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Abstract

Research suggests that females are more likely to sustain an anterior cruciate ligament (ACL) injury when compared to males and that the ACL and hamstring muscles work together to preserve joint stability. Information is limited regarding any relationship between anterior knee joint laxity, in the absence of injury, and eccentric hamstring time to peak torque. This study compared anterior knee joint displacement and eccentric hamstrings time to peak torque in 30 female athletes and 30 female non-athletes ages 14 - 18 years. The passive anterior drawer was measured on both lower extremities using the KT-1000® arthrometer before and after eccentric hamstrings time to peak torque testing on the Biodex® System 2 isokinetic dynamometer. Data were collected at two speeds, 90°/second and 150°/second. Results of this study suggest there is no relationship between eccentric hamstrings time to peak torque and anterior knee joint displacement in the two populations tested.

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Operational Definitions

ACL-anterior cruciate ligament

Anterior tibial displacement- anterior movement of the tibia on the condyles of the femur.

Athlete-eighth grade, freshman, junior varsity, or varsity basketball player who attends a class A or B school system.

Biodex®System 2- trade name for an isokinetic dynamometer.

Coefficient of Variance (CoV)-a measure of relative variation expressed as a percentage based on the size of the standard deviation relative to the mean.

Concentric contraction-a muscle contraction during which muscle shortens.

Cutting- abrupt change of direction, moving away from a linear path to avoid/evade an obstacle or an opponent.

Drawer test-the drawer test is used to assess one plane anterior and one plane posterior instabilities. (1) The **KT-1000®** will be used to obtain this measure.

Eccentric contraction- a muscle contraction during which muscle lengthens.

GRