J.D. MacDougall, H.A. Wenger & H.J. Green (editors) (1982). Canadian Association of Sport Sciences, Page 8.)

Sites of Hamstring Injuries

An injury to the musculotendinous unit may occur at any of these four sites:

1. the proximal bony attachment
2. the musculotendinous junction
3. the belly of the muscle
4. the distal bony attachment

The short head of the biceps femoris is the most commonly strained member of the hamstring muscle group (Burkett, 1970; Heiser et al., 1984; Coole & Gieck, 1987). The biceps femoris muscle is the muscle most prone to injury due perhaps to the fact that this muscle has the shortest fibres per muscle length and the smallest pennation angle of all the components of the hamstring muscle group (Wood, 1988). The biceps femoris muscle tends to be injured in the region of the belly of the muscle (Figure 6). Biomechanically, the biceps femoris is active in the midsupport or stance phase as a knee stabilizer (Coole & Gieck, 1987). Its maximal EMG activity occurs at toeoff . Therefore, it may be within this range of motion that the majority of hamstring injuries occur.

The semimembranosus and semitendinosus muscles are not as frequently cited in hamstring injuries as the biceps femoris. Nevertheless, these muscles do become injured. The semimembranosus muscle is generally injured around the belly

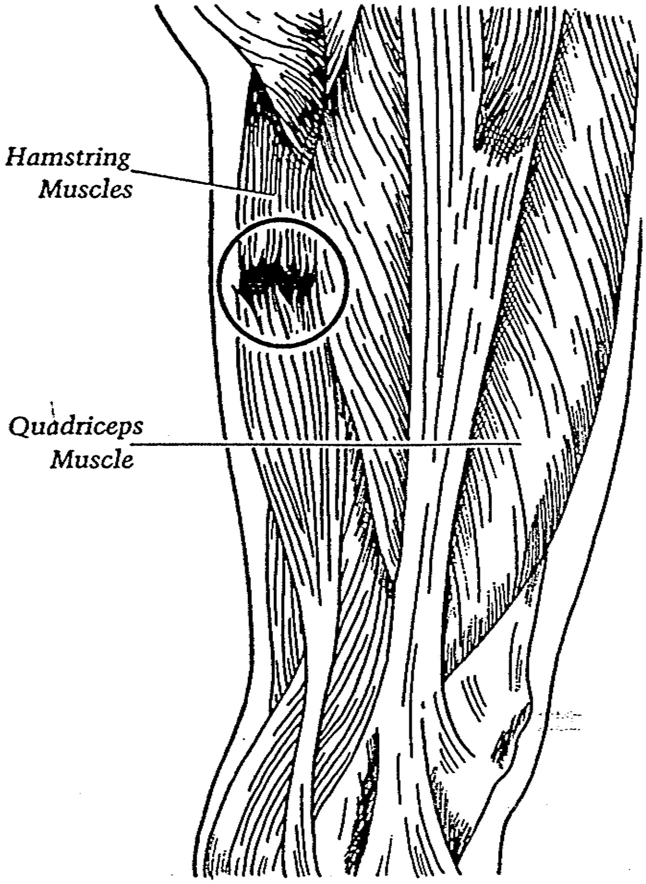

Figure 6. Site of Biceps Femoris Injury. (Taken from: Sports Health. The Complete Book of Athletic Injuries. W Southmayd & M. Hoffman (1981). New York. Quick Fox. Page 240).

region whereas the semitendinosus muscle is injured close to the bony regions of the distal and proximal attachments (Figure 7). The EMG activity of both of these medial compartment hamstring muscles occurs during the late forward swing phase. From the above information, it may be possible that strains to the medial compartment of the hamstring muscle group occur in the late forward swing phase during deceleration whereas strains to the biceps femoris or lateral hamstring compartment develop immediately before toeoff or when acceleration is occurring.

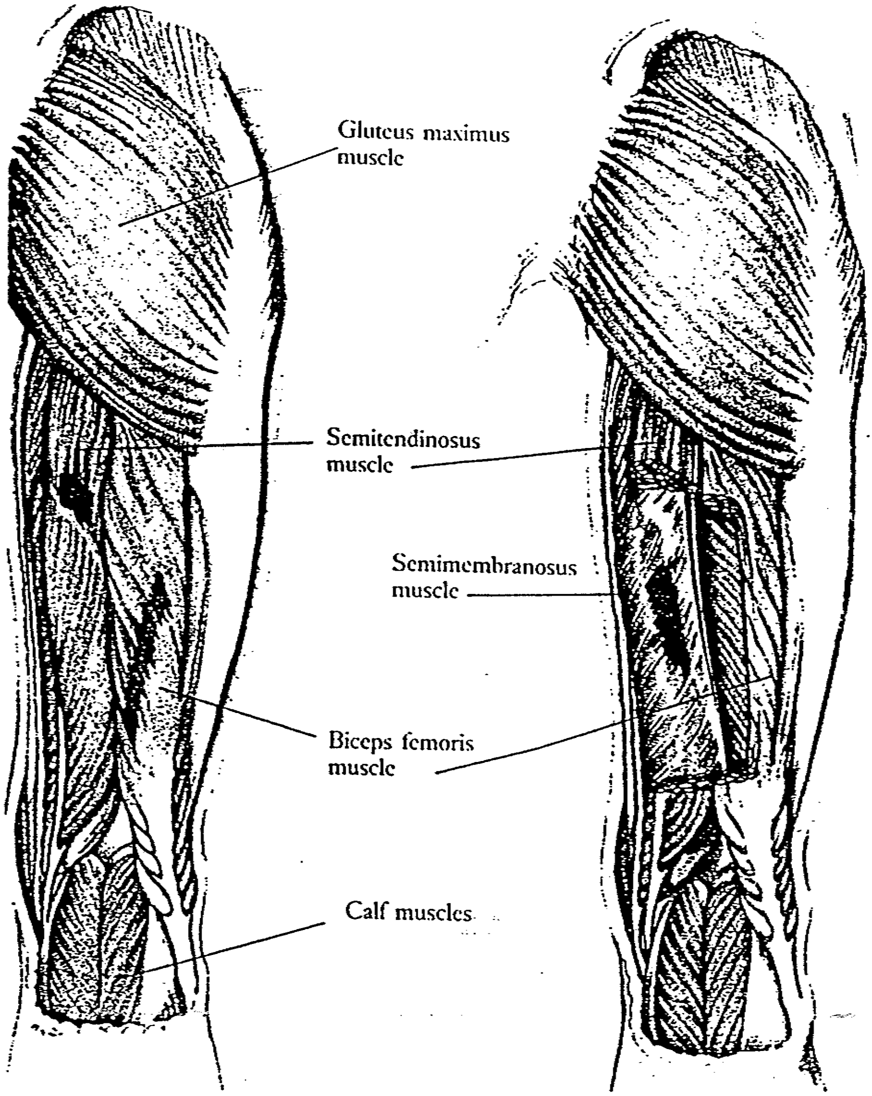

Figure 7. Site of Semimembranosus and Semitendinosus Injuries. (Taken from: Sport Injuries. Their Prevention and Treatment. L.Peterson & P. Renstrom (1986). Chicago, Illinois. Year Book Medical Publishing Inc. Page 282.)

Strength, Flexibility and Anthropometric Measurements

Strength Measurements

The strength variables were measured using the Kinetic Communicator Exercise (KIN/COM) system which is a hydraulically driven, microcomputer-controlled device for the testing, measurement and rehabilitation of human joint function (Farrell & Richards, 1986). Farrell and Richards (1986) found that the KIN/COM does not greatly overshoot the target lever arm speed. They concluded that the KIN/COM unit appeared to produce valid and reliable force measurements, as well as producing accurate lever arm speed and position measurements. This system offers a valid and reliable means of testing the isokinetic strength of an individual both eccentrically and concentrically, providing that the exercise is performed according to test protocol.

Flexibility Measurements

A Leighton Flexometer has been used by a number of investigators to measure flexibility parameters. The Leighton Flexometer is considered to be one of the most accurate instruments for the measurement of flexibility (Johnson & Nelson, 1986). MacDougall et al. (1982) used the Leighton Flexometer to measure hip flexibility with the athlete in a standing position, feet together, knees stiff, arms extended above the head and the hands clasped together with the palms up. The degree of hip flexion was measured as the individual bent forward as far as possible. The degree of hip extension was measured as the individual bent backward as far as possible. Burkett (1970) measured hip flexion using the "Well's sit-and-reach" test and a different measuring device than the Leighton Flexometer. Capiau (1981) measured hip flexion using the Leighton flexometer and a modified "sit-and-reach" test in which the athlete keeps his legs extended and slowly stretches forwards. Both of these methods are limited by the flexibility of the lower back. The method used in the current investigation was adapted from Magee (1987) which allowed for bilateral measurement of the hip of both the right and left limb and allowed more detailed analysis of the flexibility of the hip region.

Stephens and Reid (1988) measured hamstring flexibility with still photography and the "sit-and-reach" test. Gajdosik and Lusen (1983) measured hamstring tightness with a goniometer by measuring the angle of knee flexion after active knee extension while the hip of the limb being measured was stabilized at 90 degrees flexion. The subject did not force the leg being exercised past the point of initial mild resistance.

Anthropometric Measurements

A. Biiliac Breadth

MacDougall et al. (1982) measured bicristal or biiliac breadth which was defined as the distance between the most lateral points on the superior border of the iliac crests. The measurement was recorded from the anterior aspect of the subject with a sliding caliper held at an upwards angle of 45 degrees to the horizontal to encompass the largest diameter between the lateral aspects of the superior iliac crests. Wilmore et al. (1969) however measured the biiliac breadth from the posterior aspect of the subject holding the anthropometer at a downward angle of 45 degrees. In the present study the anthropometer was held at a downward angle of 45 degrees.

Wilmore and Behnke (1969) reported a test-retest correlation of .97 for measurements made the same day in college age males using the technique described by Lohman. Chumlea et al. (1984b) reported a technical error of measurement of .38 cm for adult subjects. Friedlander et al. (1977) found a population standard deviation of 1.6-1.7 cm. Hence the relative magnitude of the error variance measured by the ratio between technical error to the population variance is low and it appears that biiliac breadth has a high level of reproducibility when measured carefully (Lohman et al., 1988).

B. Bitrochanteric Breadth

Lohman et al. (1988) measured bitrochanteric breadth which was defined as the maximum distance between the most lateral projections of the greater trochanters. Wilmore and Behnke (1969) stated that the test-retest correlation was .97 for college age males using the Lohman technique. Behnke and Wilmore (1974) also stated that breadths can be measured with a high degree of reliability because the measurements approximate bone-to-bone contact which reduces variability of repeated measurement and increases accuracy.

C. Thigh Length

Lohman et al. (1988) measured direct thigh length as the distance between the midpoint of the inguinal ligament to the proximal edge of the patella. A nonstretchable tape measure was used as the measuring device. Agre and Baxter (1987) measured lower limb length from the anterior superior iliac spine to the medial malleolus. Magee (1988) measured thigh length from the anterior superior iliac spine to the lateral femoral condyle. The present study defined thigh length as the distance between the most superior aspect of the greater trochanter of the femur to the lateral joint line of the knee. This method was used because the landmarks were more easily located.

D. Calf Length

Lohman et al. (1988) measured direct calf length defined as the distance between the medial knee joint line to the tip of the medial malleolus. Magee (1988) stated also that measuring from the lateral malleolus was less likely to be affected by muscle wasting.

E. Q Angle of the Thigh

The Q angle was included as a variable in this study because it determines the angle of pull for the quadriceps during running. If there is a large Q angle, the angle at which the quadriceps are pulling will be increased. The increase in the angle of pull of the quadriceps may affect the ability of the hamstrings because the quadriceps are antagonistic to the hamstrings when running is occurring.

Chapter 3

Methods and Procedures

Introduction

This chapter is separated into four sections: subjects, experimental design, data collection and data analysis. The first section describes the selection of the subjects for this study and the characteristics or requirements for selection into each group. The experimental design section describes the research carried out. The data collection section describes in detail the anthropometric, flexibility and KIN/COM isokinetic strength testing protocol developed for this study with a description of each test performed. The data analysis is divided into subsections describing the analysis of the comparisons of the previously injured and non-injured limbs as well as the previously injured group as a whole and the non-injured group as a whole.

Subjects

The subjects for this study were active male athletes between the ages of 18 to 45. These subjects included a control group of subjects (N=20) that had not experienced a hamstring injury and an experimental group (N=19) of athletes who had experienced various degrees of hamstring muscle strains. They had also undergone a rehabilitative period under the guidance of an athletic therapist or a physiotherapist and had been allowed to return to their sport. Names of potential experimental subjects were provided upon consultation with the athletic therapy unit at the University of Manitoba, the athletic therapist from the University of Winnipeg and the Pan Am Sports Clinic. The subjects were recruited by a request from the investigator to determine if they would be willing to participate in a study and were given the opportunity to refuse. Both groups consisted of male athletes from a variety of different sports and skill levels.

Experimental Design

The design of this study followed that of a static group comparison in that each subject was only tested once and there was no follow-up testing. The researcher had no input as to the type or amount of rehabilitation that each previously injured subject may have followed prior to being tested. A questionnaire was completed by each previously injured subject at the time of testing which included such information as previous history of lower limb injuries, type of sport that he was active in and how many days per week he participated in that sport, anatomical location of the hamstring injury, if the dominant or non-dominant leg was injured and if he had any known structural defects in his lower limbs (Appendix A). Homogeneity of the two groups were established by asking for volunteers in sports that were common to the previously injured group. This information was not statistically analyzed but the information on the questionnaire was used to compare the profiles of the subjects in the previously injured group.

The tests were designed in such a manner as to minimize potential harm to all the subjects. Pilot tests were conducted to ensure safety of the subjects. The research proposal was approved by the Committee on Research Involving Human Subjects. Each subject was also asked to read and sign an informed consent form (Appendix B).

Data Collection

The testing was carried in the Sport and Exercise Sciences Research Institute located in the Max Bell Centre at the University of Manitoba. The subjects were scheduled for a two hour session and reported to the Max Bell testing laboratory. The subjects were instructed to wear shorts, a t-shirt and running shoes. A three minute warmup on a bicycle ergometer with resistance set at 1.5 kiloponds was performed before the flexibility and strength testing portion of the study to ensure that the athletes' muscles were warmed up (Hageman et al., 1988). All measurements were completed on the right side first. The subjects were briefed on the reasons for administering the various tests before they were measured or tested. Thirty-nine subjects were tested during a period of seven months. These included 20 normal subjects and 19 subjects who had been fully rehabilitated after hamstring strains of various degrees.

All tests were clearly explained and demonstrated where necessary, and any questions were answered. The subject was informed that maximal effort was required during all the phases of testing. The subjects were verbally motivated during the strength testing phase of the study. The protocol of each test was explained to the subject before the actual testing was carried out. The subjects were familiarized with the KIN/COM machine and allowed 3 practise trials to familiarize themselves with the movement. The subject was allowed a rest period of approximately two minutes after the 3 practise trials before the actual strength test was carried out. The right limb was tested first for each flexibility or strength movement followed by measurement of the left limb.

The protocol followed for each test is given below. The tests were administered in a predetermined order. The order was:

1. Weight
2. Height
3. Biiliac Breadth
4. Bitrochanteric Breadth
5. Thigh Length
6. Calf Length
7. Hamstring Flexibility
8. Flexibility of the hip during flexion
9. Flexibility of the hip during extension

10. Internal rotation of the hip
11. External Rotation of the hip
12. Strength Measures of Knee Extensors
13. Strength Measures of Knee Flexors
14 Strength Measures of Hip Extensors
15. Strength Measures of Hip Flexors
16. Q angle of the Thigh

Anthropometric, Flexibility and Strength Measurements

The anthropometric measurements that were used in this study were thigh length, calf length, biiliac breadth and bitrochanteric breadth. The anthropometric measurements were conducted using an sliding caliper (Figure 8). Biiliac breadth, bitrochanteric breadth, thigh length, calf length and Q angle were anthropometric measurements used in this study. These specific measurements were taken because anthropometric variables may be involved in the efficiency of the hamstring muscle group when an athlete is sprinting. For example, if the bitrochanteric breadth in a previously injured athlete is either larger or smaller than on a person who has not had a hamstring strain, it may affect the pull of the hamstring muscles at the knee joint by changing the angle at which the hamstrings are functioning. Thigh length and calf length were chosen as variables to be measured because lower limb extremity discrepancies may account for the difference between a limb that has not had a hamstring strain and a limb that has been injured.

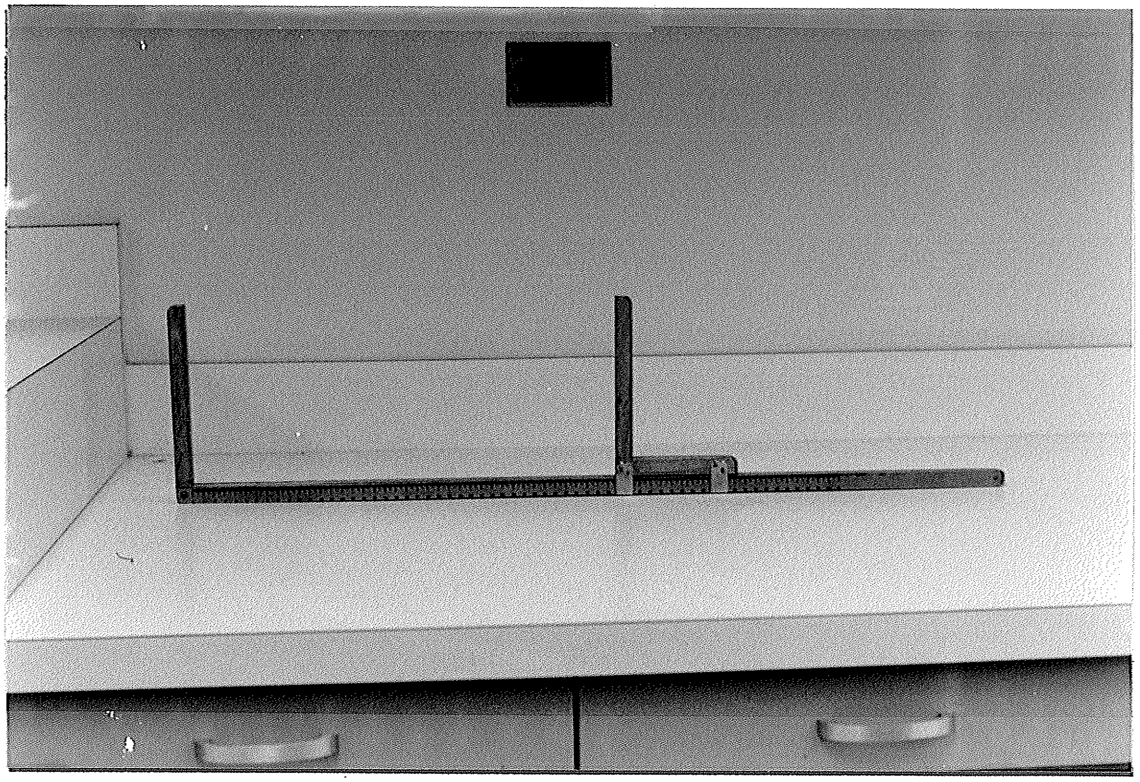

Figure 8. Sliding Caliper

If there are limb length differences, the shorter limb may be subjected to higher impact forces and therefore become fatigued more quickly than the limb that is longer.

Thigh Length

Thigh length is defined anatomically as the distance between the axis of the hip joint and the axis of the knee joint. Its measurement in the living however is approximate because it is difficult to locate these joint centres (Martin et al., 1987). The method of measuring thigh length used in this study was to locate the greater trochanter while the athlete flexed his hip and to locate the lateral joint centre while the athlete flexed his knee. The distance between the two landmarks as measured using a standard sliding caliper was recorded as the length of the thigh (Figure 9).

Calf Length

Calf length was located in a similar manner to that of thigh length. The lateral joint line was palpated and marked as the athlete flexed his knee and the distal point of lateral malleolus of the ankle was marked. The distance between the joint line and the lateral malleolus as measured using a standard sliding caliper was recorded as the length of the calf (Figure 10).

These two measurements were recorded to find out if a person with a hamstring strain history had (a) a difference in the thigh-calf length ratio or (b) noticeable leg length discrepancies

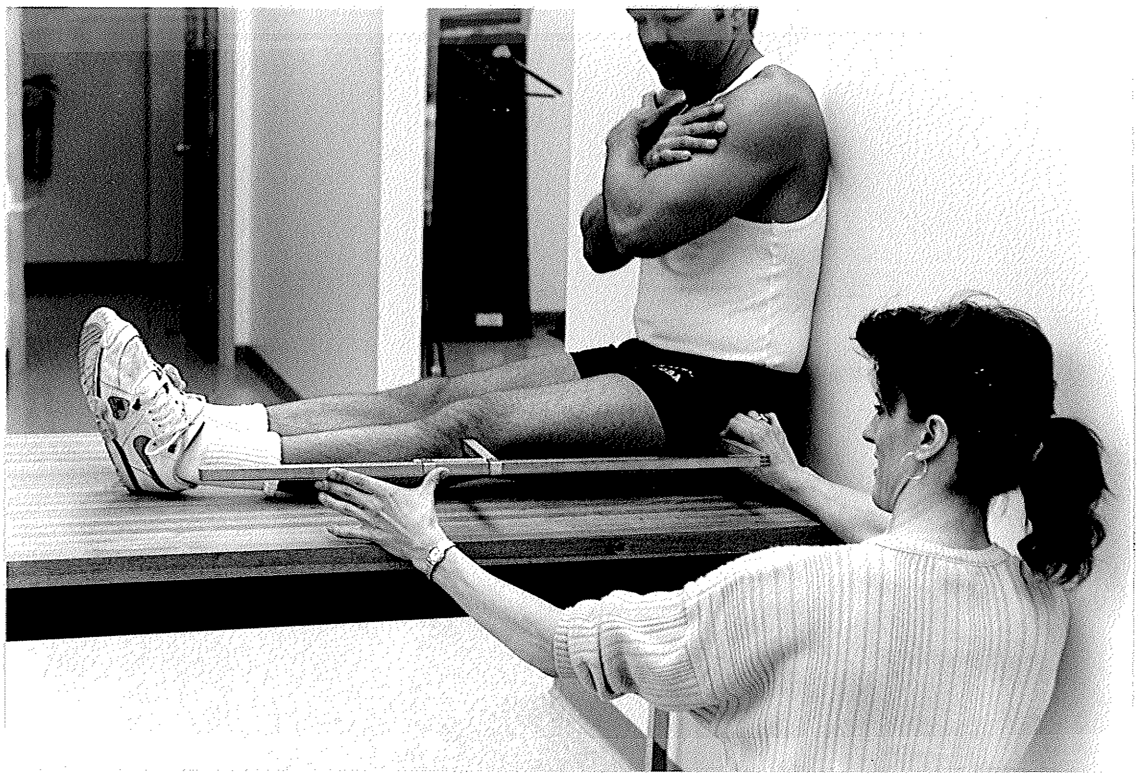

Figure 9. Measurement of Thigh Length

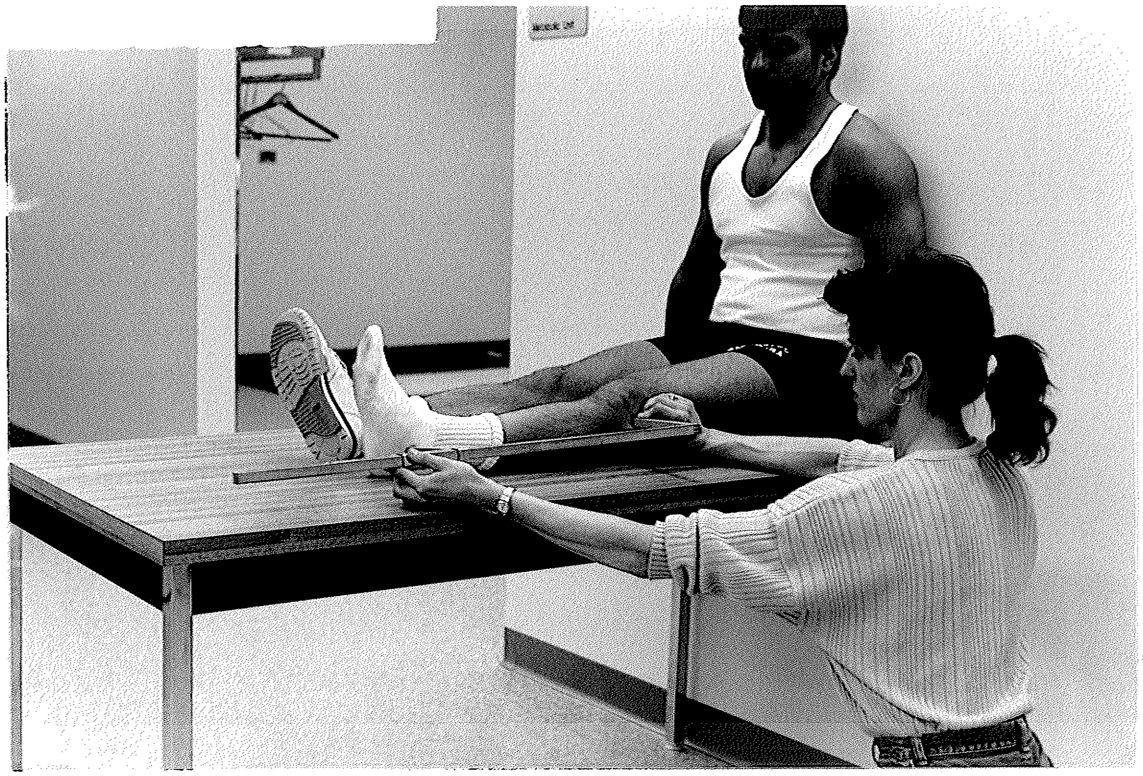

Figure 10. Measurement of Calf Length

when compared to an athlete who had never had a hamstring strain.

Biiliac Breadth

Breadths were measured to find out if previously injured subjects had breadths that were significantly different from non-injured athletes. A wider breadth may indicate that the angle at which the hamstrings are pulling at is greater than normal. This increased angle may disrupt the ability of the hamstring muscle to work directly in line with the driving foot thereby placing greater stress on one side of the muscle group during an activity such as running. Biiliac breadth was measured as the distance between the anterior superior iliac spines as measured by a standard anthropometer (Figure 11). The athlete was instructed to stand facing the measurer with his feet approximately five centimetres apart and his hands placed across his chest. The sliding caliper blades were placed at a downward angle of approximately 45 degrees at the location of the crests and the distance between the two blades was recorded as that breadth. Biiliac breadth was measured from the anterior aspect of the subject because the iliac spines are located anteriorly on the subject whereas bitrochanteric breadth was measured from the posterior aspect of the subject.

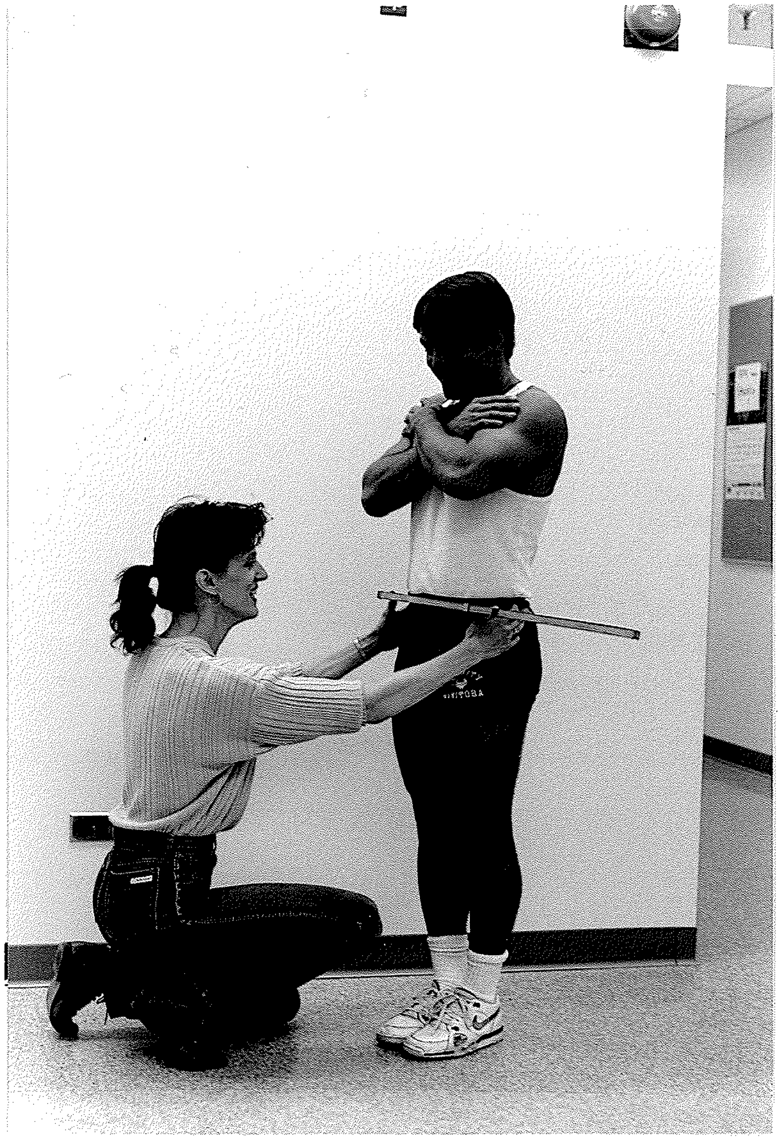

Figure 11. Measurement of Biiliac Breadth

Bitrochanteric Breadth

Bitrochanteric breadth was measured as the distance between the most lateral aspect of the greater trochanter on both sides as measured by a standard sliding caliper (Figure 12). The greater trochanter was palpated as the athlete flexed his hip. The athlete was instructed to stand with his feet together and his hands across his chest. The blades of the sliding caliper were placed on the two sites and the distance between the two blades was recorded.

Hamstring Flexibility

All tests were conducted using a Leighton flexometer to measure the degrees of motion at a given joint. Flexibility of the hamstring muscle group was measured to determine if there were any significant differences between a previously injured athlete and an athlete who had never had a hamstring strain. Internal validity is threatened because the measuring of flexibility should be done in such a way as to test the hamstrings or any other muscle in a dynamic situation. In the case of the hamstrings, the test should be performed in a dynamic situation in order to mimic the whip action of the leg as the knee approaches extension. Realistically, however, the measurement was performed statically for accuracy of measurement as well as for the safety of the athletes involved.

Figure 12. Measurement of Bitrochanteric Breadth

Figure 13. Cradle for Measurement of Hamstring Flexibility

The hamstring flexibility test that was used is a modified "Wallace Active Knee Extension" test (Blackburn et al., 1979). This test was used as opposed to the "sit-and-reach test" because the sit and reach flexibility test involves the flexibility of the lower back which would have been a limiting factor when testing hamstring flexibility. If the lower back is very flexible, the test score will be high even if the hamstrings are tight. Also, the sit-and-reach flexibility test does not have the capability of measuring the right and left limbs separately.

A modified "Wallace active knee extension" test was used in the present study because it allowed for bilateral measurement of the hamstring muscle group and it did not involve movement in the lower back. The athlete was instructed to lie in a cradle that had been constructed to ensure that the hip of the knee that was to be tested was flexed at an angle of approximately ninety degrees (Figure 13). The "Wallace test" description stated that the athlete should flex his hip and hold this position with his hands (Blackburn et al., 1979). It was felt that this was less than ideal because the athlete should be concentrating more on the knee extension test than on stabilizing his hip. The cradle that was constructed was designed to alleviate this problem. The second modification employed was that both hips were flexed at the same time. The "Wallace" test protocol proposed that the limb not being tested was to be

Figure 14. Hamstring Flexibility Measurement

extended (Blackburn et al., 1979). It was felt that this position might change the ability of the hamstrings to extend if there was any low back deficiencies. The hip and knee were flexed at approximately ninety degrees to mimic the phase of running at which the hamstring begins to stretch. The flexometer was placed just below the tibial tuberosity on the lateral side of the calf and the dial was set to zero. The athlete was allowed to hold on to the sides of the cradle to ensure that the hips stayed at 90 degrees. A velcro strap was placed over the leg that was being exercised and under the free leg. The velcro strap was fastened under the side of the cradle. The movement used to measure hamstring flexibility was:

1. The knee was flexed at 90 degrees and the dial was set at zero.

2. The athlete extended his knee to the range where he could no longer extend his knee without being comfortable. This was the point where the reading was taken (Figure 14). The measurement was recorded to the nearest degree.

Hip Flexibility of Hip Extensors During Flexion

Hip flexibility during flexion measures the elasticity of the hip extensor and hamstring muscle group. Hip flexion was measured to determine if there was any difference in this variable in athletes who had been previously injured and an athlete who had not experienced a hamstring strain. Hip

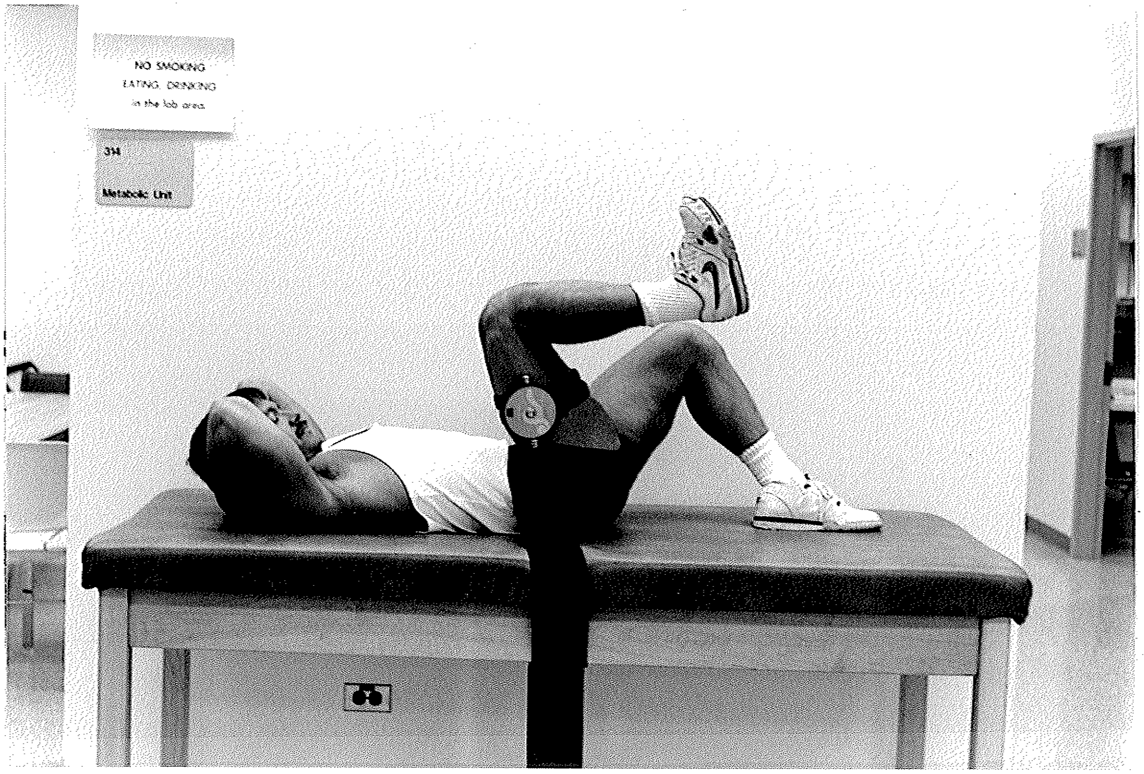

Figure 15. Measurement of Flexibility of Hip Extensors

flexion plays a very important role in sprinting because it assists in the swing phase of running when the limb must be swung through in order to make contact with the ground during the next step. If hip flexion is limited, it may interfere with the smoothness of the swing phase. For example, if the hip extensors are tight limiting the range of hip flexion, the swing phase may be shortened and therefore the eccentric lengthening of the hamstrings may be occurring in a much shorter time period.

The range of hip flexion was measured by asking the subject to lie on his back with his non-tested limb flexed at the knee and his foot on the table (Figure 15). This position was assumed in order to prevent any lower back hyperextension from occurring. A velcro strap was also placed over his waist and fastened under the examining table. The Leighton flexometer was placed approximately seven inches above the knee on the lateral side of the thigh. The athlete was asked to flex his hip as far as possible while his buttocks and lower back stayed in contact with the examining table. He was not permitted to use his hands to further flex his hips at the end of the range. The movement used to measure hip flexion was as follows:

1. The hip and knee began in an extended position.
2. The hip was flexed as far as possible with the knee bent throughout.

3. The final reading was taken at the point of maximal hip flexion.

Hip Flexibility of Hip Flexors during Extension

Hip flexibility during extension measures the elasticity of the rectus femoris and iliopsoas muscles and anterior hip ligaments and joint capsule. Hip extensor flexibility limits the amount of knee lift during the recovery in sprinting and therefore may limit the stride length of the athlete. Hip extension was selected as a variable because the flexibility of the hip flexors may dictate the length of time that the hamstrings are allowed to contract concentrically during the puch off at the end of the stance phase before they are asked to contract eccentrically. If this period between the types of contraction is shortened, the hamstrings may not be able to make a smooth transition from concentric contraction to eccentric contraction and this may cause an injury.

The athlete was asked to lie prone on the examining table with both of his lower limbs extended. A strap was placed over his lower back just above the posterior pelvic crests and fastened under the examining table. The flexometer was placed approximately seven inches above the knee on the lateral side of the thigh. The athlete was then asked to extend his hip as far as he could while maintaining contact of the anterior superior iliac spines with the examining table through the movement.

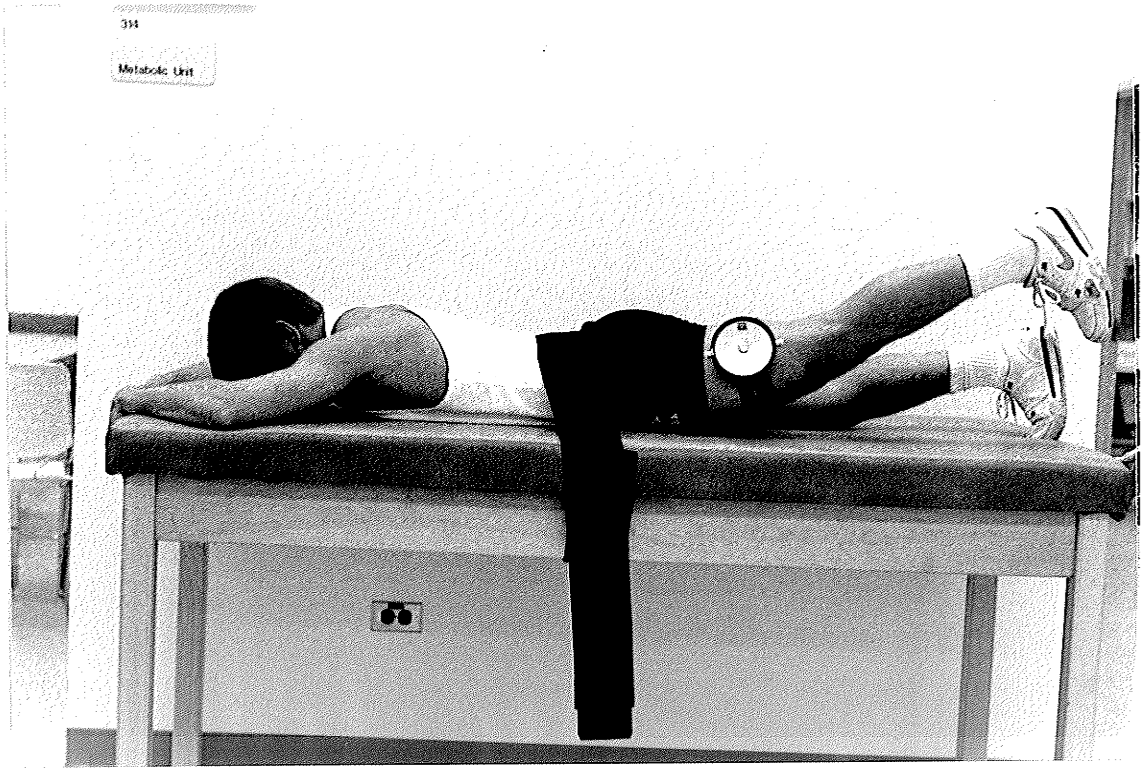

Figure 16. Measurement of Flexibility of Hip Flexors

The strap helped stop any hyperextension in the lower back from occurring as well as keeping the pelvis on the table (Figure 16). The movement sequence for hip extension was:

1. The knees and hips were completely extended.
2. The athlete then extended his hip as far as possible with the knee extended throughout.
3. The flexibility was recorded when the athlete could not extend his hip any further without his anterior superior iliac spines losing contact with the examining table.

Internal and External Rotation

Flexibility tests of internal and external rotation of the hip were chosen as measurements because during running the femur naturally rotates around a vertical axis within the hip joint capsule. It was felt that if there was an excess or deficit of movement during rotation, the angle of pull at which the hamstring muscles must function may interfere with the ability to flex the knee or extend the hip while the femur is medially or laterally rotating during the running gait.

The subject was asked to sit at the edge of an examining table while the flexometer was placed on the anterior ridge of the tibia just below the tibial tuberosity. The knees were flexed at approximately 90 degrees. A velcro strap was placed over the thigh to be measured, around the table edge and fastened under the table. The athlete was then asked to place his hands on

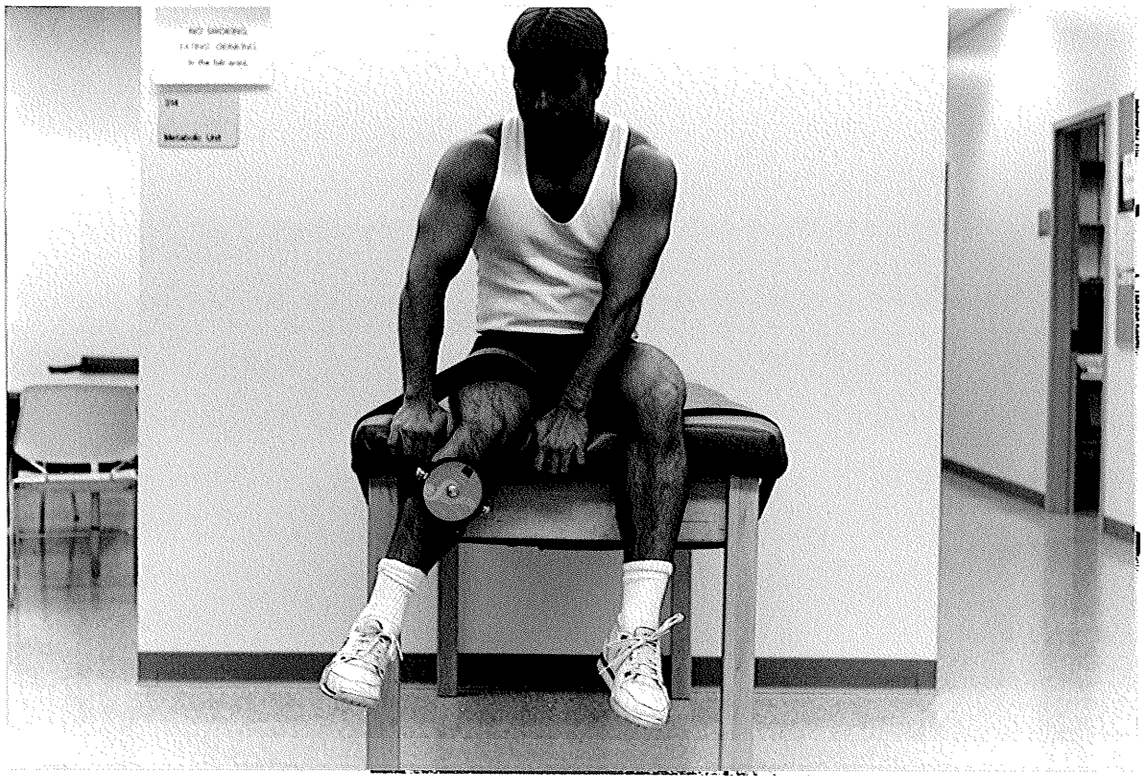

Figure 17. Measurement of Internal Rotation

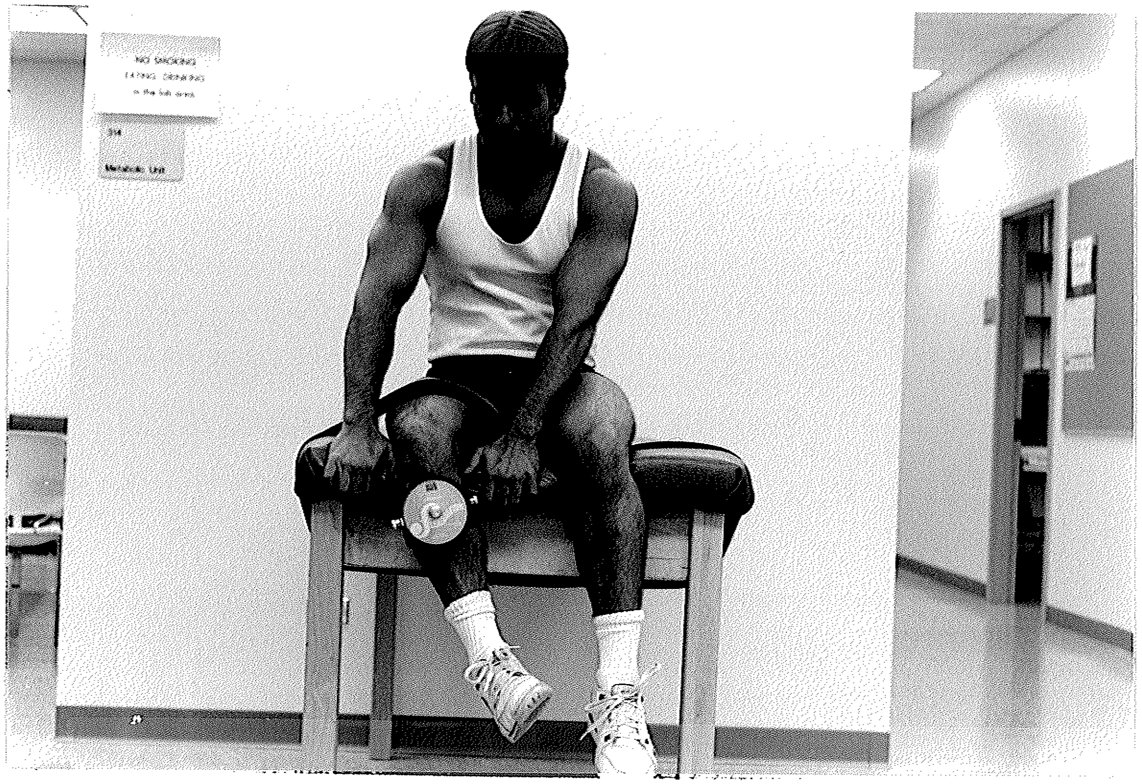

Figure 18. Measurement of External Rotation

either side of the thigh being measured to ensure that there was no side to side movement of the thigh. The athlete was asked to externally rotate the shank (Figure 17) and to internally rotate the shank (Figure 18).

The movement for the test was as follows:

1. The athlete began with his leg to be measured perpendicular to the floor. This was position zero.
2. The athlete then rotated his hip as far as he could without lifting his opposite side of the body off of the table.
3. The end range was recorded when the athlete could not comfortably rotate his hip any further.
4. The test was repeated with rotation in the opposite direction.

Strength Measurements

The KIN/COM allows the subject to perform a series of movements against a resistance which the machine provides via a rotating lever arm system. The KIN/COM is located in the Max Bell Arena at the University of Manitoba. The KIN/COM was chosen for the strength measurements because it provides an accurate and reliable assessment of an athlete's endurance, strength and power (Farrell and Richards, 1986). The advantage of using the KIN/COM is that it keeps the speed of the limb movement at a constant pre-selected velocity. There is a limitation when using the isokinetic strength testing. The standard test position used to assess hamstring-quadriceps strength ratios calls for stabilization of the thigh in a sitting posture. Stabilization limits movements of the hips which is contrary to hip action during running. Fixing hip flexion may bias the relative output of the hamstring and quadriceps muscles. The sitting position forces the quadriceps to work against gravity in initiating motion and the hamstrings are aided by gravity. This affects the testing procedure because the hamstring may not fatigue as readily as when the athlete is sprinting in a more upright position. Isokinetic testing is also performed in a posture when the athlete's body weight is not a contributing factor. Dismissing the contribution of the athlete's body weight ignores any weakness that the hamstrings may have in extending the hip during the support phase and assisting in extension of the knee during the takeoff phase of the running cycle. Despite these weaknesses, the KIN/COM is the best machine available to measure the strength, power and endurance of this muscle group.

All isokinetic strength tests were administered with the velocity of the KIN/COM set at 30 degrees per second for both concentric and eccentric contractions. Strength measurements of the knee extensors, knee flexors , hip flexors and hip extensors of both the right and left limbs were conducted. Muscle strength imbalances or asymmetries between the left and right limbs have been proposed as factors related to hamstring strains (Liemohn, 1984; Burkett, 1970; Sutton, 1984; Heiser et al., 1984).

Knee Extensors

(1). The subject was seated in place and the KIN/COM table and head height were adjusted to make a horizontal line through the centre of the knee joint.

(2). The knees were flexed at approximately 90 degrees to the thigh.

(3). The KIN/COM arm radius was adjusted so that the pad was placed just above and in front of the ankle.

(4). A strap was placed tightly over the measured thigh and under the free lower limb and fastened under the table.

The knee angle of 90 degrees was used as a start angle and the subject extended the knee as far as was comfortable. The complete extension was approximately 5 degrees less than full extension. Three trials were performed for each movement tested (Figure 19).

Knee Flexors

The same protocol was used as for knee extension except:

(1). The pad was placed behind the limb and just above the ankle.

(2). The athlete began the movement from near full extension and returned to approximately 90 degrees flexion.

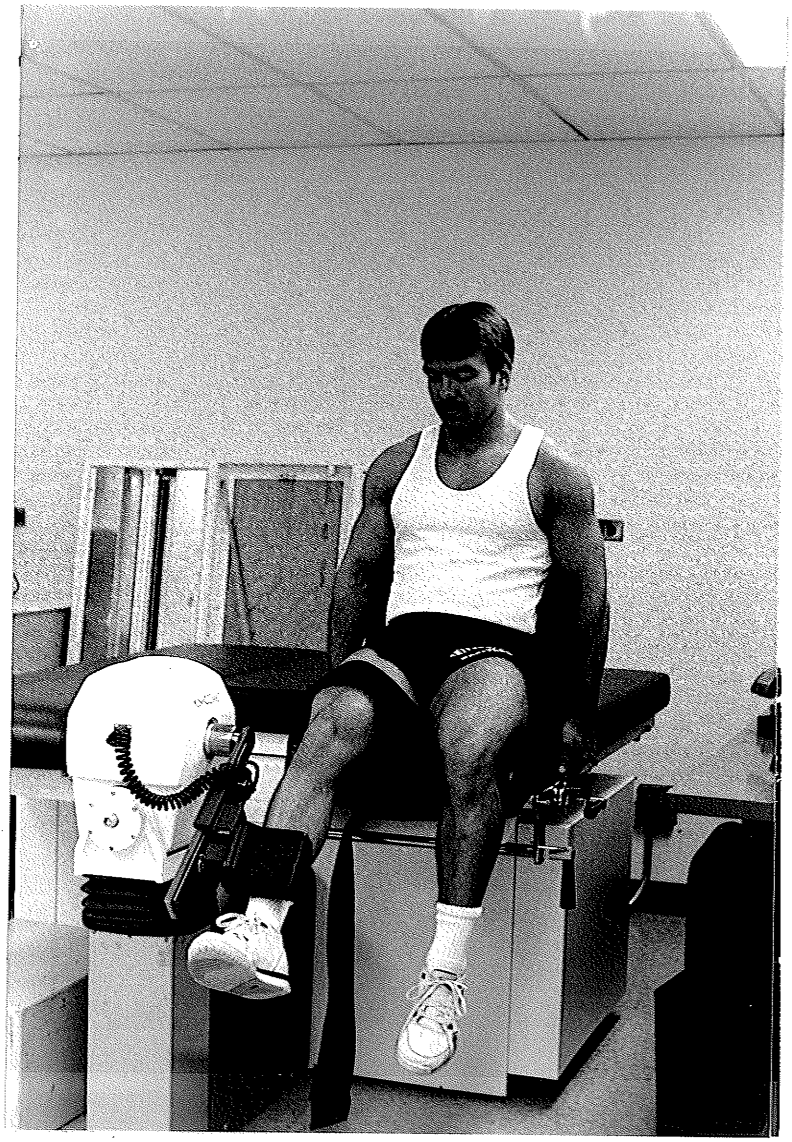

Figure 19. Strength Measurement of Knee Extensors

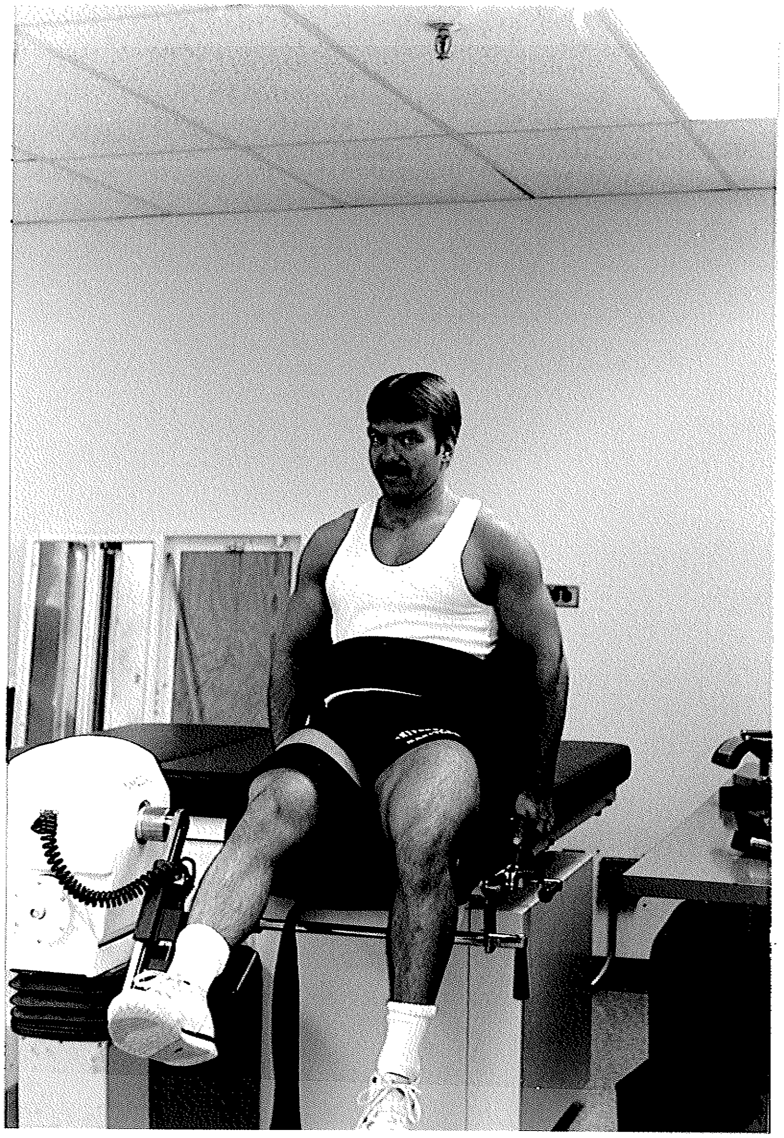

Figure 20. Strength Measurement of Knee Flexors

(3). An additional strap was placed around the waist and back of the KIN/COM seat in order to stabilize the athlete's upper body.

(4).Three trials were used for each movement tested (Figure 20).

Hip Extensors

(1). The subject leaned over the KIN/COM table with the free lower limb on the ground and the limb being exercised slightly bent.

(2). The KIN/COM head was aligned with the centre of the hip joint.

(3). The arm radius was adjusted so that the pad was placed midway on the posterior thigh.

(4). The start angle was placed at maximal flexion of the hip (which was stopped only because of contact of the thigh with the front of the table) and the return position was one where the subject had extended the hip to his full range of motion (Figure 21).

Hip Flexors

(1). The subject stood beside the KIN/COM table and head height so that the head height could be adjusted to a position which would form a horizontal line to the centre of the hip joint.

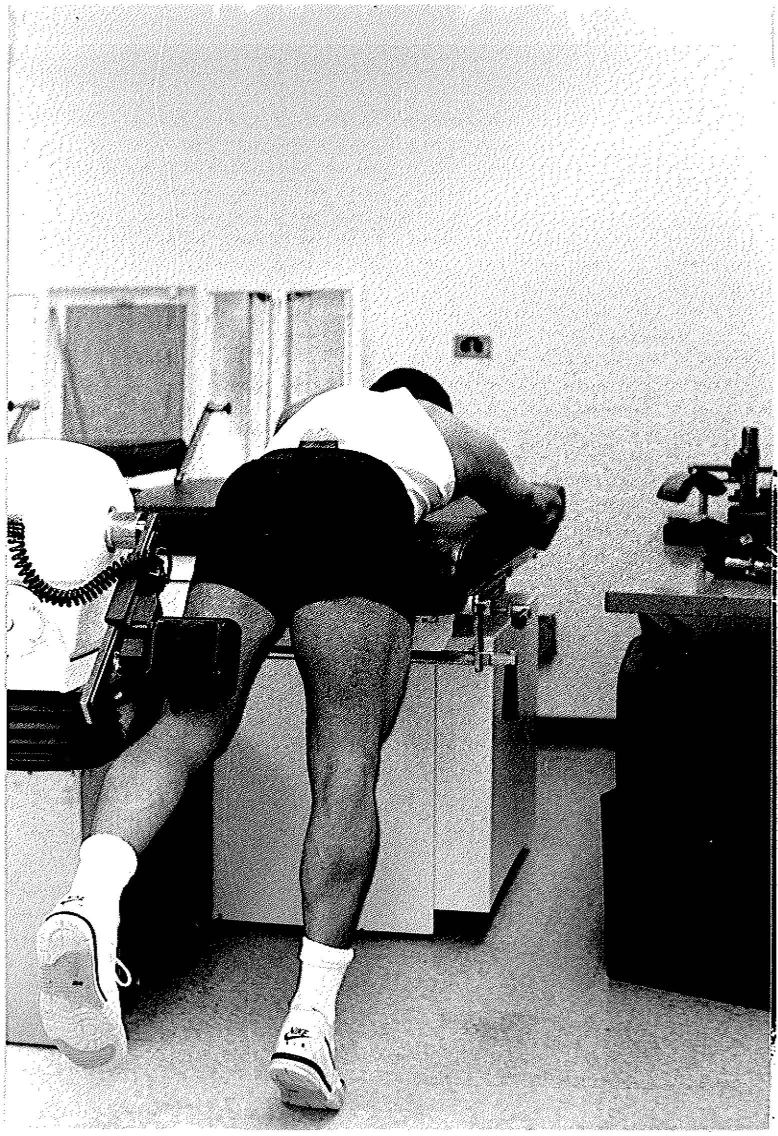

Figure 21. Strength Measurement of Hip Extensors

Figure 22. Strength Measurement of Hip Flexors

(2). The KIN/COM arm radius was adjusted so that the pad was placed approximately two inches above the knee joint. The subject performed the test with the knee flexed.

(3). The subject was allowed to stabilize himself by holding onto the KIN/COM table and the hand grip on the head.

4). The start angle was where the thigh was in line with the upright body and the finish or return angle was with the thigh slightly past the horizontal position. Three trials were run of each movement tested (Figure 22).

The KIN/COM recorded the torque output of the muscle group throughout the range of motion tested. The strength of each group was represented here by the peak torque, in Newton-metres (Nm) that the subject could produce in both the eccentric and concentric directions for both limbs for each of the joint movements tested.

Estimate of the Q angle

Q angle is the angle formed by a line connecting the anterior superior iliac spine to the center of the patella and a line connecting the center of the patella to the middle of the tibial tuberosity (Lyon et al., 1988). Q angle was measured by using a 35 mm photograph (Figure 23). The subject was asked to stand against a wall alongside a plumb line keeping his feet and knees as close together as possible. His hands were placed across his chest. Two markers were placed on the bony landmark of the

Figure 23. Measurement of Q Angle

anterior superior iliac spine. A picture was taken of each subject. A straight line was drawn connecting the markers. A second line perpendicular to the floor was drawn along the side of the subject parallel to the plumb line. A line connecting one of the markers and the middle of the patella was drawn. The angle created by the straight line along the side of the subject and the line connecting the anterior superior iliac spine and midpatella was measured as an estimate of the Q angle.

Data Analysis

When all the flexibility and anthropometric testing was completed, the results were recorded onto a micro disc in a Macintosh SE microcomputer. The data that had been stored on a floppy disc during the strength testing were printed so that peak concentric and eccentric strength scores for each individual during each movement could be recorded and stored on a micro disc.

The strength data were obtained using the force/velocity option of the report mode located in the exercise program of the KIN/ COM software package. This program plotted the concentric and eccentric curves separately on one page and also recorded the peak torque score on each graph. These graphs were edited to eliminate any torque overshoots that may have occurred by removing the first several degrees of the curve if it was evident that a false peak had occurred. The peak torque scores for each movement were recorded for each subject. An example of one of these graphs can be found in Appendix C.

Statistical Analysis

The data from all tests was then put into the Macintosh SE micro computer in the form of a table. The STATSVIEW statistical package was used to carry out t-tests. The t-test is used to test statistical hypotheses about the means of the groups and to determine if any differences between the means of two groups are significant. A principal component analysis is a type of factorial analysis that determines the relationship of all variables measured without predicting which group a new subject would be placed into on the basis of his score. It was conducted to determine if there were any underlying relationships among any of the variables measured. The basis of a principal component analysis is that it reduces the amount of data by separating the variables into factors that are most important.

Discriminant analysis was carried out by inputting the data into the Amdahl mainframe computer using the SAS program at the University of Manitoba. Discriminant analysis builds on the factor analysis. It indicates how well the data can classify an individual in this study as being in the previously injured category or the non-injured category. The discriminant analysis produces one equation involving all the variables that can be used to classify the individual in either group from the score that is calculated from the equation.

The injured limb for each subject was used in the statistical analysis regardless of whether it was the left or right limb. However, the side of the injured limb was recorded for future comparisons with noninjured limbs of the same side. All of the non injured limbs, whether from the control or experimental group, were used in the data analysis.

Means and Comparisons

Mean values were calculated to three decimal places for each test variable and for other variables such as age, height, and weight. T tests were carried out to determine if there were any significant differences between the injured and non-injured group, between the injured and non-injured limbs of the same side, the hamstring-quadriceps ratio, thigh-calf ratio, relative strength ratios, the biiliac breadths and the bitrochanterc breadths, the left to right ratios for flexibility and raw and relative strength data and eccentric/concentric strength ratios for both relative and raw strength data. The hamstring-quadriceps strength ratio was determined by dividing the concentric strength of the hamstrings by the concentric strength of the quadriceps. The hamstring quadriceps strength ratio was also determined by dividing the eccentric strength of the hamstrings by the eccentric strength of the quadriceps. Concentric/eccentric strength ratios for all the strength measurements was also calculated by dividing the concentric strength of the muscle group by the eccentric strength of the muscle group. Right to left ratios for strength were determined by dividing, for example, the concentric strength of the right hamstring group by the concentric strength of the left hamstring muscle group. This procedure was also followed to calculate the right to left ratios for flexibility. The thigh-calf ratio length was calculated by dividing the length of the thigh by the length of the calf. Relative strength ratios were calculated by dividing the peak torque of each movement by the subjects weight. The resulting relative strength score was measured in Newton-meters per kilogram. The alpha level was set at $p \leq .05$ for all the statistical tests used in this study.

Unfortunately, the film used to photograph the Q angles was defective so the Q angle estimation was omitted from the data analysis.

Chapter 4

Results and Discussion

Introduction

The present study was conducted to determine if there were any structural differences between athletes who had suffered a hamstring injury and athletes who had not experienced a hamstring injury. The athletes were tested using anthropometric measures of biiliac breadth, bitrochanteric breadth, thigh length, calf length; flexibility measurements of the hamstrings, hip flexors and hip extensors and concentric and eccentric strength measurements of the hamstring, quadriceps, hip flexor and hip extensor muscles. Both the right and left limbs were measured without regard to dominant or non-dominant limb. It was noted, however, which of the limbs was previously injured by each subject in the experimental group for purposes of comparison with the non-injured limb of each subject in the control group.

Subjects

The control group consisted of 20 male athletes . The experimental group consisted of 19 male athletes which had experienced a hamstring injury but had been rehabilitated to the extent of returning to activity. Table 1 describes the mean age, weight, height and number of athletes involved in each sport. The results are reported in 3 sections. The first section presents a descriptive analysis of the injury survey completed by each of the experimental subjects. The second section presents a descriptive analysis of the anthropometric, flexibility and strength variables for both the experimental and control group. The third section will present findings of statistical significance from the analysis of data.

Section I. Analysis of Injury Questionnaire

An injury questionnaire was completed by all of the nineteen previously injured subjects. Frequency of participation in their particular activity ranged from one day per week to 13 times per week. The mean participation frequency was 5.47 times per week. The most common sports activity was track and field (9), followed by hockey and basketball (3 each), football (2), weightlifter (1) and waterskier (1). The waterskier was principally a basketball player but the injury had occurred while the athlete was skiing.

There were 11 right hamstrings that had been injured. Of these 11, seven of the athletes believed it was their dominant leg that had been injured. There were 8 athletes who had injured their left hamstrings and, of these 8, five believed that their

Table 1. Descriptive Characteristics of the Previously Injured and Non injured Groups.

	Previously Injured (N=19)	Non-injured (N=20)
Mean Age (years)	23	21.6
Mean Weight (Kg)	72.295	81.134
Mean Height (cm)	174.87	174.616
Type of Sport Involved in:		
soccer	0	4
track and field	9	5
bodybuilder/weightlifter	1	1
waterskiing	1	1
basketball	2	2
football	3	2
hockey	3	5

dominant extremity had been injured. The length of therapy that the athletes received for these injuries ranged from 3 days to twelve weeks. The period of inactivity in which that athlete could not participate at all in his sport also ranged from 3 days to 12 weeks with a mean of 4 weeks. The 12 week inactivity period was due to a cast on one of the athletes' legs. The site of injury most commonly cited was the mid thigh or muscle belly region (8) followed by the bony insertion near the knee (6) and the bony origin on the ischial tuberosity. (2). Two of the subjects stated their hamstring was injured both at the origin and the belly. One of the subjects stated that he had hurt his hamstring at the origin, insertion and belly of the muscle.

II. Descriptive Data and t test results of the Anthropometric Flexibility and Strength Variables between the Previously Injured and Non-injured Athletes

No significant differences were found between the previously injured and non-injured groups when comparing any of the raw variables tested (Table 2 and 3).

A. Comparison of the Right and Left Limb of the Non-Injured Group.

Anthropometric, flexibility and strength variables were compared between the right and left limbs of the non-injured

Table 2. A Comparison of the Flexibility and Anthropometric Variables of the Non-Injured (N=20) and Previously Injured Groups (N=19).

	Non-injured Mean ± S.D	Previously Injured Mean ± S.D.	t value
Biiliac (cm)	28.95 ± 1.932	28.53 ± 1.61	-.742
Bitrochanteric (cm)	32.75 ± 1.713	32.26 ± 1.66	-.9
Rt. Leg Length (cm)	43.03 ± 1.95	43.00 ± 3.25	-.039
Lt. Leg Length (cm)	43.98 ± 2.33	44.21 ± 1.99	.801
Rt. Calf Length(cm)	43.33 ± 1.64	43.95 ± 2.99	.327
Lt. Calf Length (cm)	43.35 ± 2.4	43.79 ± 1.84	.639
Rt. Ham. Flex. (deg)	74.73 ± 8.77	70.91 ± 8.52	-1.379
Lt. Ham. Flex. (deg)	74.53 ± 10.37	74.86 ± 9.81	.101
Rt. Hip Flex. (deg)	115.12 ± 10.29	116.75 ± 17.18	.363
Lt. Hip Flex. (deg)	110.02 ± 11.12	115.84 ± 17.52	1.247
Rt. Hip Ex. (deg)	21.75 ± 4.75	24.05 ± 9.70	.949
Lt. Hip Ex. (deg)	20.43 ± 4.83	23.03 ± 9.34	1.227
Rt. Int.Rotn. (deg)	26.15± 7.16	27.07 ± 6.55	.411
Lt. Int.Rotn. (deg)	27.28 ± 5.45	26.53 ± 5.14	-.548
Rt. Ext.Rotn. (deg)	33.18 ± 9.56	33.74 ± 10.69	.165
Lt. Ext.Rotn. (deg)	33.32 ± 9.12	34.14 ± 9.72	.273

*Key:Ext=external,int=internal,Ham=hamstring,rotn=rotation, flex= flexion, ex=extension

Note: A t value required for p<.05 is 2.03.

Table 3. A Comparison of the Strength Measurements of the Non-injured Group (N=20) and Previously Injured Groups (N=19).

	Non injured Mean + S.D. (Newton metres)	Previously Injured Mean + S.D. (Newton metres)	t test values
Rt.Quad.Conc.	224.5±64.83	221.89 ±63.37	-.127
Lt.Quad.Conc.	213.05±68.32	221.10 ±61.58	.386
Rt.Quad.Ecc.	233.2±64.97	245.00 ±65.26	.566
Lt.Quad.Ecc.	216.3±75.16	217.63 ±63.18	.06
Rt.Ham.Conc.	124.00 ±28.24	128.26 ±22.29	.521
Lt.Ham.Conc.	133.15±31.764	137.58±33.52	.424
Rt.Ham.Ecc.	140.60±30.35	139.16±22.81	-.167
Lt.Ham.Ecc.	138.35±30.06	149.79±41.66	.987
Rt.Hip Ext.Conc.	224.75±97.92	197.16±52.02	-1.09
Lt.Hip Ext.Conc.	194.3±53.82	202.79±64.51	.477
Rt.Hip.Ext.Ecc.	245.5 ±102.97	198.26 ±51.19	-1.801
Lt.Hip Ext Ecc.	233.5 ±82.95	194.16±52.72	-1.759
Rt.Hip Flex.Conc.	156.6±46.43	157.74±48.08	.075
Lt.Hip Flex.Conc.	164.6±48.7	161.74±54.04	-.174
Rt.Hip Flex.Ecc.	171.25±56.27	163.74±64.42	-.388
Lt.Hip Flex.Ecc.	176.6±51.06	180.53±66.24	.208

(Key: Rt=right, Lt=left, Ham.=hamstring, ext=extensors, ecc=eccentric, conc=concentric , quad= quadriceps, flex=flexors)

Note: t-value required for $p<.05 = 2.03$.

athletes using t tests. Means, standard deviations and t values are reported for the right and left limbs of the non-injured athletes (Table 4). No significant differences were found between the limbs ($p > .05$) and therefore it was assumed that the left and right limbs of the control group of non-injured athletes were symmetrical in all of the variables.

B. Comparisons of the Right Non-Injured Limbs and the Right Previously Injured Limbs

No significant difference was found between the variables of the anthropometric, flexibility and strength measurements between the right non-injured limbs and right previously injured limbs when t-tests were evaluated (See Table 5). Relative strength (strength divided by body weight) was calculated for all the strength measurements and concentric strength divided by eccentric strength was also calculated to obtain a ratio for all of the strength measures to determine if there was an imbalance between the two types of contractions. A ratio of right side measures divided by left side measures was calculated to determine if there were differences from side to side for the strength and flexibility measures collected for both the previously injured limbs and the non-injured limbs. Ratios of hamstring/quadricep concentric strength and eccentric strength were also calculated.

Table 4. A Comparison of the Anthropometric, Flexibility and Strength Variables of the Right and Left Limbs of the Non-injured Group.

	Right Limb	Left Limb	t value
Thigh Length (cm)	43.03 ± 1.95	43.35± 2.4	.458
Calf Length (cm)	43.33 ± 1.64	43.35± 2.4	.026
Hamstring Flexibility (deg)	74.73 ± 8.78	74.53 ± 10.37	-.066
Hip Flexion (deg)	115.12± 10.29	110.02± 11.12	-1.506
Hip Extension (deg)	21.75± 4.755	20.43 ± 4.83	-.869
Internal Rotation (deg)	26.17± 7.16	27.28 ± 5.45	.555
External Rotation (deg)	33.18 ± 9.56	33.32± 9.12	.045
Quadriceps Concentric (Nm)	224.5± 64.82	213.05± 68.23	-.544
Quadriceps Eccentric (Nm)	233.2± 64.97	216.3± 75.16	-.761
Hamstring Concentric (Nm)	124.00 ± 28.24	133.15± 31.76	.963
Hamstring Eccentric (Nm)	140.6± 30.35	138.35± 30.06	-.263
Hip Extensors Concentric (Nm)	224.75± 97.92	194.3± 53.82	-1.219
Hip Extensors Eccentric (Nm)	245.55± 102.97	233.55± 82.95	-.406
Hip Flexors Concentric (Nm)	156.6± 46.43	164.6± 48.69	.532
Hip Flexors Eccentric (Nm)	171.25± 56.27	176.6± 51.06	.315

(Key: cm=centimeters, deg=degrees, Nm= Newton-metres)
Note: t-value required for $p<.05$ = 2.03.

Table 5. Comparison of Anthropometric, Flexibility and Strength data for Right Non-injured limbs (N=28) versus Right Previously Injured limbs (N=11).

	Non-injured	Previously injured	t value
Biiliac breadth(cm)	28.821 ± 1.906	28.545 ± 1.44	-.433
Bitrochanteric breadth(cm)	32.5 ± 1.816	32.545 ± 1.368	+.075
Thigh Length(cm)	42.952 ± 2.403	43.182 ± 3.25	+.243
Calf Length(cm)	43.417 ± 2.255	44.182 ± 2.714	+.901
Hamstring Flexibility (deg)	74.047 ± 8.303	69.879 ± 9.547	-1.353
Hip Flexibility (deg)	114.202 ± 12.166	120.273 ± 17.497	+1.235
Hip Extension (deg)	22.035 ± 7.107	25.000 ± 8.622	+1.104
Internal Rotation (deg)	26.452 ± 7.401	27.000 ± 5.209	+.224
External Rotation (deg)	33.928 ± 10.405	32.212 ± 9.261	-.477
Quadriceps Concentric (Nm)	223.75 ± 59.099	221.909 ± 76.07	-.081
Quadriceps Eccentric (Nm)	235.143 ± 59.249	248.636 ± 78.735	-.583
Hamstrings Concentric (Nm)	125.75 ± 26.601	126.909 ± 22.709	+.127
Hamstrings Eccentric (Nm)	141.107 ± 27.55	136.818 ± 24.999	-.448
Hip Flexors Concentric (Nm)	150.643 ± 43.93	173.727 ± 51.249	+ 1.41
Hip Flexors Eccentric (Nm)	164.821 ± 50.629	174.636 ± 80.844	+.457
Hip Extensors Concentric (Nm)	214.643 ± 86.714	202.818 ± 58.749	-.415
Hip Extensors Eccentric (Nm)	234.107 ± 94.033	193.000 ± 42.83	-1.386

*Key: cm=centimeters, deg= degrees, Nm=Newton-metres.
Note: t value required for p<.05 = 2.03.

There were no significant differences in the concentric/eccentric ratios or in the comparisons involving the hamstring/quadriceps concentric ratio or the hamstring/quadriceps eccentric ratio. The right to left ratio of relative hamstring strength during eccentric contraction was significant ($p<.05$). The right previously injured limb group tended to have stronger hamstrings on the left non-injured side (Mean = .834) while the noninjured group tended to have stronger hamstrings on the right limb side (Mean =1.029). Significance was also found when comparing the relative strength of the left hamstring muscles during eccentric contraction. The previously injured group (Mean =2.2) tended to have stronger left hamstrings than the non-injured group (Mean =1.7). This t test indicated that the right previously injured hamstring was the weaker of the two hamstring groups when comparing the injured to the non-injured side of the athlete.

The ratio of right to left hamstring flexibility was significant ($p<.05$). The left hamstring flexibility was greater than the right for the previously injured group (Mean =.937) whereas the right hamstring muscles were more flexible than the left in the non-injured group (Mean =1.009). This would tend to indicate that the least flexible limb was the limb that was injured in this comparison of right non-injured limbs and right previously injured limbs.

C. Comparison of the Left Non-injured and Left Previously Injured Limbs.

The means, standard deviations and calculated t values for all of the previously injured and non-injured left limbs of the athletes were calculated (Table 6). The right to left ratios, relative strength measures , concentric/eccentric ratios and the ratio of hamstrings/quadriceps concentric strength and hamstrings /quadriceps eccentric strength values were all calculated once more for the left non-injured and left previously injured limb comparisons.

No significance was found in the hamstrings/quadriceps eccentric ratio, hamstrings/quadriceps concentric ratio, concentric/eccentric ratios for all knee flexor, knee extensor , hip flexor or hip extensor strength measurements using both the raw and relative strength data. However, the ratio of right to left hip flexion flexibility was found to be significant ($p<.05$). The left previously injured limb group tended to be more flexible on the left injured side (Mean =.979) where as the noninjured group tended to be more flexible on the right limb side (Mean=1.05). This indicates that decreased flexibility of the hip on the injured side during flexion was not present in the left previously injured limb.

The ratio of right to left relative strength of the hamstrings during eccentric contraction was also found to be significant in this group comparison. The right hamstrings of the previously injured left limbs tended to be stronger (Mean= 1.289). The non-injured group also tended to have stronger right hamstrings muscles than left side hamstrings muscles (Mean=1.029). The finding for the left previously injured group indicates that the left side was indeed the side that had the weaker hamstring muscle strength.

D. Comparison of the Hamstring-Quadriceps Ratio of the Non-injured Group and the Previously Injured Group

The hamstring-quadriceps strength ratio is a comparison of the quadriceps strength in relationship to hamstring strength. A ratio approximating 1.00 means that the strengths of these two muscle groups are close while values high or lower than 1.00 indicates one of the muscles groups is weaker or stronger than the other. A mean value is usually .60 (Liemohn, 1984; Sutton, 1984; Heiser et al., 1984). No significant difference was found between the hamstrings-quadriceps strength ratio (Table 7). There were several H/Q ratios in the previously injured group that were very high. Three of the previously injured right limbs

Table 6. Comparison of the Left Non-injured limbs (N=31) versus the Left Previously Injured limbs (N=8) for the Anthropometric, Flexibility and Strength data.

	Non-injured	Previously injured	t values
Biiliac Breadth (cm)	28.81 ± 1.76	28.5 ± 1.93	-.431
Bitrochanteric Breadth (cm)	32.68 ± 1.58	31.86 ± 2.03	-1.209
Thigh Length (cm)	43.99 ± 2.11	44.5 ± 2.39	.595
Calf Length (cm)	43.52± 2.13	43.75 ± 2.25	.273
Hamstring Flexibility (deg)	74.62 ± 10.38	74.96 ± 8.87	.084
Hip Flexion (deg)	112.52 ± 14.97	114.17 ± 14.46	.28
Hip Extension (deg)	21.72 ± 6.54	22.33 ± 10.77	.205
Internal Rotation (deg)	26.83 ± 5.11	26.83 ± 6.19	.003
External Rotation (deg)	33.24 ± 8.56	35.58 ± 12.26	.631
Quadriceps Concentric (Nm)	215.61 ± 68.93	222.25 ± 45.54	.257
Quadriceps Eccentric (Nm)	218.13 ± 74.67	212.37 ± 40.87	-.209
Hamstrings Concentric (Nm)	133.03 ± 29.72	144.12 ± 41.91	.864
Hamstrings Eccentric (Nm)	141.77 ± 31.11	152.25 ± 53.41	.726
Hip Flexors Concentric (Nm)	162.64 ±48.53	165.37 ± 62.11	.134
Hip Flexors Eccentric (Nm)	177.52 ± 54.45	182.37 ± 75.19	.208
Hip Extensors Concentric (Nm)	197.84 ± 59.66	200.75 ± 58.36	.124
Hip Extensors Eccentric (Nm)	214.97 ± 74.36	212.00 ± 65.43	-.103

*Key: cm=centimeters, deg = degrees, Nm = Newton-metres.
Note: t-value required for $p<.05 = 2.03$.

Table 7. Hamstring-Quadriceps ratios for Non-injured and Previously Injured Limb.

Previously Injured		Non-injured	
Right	**Left**	**Right**	**Left**
.97*	.66	.73	.54
.93*	.66	.64	.68
.72	.58*	.56	.60
.63*	.70	.95	.55
1.49*	1.02	.74	.57
.44	.57*	.80	1.10
.57	.65*	.47	.53
.38*	.46	.47	.47
.57*	.62	.57	.73
.50*	.53	.48	.77
.55*	1.03	.51	.52
.77	1.22*	.53	.49
.47*	.54	.43	.84
.39*	.55	.40	.60
.62	.68*	.74	.82
.53	.37*	.47	.62
.38*	.42	.51	.61
.87	.77*	.40	.62
.55	.61*	.83	.75
		.41	.60

NOTE: * denotes injured limb

and one of the previously injured left limbs had ratios that were much greater than .60 and actually approached or exceed a ratio of 1.00.

E. Comparison of the Thigh-Calf Ratio of the Previously Injured and the Non-injured Groups

This is the ratio between the lengths of the thigh to that of the calf. Values that are close to 1.00 indicate both segments are of similar length. The thigh-calf ratio was calculated to determine if there were any statistically significant differences between the injured and non injured groups (Table 8). The comparison between the mean right and mean left limb thigh-calf ratios of the non-injured group indicated that there was a statistically significant difference between the right and left limb (p<.05). The t value was 2.728. A comparison of the mean right and left thigh-calf ratios of the previously injured group also showed a statistically significant difference (t=3.027)(p<.05). Comparison of the mean thigh-calf ratio of the right previously injured limbs (.977) as compared to the right non-injured limbs (.989) was not significant. Comparison of the mean thigh-calf ratio of the left previously injured limbs (1.017) and the left non-injured limbs (1.011) was not found to be statistically significant.

Table 8. Thigh to Calf Ratio of the Previously Injured Group and the Non-injured Group.

	Previously Injured		Non-injured	
	Right	Left	Right	Left
	.977	1.022	.951	1.049
	.935	1.000	.977	1.000
	1.000	1.000	.977	1.0075
	1.000	.952	1.000	1.025
	.905	1.045	1.023	.957
	.950	1.048	1.015	.985
	.978	1.022	.9565	1.042
	1.000	.9555	1.022	1.000
	.977	1.000	1.000	1.045
	.9545	1.073	1.000	1.000
	1.000	1.024	.975	1.026
	.977	1.024	1.008	1.022
	1.021	1.000	.933	1.071
	1.000	1.000	1.000	1.023
	.980	1.021	1.000	1.000
	.978	1.022	1.000	1.000
	.978	.978	1.000	1.000
	1.000	1.000	1.000	1.025
	.977	1.000	1.023	.977
Mean	.98	*1.01	.99	*1.01

F. Comparison of the Relative Strength of the Previously Injured Group and the Non-Injured Groups

The mean relative strengths of the previously injured group and the non injured groups were calculated and compared using a t test (Table 9). Relative strength is the peak torque divided by the body weight. No significant differences were found between the two groups when divided into right previously injured limbs compared to right non-injured limbs (Table 10) and left previously injured limbs compared to left non-injured limbs (Table 11).

Discriminating Characteristics

There were 37 variables in the total data set when all of the ratios and the relative strengths were included. These 37 variables were then taken and analyzed through the SAS Princomp Procedure to determine which of these variables contributed most to the hamstring strain incidences. Of the 37 variables in the total data set, the variable group designating non-injured/previously injured was dropped before the set was analyzed. Two previously injured subjects were also deleted from the data set because their inclusion decreased the homogeneity of variance in the principal component procedure.

Table 9. Comparison of the Right Previously Injured Limb (N=11) with the Non-injured Limbs of the entire Study (N= 67).

	Right Previously Injured (Nm/kg)	Non -injured (Nm/Kg)	t values
Quadriceps Con.	2.857	2.824	.161
Quadriceps Ecc.	3.045	2.93	.492
Hamstrings Con.	1.731	1.666	.677
Hamstrings Ecc.	1.945	1.802	1.119
Hip Extensors Conc.	2.66	2.656	.017
Hip Extensors Ecc.	2.69	2.916	-.833
Hip Flexors Conc.	2.131	2.075	.296
Hip Flexors Ecc.	2.341	2.213	.605

Note: A t value required for $p<.05$ is 1.994

Table 10. A Comparison of the Previously Injured Left limb (N=8) and the Non-injured Limbs (N=70).

	Previously Injured Left Limb (Nm/Kg)	Non-injured Limb (Nm/Kg)	t values
Quadriceps Conc.	2.898	2.816	.36
Quadriceps Ecc.	3.126	2.918	.811
Hamstrings Conc.	1.739	1.669	.655
Hamstrings Ecc.	1.891	1.827	.454
Hip Extensors Conc.	2.671	2.653	.072
Hip Extensors Ecc.	2.628	2.913	-.961
Hip Flexors Conc.	2.155	2.073	.393
Hip Flexors Ecc.	2.258	2.244	.057

(Key: Conc= concentric, Ecc = eccentric)

Note: A t value required for p<.05 is 1.994.

Table 11. Comparison of the Relative Strength of the Previously Injured Groups and the Non-injured Groups.

	Previously Injured (Nm/kg)	Non injured (Nm/kg)	t values
R. Quad Conc.	2.922	2.852	.247
L. Quad Conc.	2.868	2.696	.7
R. Quad Ecc.	3.351	2.968	1.201
L. Quad Ecc.	2.826	2.712	.451
R. Ham.Conc.	1.684	1.575	.985
L.Ham Conc.	1.794	1.686	.827
R. Ham Ecc.	1.847	1.781	.482
L.Ham Ecc.	1.996	1.746	1.393
R.Hip Ext. Conc.	2.618	2.855	-.793
L. Hip Ext. Conc.	2.681	2.472	.823
R. Hip Ext. Ecc.	2.666	2.974	-1.29
L. Hip Ext. Ecc.	2.621	2.974	-1.146
R.Hip Flex. Conc.	2.095	2.006	.393
L. Hip Flex. Conc.	2.159	2.104	.219
R. Hip Flex. Ecc.	2.162	2.195	-.123
R. Hip Flex. Ecc.	2.399	2.235	.598

(*Key: R=right, L=left, Ham=hamstring, Flex=flexors, Quad=quadriceps, Ext=extensors, Ecc=eccentric, Conc=concentric)

** The t value required for p<.05 =2.03.

The principal component procedure analysis was thus applied to 36 variables and yielded 8 components which accounted collectively for approximately 84% of the total variation. The variables contributing to these components are listed in Table 14 in Appendix D.

The largest principal component (PrinComp #1) was composed of strength measurements involving the quadriceps and hip extensor muscle groups and clearly represented "Knee and Hip Extensor Strength". The second component was labelled "General Eccentric Strength of the Hip and Knee Joints relative to their Concentric Strength" because of the contributions of the hamstrings, quadriceps and hip extensor muscles. The third and fourth components were dominated by hamstring muscles strength measures. PrinComp#3 was labelled "General Concentric Hamstring Strength and Relative Weakness of Hip Flexors" while PrinComp #4 was labelled "General Hamstring Strength Relative to Quadriceps Strength and Body Weight".

Principal Component 5, labelled "Knee and Hip Flexor Strength", was dominated by positive contributions from hip flexor and hamstring strength measures. The sixth principal component predominantly involved hip flexion strength, hip flexibility and internal and external rotation of the hip joint and thus was labelled "Deficit in Hip Flexor strength, Hip Flexion

Flexibility and Internal and External Rotation". Principal Component 7 was labelled "Absolute Hip Joint Strength, Greater Body Weight and Greater Limb Lengths" because of the positive contributions of hip strength measures, body weight and segment lengths. The last principal component was labelled "Segment Length Relative to Low Hip Extensor Strength". The positive contributions in PrinComp #8 were from segment lengths (the thigh length and the calf length anthropometric measures) and hip extensor strength measures.

Approximately 84% of the total variance was accounted for by these 8 principal components. The rest of the components were not identifiable and each accounted for less than 5% of the total variation. Principal Components #1-#8 were then used as variables in a discriminant analysis (SAS Discrim Procedure) with injured=1 and non-injured=0 as the classification variable. In 82% of the cases, the procedure correctly identified previously injured subjects while 76% of the non-injured subjects were correctly identified (Table 12).

Table 12. Results of Discriminant Analysis for Whole Sample.

	From	Total	To: Not Injured	Injured
Whole Sample (N=76)	Not Injured	59	45 (76.27)	14 (23.73)
	Injured	17	3 (17.65)	14 (82.35)

Note: The values in parentheses denote the percentage of those athletes in the row who were classified in the discriminant analysis as belonging in that column.

Table 13. Results of the Stepwise Discriminant Analysis with Injured/Non-injured as the Classification Variable for the Whole Sample.

	Test for Entry	
Step	Variable	Probability
1	PrinComp #6	p<.0676
2	PrinComp #7	p<.1057

Note: No variables were removed.

The individual contributions of the eight principal components were examined through a stepwise regression analysis (SAS Stepdisc procedure) for the sample as a whole. The results are presented in Table 13. For the entire sample (N=76), no components were significant at the .05 level of confidence but PrinComp #6 involving a deficiency in hip flexor strength, hip flexion flexibility and internal and external rotation and PrinComp #7 which involved the absolute hip joint strength, body weight and segments lengths were singled out as contributing to the sorting of the subjects into previously injured and non-injured categories.

Principal Component #1 and #2 had higher class means for the previously injured group indicating that athletes who had greater knee and hip extensor strength tended to fall into the previously injured group and also that athletes who had relatively higher eccentric strength measure values over concentric strength measure values also could fall into the previously injured group category. Principal Component #3 had a higher class mean for the non-injured category indicated that the previously injured group as a group had less hamstring strength than the non-injured group. Principal Component #4 however indicated that the previously injured group did have higher hamstring strength relative the the quadriceps strength and relative to their body weight than the non-injured group.

In Principal Component #5, the previously injured group had a higher class mean indicating that knee and hip flexor strength were characteristic of this class grouping. Principal Component #6 which involved lack of hip flexor strength, hip flexion flexibility and internal and external rotation of the hip joint, had a higher class mean for the previously injured group indicating that athletes who were lacking in this area tended to fall into the previously injured classification. Principal Component #7 had a higher class mean for the noninjured group indicating that athletes with high absolute hip strength and body weight were classified into the non-injured group. Principal Component #8 had a higher class mean for the non-injured group and indicated that lack of hip extensor strength relative to segments length was more characteristic of the non-injured group. This component complimented PrinComp #1 and #5 because they both indicated that strong hip extensor strength and hip flexor strength were more characteristic of the previously injured group category.

Discussion

There were several t tests that found significance in the data. Significance was found when comparing right to left relative eccentric hamstring strength in both the right previously injured group and right non-injured group as well as the left previously injured group and the left non-injured group. Both of the ratios indicated that the injured limb was the limb that had weaker hamstring muscle strength during eccentric contraction. This indicates that for this population the injured hamstring was the weaker muscle during eccentric contraction when compared to its non-injured counterpart.

Significance was also found when comparing the right to left ratio for hip flexion flexibility. The injured left limb tended to be more flexible than its non-injured right limb. This finding does not support the study by Capiau (1981) who found that athletes with decreased hip flexibility were more susceptible to hamstring strain. T tests calculated comparing hip flexion flexibility between the previously injured and non-injured groups also did not support findings by Liemohn (1978) who found that the injured group tended to be less flexible than the non-injured group. This may be due, however, to the different methods of testing flexibility in athletes. The comparison between the left previously injured limbs and left non-injured limbs involving the right to left ratio for hip flexion flexibility did however support Liemohn (1978) who found that the left hip joint was more flexible than the right hip joint. This suggests that a predisposing factor of hamstring strain may not be an overall hip flexibility deficit but may instead be an imbalance between the right and left side hip joints. Agre and Baxter (1987) also found asymmetries in the hip flexion flexibility of soccer players in their study. These asymmetries may be accounted for by identifying which leg is dominant in an athlete and also by looking at the flexibility requirements for the sport that the athlete is involved in.

The previous study did find significant differences in the right to left relative eccentric strength of the hamstring muscles indicating a strength imbalance between the knee flexors. The comparison of the left previously injured limbs and left non-injured limbs indicated that the left previously injured limb was weaker than its right non-injured limb. The comparison of the right previously injured limb and right non-injured limb also indicated that the right previously injured limb was weaker than the left non-injured limb of the same athlete. This finding tends to support Burkett (1970) who found significant strength imbalances between knee flexors of both legs. This again may indicate that a predisposing factor may not be deficit of overall strength in the hamstrings but instead a side to side imbalance causing asymmetry in muscle group strength.

This study did not find any significant differences in the raw data of knee flexor, knee extensors, hip flexor or hip extensor strength measures and therefore supports the finding of Stephens and Reid (1988) who found no significant differences in strength or flexibility measures in their study.

Significance was found when comparing the right previously injured limb with the right non-injured limb on right to left hamstring flexibility. The previously injured right limb hamstrings tended to be less flexible than the left non-injured limb of the same subject. This indicates that side to side imbalances in hamstring flexibility may be a better predictor of hamstring injury than an overall flexibility measure. This finding does not agree with Stephen and Reid (1988) who found no significant differences in flexibility of the hamstrings and Burkett (1970) who found no significant difference in hamstring flexibility. Again, the various methods of measuring flexibility of the hamstring muscles may account for the findings of each study.

The discriminant analysis of the 36 variables indicated that the variables involved in the total variation of the group were strength measures, hip joint flexibility measurements and anthropometric measures. When the eight principal components were subjected to a stepwise analysis, none of the principal components reached significance at the .05 level of confidence. Principal Components #6 and #7 however, were singled out as contributing to the ability of the procedure to classify the subjects into the injured or non-injured groups. PrinComp #6 involved the lack of hip flexor strength, hip flexion flexibility and internal and external rotation of the hip joint. The t-tests involving the comparison of right to left ratio of hip flexion flexibility supports this finding because the left previously injured limb tended to have a smaller ratio of right to left indicating that there was a larger deficit of hip flexion flexibility from side to side than in the non-injured group. No specific conclusions can be drawn from the principal components that were singled out by the discriminant analysis because there were no components that reached that .05 level of significance. It however should be pointed out that further study of hamstring strains should center around the strength,flexibility and anthropometric variables that were chosen in the eight principal components because these components were able to help correctly identify the previously injured subjects in 82% of the cases.

Chapter 5

Summary, Conclusions and Recommendations

Introduction

The main purpose of this study was first to determine which strength, anthropometric and flexibility factors are related to the incidence of hamstring strains. A further purpose was to determine if there are any interrelationships among the strength, anthropometric and flexibility measures. A final purpose was to determine which of the interrelationships (if any) best describe an athlete who was predisposed to hamstring strains. The testing protocol was implemented on 20 healthy male subjects who had never experienced a hamstring strain and 19 male subjects who had experienced a hamstring strain and were rehabilitated to the extent of returning to their activity. The results of each group were compared on each measure studied. The comparisons included anthropometric measurements of biiliac breadth, bitrochanteric breadth, thigh length, calf length, and the thigh-calf ratio. Comparisons were made involving the flexibility of the hamstring muscle group, the hip extensors and the hip flexors. Strength comparisons of the hamstring muscle group, quadriceps muscles, hip flexors and hip extensors during eccentric and concentric muscle contraction as well as the hamstring-quadriceps strength ratio and relative strength of the muscle groups were conducted. Right to left side ratios using both the raw and relative strength data and the flexibility data were compared to check for differences between the injured and non-injured limbs. Both the right and left limbs of the subjects were measured in order to compare the previously injured group and non-injured group as a whole as well as to compare the injured limbs with the entire groups non-injured limbs.

The comparison of the right to left ratio of relative hamstring strength of the right previously injured and right non-injured limbs during eccentric contraction was significant ($p< .05$). Significance was also found when comparing the relative strength of the left hamstring muscles of the right previously injured limbs and right non-injured limbs during eccentric contraction ($p<.05$). The ratio of right to left hamstring flexibility was found to be significant ($p<.05$).

The comparison of the right to left ratio of hip flexion flexibility between the left previously injured limbs and the left non-injured limbs was significant ($p<.05$). The ratio of right to left relative strength of the hamstrings of this same group comparison during eccentric contraction was also found to be significant ($p<.05$).

The comparison of the right and left limb thigh-calf ratio of the previously injured group and of the non-injured group was significant in both groups ($p<.05$).

A factorial analysis of the 37 variables yielded 8 components which accounted collectively for approximately 84% of the total variation. These 8 principal components were then subjected to a discriminant analysis. In 82% of the cases, the procedure correctly identified previously injured subjects while 76% of the non-injured subjects were correctly identified. A stepwise regression analysis found that none of the 8 components were significant at the .05 level of confidence. However, PrinComp #6 involving a deficiency in hip flexor strength, hip flexion flexibility and internal and external rotation and PrinComp #7 which involved the absolute hip joint strength, body weight and segment lengths were singled out as contributed to the sorting of subjects into the previously injured and non-injured categories.

Conclusions

There were several statistically significant differences found from the data analysis of this investigation of the the previously injured and non-injured groups. Therefore, the conclusions are stated as follows:

1. The left and right limbs of the control group of non-injured athletes were symmetrical in the strength and flexibility measures.

2. The weaker hamstring muscle group was the muscle group that sustained the hamstring strain.

3. The least flexible hamstring muscle group sustained the injury in the comparison of the right previously injured limbs and the right non-injured limbs.

4. The least flexible hip was not the hip that was on the limb side that sustained the hamstring strain.

5. It was possible to correctly identify 82% of the previously injured subjects when using the discriminant analysis and the 37 variables from this investigation.

6. In this investigation, a deficit of hip flexor strength, hip flexibility during flexion, internal and external rotation as well as absolute hip strength, body weight and segment length are characteristics that contribute to the ability of a discriminant analysis to classify subjects into previously injure and non-injured groups.

Recommendations

The following recommendations have been made on the basis of the current study and may be of benefit to another researcher planning on conducting a study of similar design.

1. A larger sample population is recommended. The larger sample size may draw out more differences between previously injured hamstrings and non-injured hamstrings.

2. It may be necessary to test the groups in more active situations during flexibility testing to approximate what is happening to the hamstrings during the late forward swing phase and toe-off in sprinting. Filming the athletes and measuring the amount of knee flexion and the velocity at which the knee flexion is actually occurring during these two phases may provide important information.

3. Strength testing the athletes at a speed closer to the actual velocity that occurs during their activity may be a necessary addition to the strength testing procedures as strength at high speeds is more closely related to sprinting performance.

4. A longitudinal study of the previously injured athletes who have been participating in special strength and flexibility programs is suggested to determine if there are any more hamstring strain incidences after the athletes have been participating in the special program.

5. Different variables such as lower back strength and flexibility as well as tests involving the knee and ankle such as inversion/eversion, pronation/supination should be measured. The body segments act as a kinetic chain and it may be the activities below the knee or above the hips that are affecting the flexion and extension at the knee and may produce the asymmetries that lead to injuries.

6. A prospective study involving hamstring strains is also recommended to see which athletes of the non-injured group develop hamstring strains. The results of the discriminant analysis could be used to pinpoint athletes previously classified as non-injured athletes that are at a risk for hamstring strains.

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Appendix A

Example of Subject Information Sheet and Injury Questionnaire

Name: ____________________ Age: ____________

Measurements:

Height: ________________(cms)

Weight: ________________(Kg)

				Mean
Biiliac breadth	________	________	________	________
Bitrochanteric	________	________	________	________

Thigh Length	1.	2.	3.	(x)________
Calf Length	1.	2.	3.	(x) ________
Hamstring Flex.	1.	2.	3.	(x) ________
Hip Flexion	1.	2.	3.	(x) ________
Hip Extension	1.	2.	3.	(x)________
Internal Rot.	1.	2.	3.	(x)________
External Rot.	1.	2.	3.	(x)________

Injury Questionnaire

Age: ....

Weight: ....

Sports involved in (currently) and Frequency
eg. softball 3x/ week

Previous injuries which required Professional Treatment
(This includes only lower extremity injuries such as the lower back, knee, ankle).

	Injury	Date (Mo/yr)	# of weeks inactivity	Treatment
EG.	ankle sprain	07/86	3 weeks	one week physio.

Do you have any known structural abnormalities?

E.G: one leg shorter than the other
bowlegged

Actual site of hamstring injury: origin....................
near knee..............
mid thigh..............

Do you believe that it was your dominant leg.............. or your non-dominant leg.............. that you injured?

Appendix B

Example of Informed Consent

Adult Informed Consent

I, the undersigned, do hereby acknowledge my consent to be tested for strength , flexibility and anthropometric measures as part of a thesis research project. I understand that a photograph will be taken to measure leg angles for research purposes only.

I hereby release the Faculty of Physical Education, the University of Manitoba, its agents, officers and employees from any liability with respect to any damage or injury that I may suffer during the administration of the strength, flexibility and anthropometric measurements.

--- ---

Signature Date

--- ---

Witness Date

Appendix C

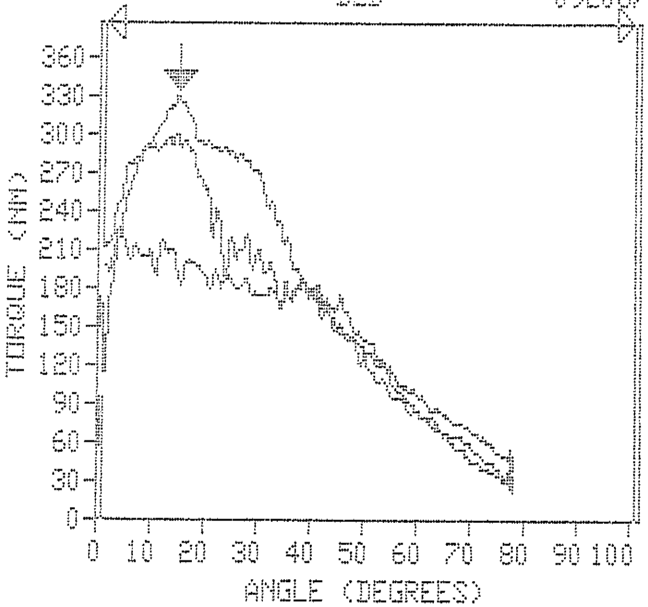
Example of KIN/COM Graph

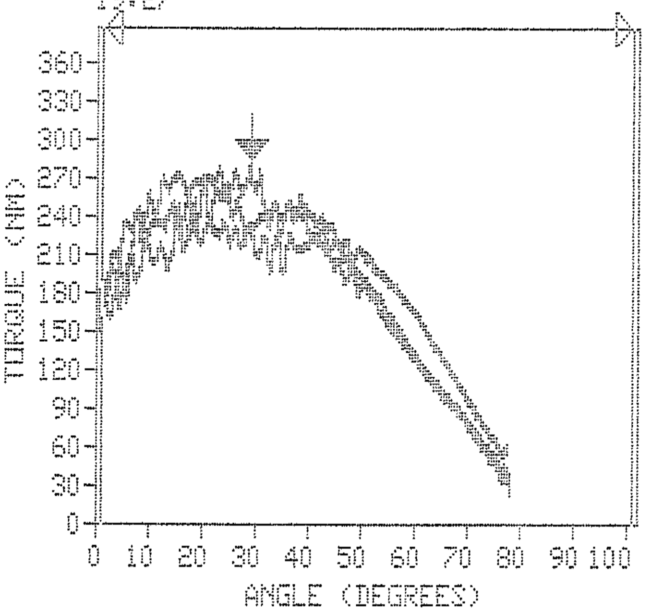
CON ————
ECC ▬▬▬▬

TORQUE VS ANGLE REPORT

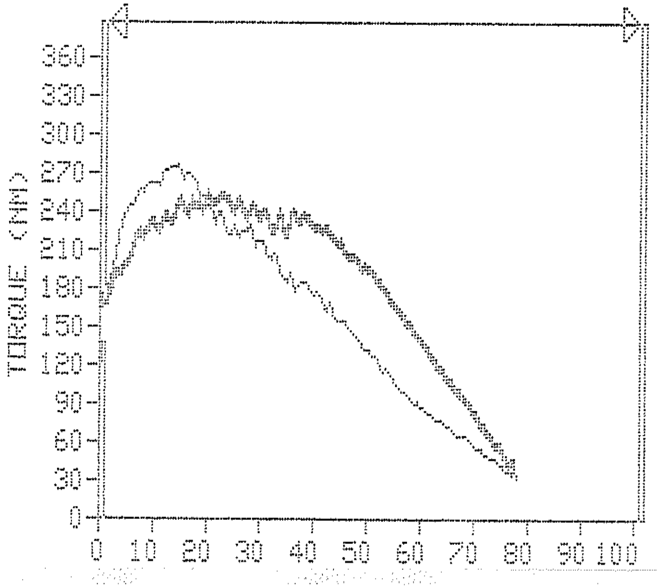
TORQUE CALCULATION
REGION ⟷
PEAK TORQUE ↓

PRKFLR.30 PETER
K EX R
DEB 092087 19:27





AVERAGE



TORQUE / MOTION	PEAK OVERALL (NM)	AVG (NM)	% PEAK / AVG
CON	330 (@ 15°)	157	210
ECC	280 (@ 29°)	189	148
% CON / ECC	118	83	REGION: 1°-102°

Appendix D

Table 14. Principal Components

Table 14. Principal Components and Their Variables

Prin1

Positive Loading	
relative quad conc.	.332302
raw quad con	.319910
rel hip ex conc.	.253367
rel qua ecc	.239088
raw hip ext con.	.222139
raw qua ecc	.208873
hip flexibility	.195935
Negative Loading	
raw ham/qua conc	-.238889
rel ham/qua conc	-.238889
raw ham/qua ecc	-.191250
rel ham/qua ecc	-.191250

Prin2

Postive loading	
raw ham ecc.	.268861
rel hams ecc	.253030
rel hip ext ecc	.219103
rel qua ecc	.209861
raw hip ext ecc	.197605
raw qua ecc	.195053
Negative Loading	
raw hip flex c/e	-.272190
rel hip flex c/e	-.272190
raw quad c/e	-.259073
rel quad c/e	-.259073
raw hip ext c/e	-.252330
rel hip ext c/e	-.252330
raw ham c/e	-.218659
rel ham c/e	-.218659

Prin3

Positive Loading	
raw ham conc	.363314
rel ham conc	.272694
raw hams c/e	.209983
rel hams c/e	.209983
Negative Loading	
rel hip fle ecc	-.347826
rel hip fle conc	-.339417
raw hip fle conc	-.330250
raw hip fle ecc	-.325462

Prin5

Positive Loading	
raw hams con/ecc	.328925
rel ham conc/ecc	.328925
raw hip fle ecc	.258854
rel hip fle ecc	.253807
rel ham con.	.224826
raw ham conc	.220035
hip flexibility	.197034
Negative Loading	
raw hip ext conc	-.298019
rel hip ext conc	-.264580
raw hip ext ecc	-.200657

Prin6

Positive Loading	
raw hip fle conc	.254949
rel hip fle conc	.205575
raw ham/qua con	.200480
rel ham/qua conc	.200480
Negative Loading	
int rotn	-.337094
ext rotn	-.337094
raw quad c/e	-.301102
rel quad c/e	-.301102
hip flexibility	-.230178

Prin7

Positive Loading	
weight	.409544
raw hip ext ecc	.358397
raw hip flex con	.295097
calf length	.239330
raw hip fle ecc	.227625
thigh length	.226885
raw hip fle conc	.211016
Negative Loading	
raw qua ecc	-.242289
hip extension	-.212011

Prin4

Positive Loading

raw ham /qua ecc	.400275
rel ham/qua ecc	.400275
rel ham ecc	.319210
rel ham conc	.227153
raw hip ext c/e	.216918
rel hip ext c/e	.216918
rel hip ext conc	.200667
raw ham ecc	.196104

Negative Loading

weight	-.237811
raw quad ecc	-.217168

Prin8

Positive Loading

calf length	.352473
thigh length	.292545
raw ham ecc	.249799
raw hip ext c/e	.217943
rel hip ext c/e	.217943

Negative Loading

rel hip ext ecc	-.370877
raw hip ext ecc	-.325839
raw hams c/e	-.231376
rel ham c/e	-.231376
rel hip ext conc	-.203511

Appendix E

Raw Data

	Biiliac	Bitrochanteric	Right thigh length	Right Calf Length
1	30.000	34.000	43.000	44.000
2	29.000	33.000	43.000	46.000
3	30.000	34.000	39.000	39.000
4	28.000	33.000	38.000	38.000
5	26.000	31.000	38.000	42.000
6	28.000	30.000	38.000	40.000
7	28.000	32.000	45.000	46.000
8	29.000	33.000	44.000	44.000
9	28.000	30.000	43.000	44.000
10	26.000	32.000	42.000	44.000
11	30.000	33.000	43.000	43.000
12	27.000	31.000	43.000	44.000
13	29.000	34.000	48.000	47.000
14	29.000	34.000	48.000	48.000
15	31.000	35.000	49.000	50.000
16	31.000	33.000	44.000	45.000
17	30.000	31.000	45.000	46.000
18	26.000	29.000	42.000	42.000
19	27.000	31.000	42.000	43.000
20	28.000	33.000	39.000	41.000
21	28.000	31.000	43.000	44.000
22	28.000	31.000	43.000	44.000
23	28.000	32.000	43.000	43.000
24	30.000	33.000	45.000	44.000
25	29.000	33.000	44.666	44.000
26	29.000	33.000	44.000	46.000
27	31.000	37.000	47.000	46.000
28	30.000	33.000	43.000	43.000
29	25.000	30.000	43.000	43.000
30	27.000	30.000	39.000	40.000
31	32.000	35.000	43.333	43.000
32	33.000	35.000	42.000	45.000
33	28.000	32.000	43.000	43.000
4	29.000	34.000	44.000	44.000
5	26.000	32.000	39.666	39.666
6	30.000	32.000	44.000	44.000
7	31.000	33.000	43.000	43.000
8	29.000	34.000	44.000	43.000
9	28.000	32.000	44.000	44.000

	Left Thigh Length	Left Calf Length	Right Hamstring Flex.
1	46.000	45.000	69.000
2	44.000	44.000	67.000
3	44.000	44.000	61.000
4	40.000	42.000	81.000
5	46.000	44.000	60.000
6	44.000	42.000	80.000
7	46.000	45.000	65.000
8	43.000	45.000	75.000
9	43.000	43.000	63.000
10	44.000	41.000	71.666
11	43.000	42.000	62.666
12	42.000	41.000	72.000
13	45.000	45.000	65.333
14	45.000	45.000	91.666
15	49.000	48.000	70.666
16	46.000	45.000	83.000
17	45.000	46.000	62.333
18	42.000	42.000	71.666
19	43.000	43.000	75.333
20	43.000	41.000	81.666
21	45.000	44.000	75.333
22	44.666	44.333	80.333
23	41.000	40.000	78.333
24	45.000	47.000	79.000
25	45.000	45.666	77.000
26	50.000	48.000	70.333
27	46.000	46.000	84.333
28	46.000	44.000	76.333
29	43.000	43.000	94.000
0	40.000	39.000	83.000
1	46.000	45.000	74.000
2	45.000	42.000	61.666
3	44.000	43.000	78.333
4	45.000	45.000	66.666
5	41.000	41.000	61.333
6	43.000	43.000	70.333
7	41.000	40.000	57.333
8	42.000	43.000	76.666
9	44.000	43.000	68.666

	Left Hamstring Flex.	Right Hip Flexion	Left Hip Flex	Right Hip Ext.
1	73.000	118.000	118.000	15.000
2	73.000	118.000	109.000	20.333
3	79.666	90.000	96.333	23.333
4	83.666	119.666	121.000	23.333
5	64.333	117.000	113.333	23.333
6	77.000	128.666	136.666	48.666
7	57.666	104.000	107.666	19.666
8	82.000	134.666	123.333	28.000
9	74.000	140.000	145.000	44.000
10	80.000	99.000	92.000	19.333
11	61.666	90.000	87.666	15.000
12	71.000	95.666	108.666	21.333
13	73.333	131.666	126.000	28.333
14	97.666	148.000	152.333	35.000
15	76.333	108.333	103.666	14.333
16	87.333	128.333	123.000	15.666
17	60.000	107.000	100.000	23.333
18	80.000	134.666	131.666	26.666
19	70.666	105.666	105.666	12.333
20	85.000	123.333	105.000	25.000
21	75.666	115.000	113.333	22.666
22	79.666	115.666	108.333	18.666
23	82.000	110.000	110.000	9.666
24	84.333	111.666	113.333	18.333
25	63.333	110.000	103.333	14.666
26	68.333	100.000	94.666	21.333
27	87.666	119.666	106.333	26.666
28	76.333	102.666	94.666	23.333
29	96.333	138.666	138.333	23.333
30	73.333	118.333	122.000	30.000
31	76.000	116.333	116.333	25.000
32	56.333	101.000	90.333	22.000
33	76.000	121.333	112.666	23.333
34	66.666	115.666	114.666	16.666
35	71.666	106.000	110.000	27.333
36	75.333	121.666	100.000	20.666
37	51.666	100.000	105.000	23.333
38	71.666	127.000	120.333	25.333
39	73.333	128.333	121.666	17.666

	Left Hip Ext.	Right Int. Rot.	Left Int. Rot.	Right Ext. Rot.
1	15.000	24.666	31.000	23.333
2	18.333	23.333	20.000	38.330
3	17.333	15.333	20.333	17.000
4	23.333	35.000	27.333	47.333
5	17.666	32.666	28.000	36.666
6	46.666	19.333	21.000	39.000
7	21.666	27.666	26.000	26.666
8	34.000	27.000	30.333	30.000
9	36.666	33.000	26.000	25.000
10	23.333	25.000	23.333	30.000
11	13.333	23.333	19.333	22.666
12	21.666	19.666	29.000	48.666
13	24.000	21.333	26.666	28.666
14	38.333	31.666	32.666	48.333
15	10.000	29.666	22.333	24.666
16	17.666	36.000	24.666	32.000
17	20.666	20.000	21.333	24.000
18	25.000	30.333	37.333	53.666
19	18.666	39.333	34.000	44.666
20	16.000	30.666	28.666	23.333
21	19.333	23.666	27.666	33.000
22	15.666	39.666	37.000	43.333
23	11.666	15.666	20.666	17.666
24	21.000	22.666	27.666	48.333
25	19.666	13.000	23.333	28.333
26	23.666	31.333	30.000	33.333
27	29.666	29.666	31.333	35.333
28	21.333	24.000	31.666	48.666
29	24.666	32.666	31.000	43.000
30	22.000	30.000	30.000	32.000
31	11.666	34.000	25.000	31.333
32	27.666	18.666	17.666	26.000
33	24.666	20.666	18.666	31.666
34	18.000	29.000	27.333	40.333
35	26.000	24.333	30.333	34.666
36	19.666	20.666	18.666	20.000
37	21.666	23.000	25.333	36.666
38	17.333	21.666	27.000	15.000
39	17.333	38.333	36.666	41.666

	Left Ext. Rot.	inj.cat	Limb Injured	REL. QUA.CONC. r inj vs ninj
1	30.333	yes	ri	1.618
2	32.666	yes	ri	2.139
3	10.333	yes	li	3.727
4	46.000	yes	ri	1.270
5	32.666	yes	ri	3.708
6	35.000	yes	li	3.333
7	29.333	yes	li	3.183
8	26.666	yes	ri	1.907
9	30.000	yes	ri	3.519
10	23.000	yes	ri	4.027
11	29.000	yes	ri	4.261
12	48.333	yes	li	1.908
13	38.000	yes	ri	3.297
14	48.000	yes	ri	2.682
15	31.000	yes	li	2.710
16	43.000	yes	li	2.744
17	27.666	yes	ri	3.622
18	44.666	yes	li	2.838
19	43.000	yes	li	3.025
20	19.666	no	ni	2.366
21	33.333	no	ni	2.902
22	42.333	no	ni	3.721
23	20.000	no	ni	1.948
24	47.666	no	ni	2.767
25	23.666	no	ni	1.559
26	30.333	no	ni	3.659
27	38.000	no	ni	3.073
28	45.000	no	ni	2.284
29	43.333	no	ni	4.474
30	30.666	no	ni	3.676
31	34.666	no	ni	2.989
32	20.000	no	ni	1.576
33	32.666	no	ni	3.984
34	42.666	no	ni	1.428
35	41.333	no	ni	3.382
36	24.333	no	ni	2.237
37	41.666	no	ni	2.743
38	25.000	no	ni	2.120
39	30.000	no	ni	4.162

	REL QUA.CONC. L	REL QUA ECC R	REL QUA ECC L	REL HAM CON.R
1	2.855	3.843	2.526	1.573
2	2.892	2.023	1.946	2.000
3	2.386	4.654	2.648	2.364
4	2.566	5.068	3.539	1.892
5	2.822	3.146	2.567	1.427
6	3.878	3.508	2.732	1.905
7	2.549	4.085	2.564	1.597
8	2.869	2.307	3.366	1.053
9	2.910	1.304	4.022	1.658
10	2.907	4.703	2.174	1.554
11	2.073	4.058	2.400	1.609
12	1.594	1.803	2.446	1.474
13	3.359	3.527	3.056	1.459
14	3.048	2.739	3.079	1.523
15	3.146	3.579	3.780	2.079
16	1.480	2.556	1.373	1.700
17	3.278	3.390	2.557	1.902
18	3.946	4.036	3.905	1.548
19	3.928	3.338	3.014	1.676
20	3.845	2.704	2.901	1.732
21	2.939	3.293	2.878	1.854
22	3.676	4.912	4.853	2.088
23	3.000	2.221	2.688	1.844
24	3.209	2.988	3.628	2.058
25	1.726	1.631	1.952	1.250
26	3.805	2.232	3.195	1.719
27	3.266	2.560	3.835	1.440
28	2.309	2.827	1.778	1.296
29	3.171	4.447	3.618	2.171
30	2.926	3.956	2.676	1.868
31	3.133	2.689	2.733	1.578
32	1.009	1.892	1.829	.676
33	3.109	4.188	3.219	1.609
34	1.182	4.454	2.130	1.052
35	3.147	3.147	3.118	1.573
36	1.565	1.944	1.565	1.149
37	1.964	3.104	1.580	1.095
38	2.467	1.907	2.333	1.760
39	2.470	2.260	1.737	1.692

	REL HAM CONC L	REL HAM ECC R	REL HAM ECC L	REL EXT CONC R
1	1.658	2.022	1.671	1.191
2	1.662	1.360	1.635	3.302
3	1.545	3.145	1.523	2.945
4	3.118	2.054	3.447	1.649
5	1.911	1.506	2.178	2.225
6	1.305	2.032	1.097	3.286
7	1.958	1.354	2.111	3.158
8	1.747	1.307	2.116	3.467
9	1.932	1.810	2.202	2.139
10	1.919	1.932	1.546	2.878
11	1.455	1.826	3.945	3.638
12	1.622	1.934	1.959	2.842
13	1.539	1.527	1.618	3.243
14	1.905	1.318	2.095	1.841
15	1.683	2.131	1.305	1.526
16	1.520	1.867	1.533	1.878
17	1.759	1.927	1.721	2.098
18	2.189	2.170	2.297	2.898
19	1.652	1.875	1.927	3.537
20	2.084	2.070	1.662	3.775
21	2.000	1.512	2.037	3.000
22	2.206	2.926	2.323	4.206
23	1.662	1.857	1.740	2.467
24	1.826	2.081	1.872	3.953
25	1.893	1.476	1.679	1.083
26	2.000	1.463	1.585	2.098
27	1.541	1.826	1.624	4.688
28	1.679	1.568	1.518	2.568
29	2.460	2.474	2.816	3.396
30	1.515	2.029	1.603	3.426
31	1.722	1.767	1.733	2.367
32	.847	1.225	1.297	.784
33	1.859	2.109	2.125	5.359
34	.974	1.883	1.987	1.519
35	1.941	1.618	1.838	3.176
36	.953	1.112	1.088	1.748
37	1.219	1.264	1.050	2.539
38	1.853	1.480	1.840	2.080
39	1.482	1.871	1.512	2.859

	REL EXT CON L	REL EXT ECC R	REL EXT ECC L	REL FLE CON.R	REL FLE CON L
1	2.447	2.022	2.447	2.876	2.908
2	3.122	2.744	3.392	1.779	2.716
3	1.795	2.891	1.477	2.727	1.614
4	3.013	3.838	2.960	1.068	.500
5	1.544	2.359	1.711	1.270	1.333
6	2.780	3.619	2.171	2.825	2.390
7	1.988	1.707	3.551	1.927	2.959
8	4.318	2.227	4.801	2.440	2.983
9	1.236	1.494	2.135	2.494	1.483
10	3.407	2.811	2.744	2.838	1.372
11	3.182	3.319	2.854	3.391	2.909
12	1.608	2.447	3.040	2.750	.973
13	1.708	4.149	2.067	2.176	2.292
14	2.238	1.955	2.730	1.466	2.143
15	2.756	1.605	2.341	1.395	1.341
16	3.453	2.178	2.173	1.089	2.480
17	4.063	1.902	1.734	1.598	2.316
18	3.405	3.308	3.013	1.806	2.851
19	2.884	4.077	2.449	1.889	3.464
20	2.549	2.972	3.028	2.690	3.648
21	2.817	3.049	2.305	2.061	2.061
22	3.353	6.573	4.220	3.368	3.220
23	2.182	3.052	3.909	3.130	2.571
24	3.198	3.686	3.163	.814	1.767
25	.869	1.155	.976	1.095	1.333
26	2.256	2.146	2.134	2.049	1.415
27	2.862	4.477	3.660	1.615	1.587
28	2.148	2.667	1.840	2.296	2.506
29	2.921	4.263	4.513	2.000	2.118
30	2.897	3.000	2.382	1.912	1.706
31	2.367	2.478	2.211	2.056	2.478
32	.919	.829	1.667	1.288	1.306
33	3.422	5.406	4.109	3.094	3.391
34	1.636	4.078	5.195	.987	.675
35	2.956	3.250	4.015	2.779	2.720
36	2.041	1.858	2.188	1.491	1.773
37	2.404	2.743	2.122	1.851	1.840
38	2.680	1.893	2.413	1.733	2.293
39	2.964	3.189	3.428	1.811	1.677

	REL FLE ECC R	REL FLE ECC L
1	4.371	3.079
2	1.639	3.878
3	2.527	1.250
4	1.730	.710
5	1.506	2.067
6	3.127	1.817
7	1.939	3.536
8	2.013	2.926
9	.962	2.843
10	2.973	1.465
11	2.710	2.818
12	2.631	1.540
13	2.189	2.932
14	1.170	3.286
15	2.000	1.122
16	1.633	2.187
17	1.402	1.886
18	2.306	3.770
19	2.258	2.478
20	2.000	2.676
21	1.963	1.890
22	3.868	3.809
23	3.831	2.688
24	1.035	2.035
25	1.167	1.286
26	1.658	1.256
27	1.220	1.202
28	2.913	2.667
29	2.289	3.197
30	1.618	1.573
31	2.456	3.078
32	1.369	1.414
33	2.953	3.609
34	3.130	1.948
35	2.853	2.296
36	1.626	1.993
37	2.088	1.524
38	1.893	2.507
39	1.961	2.051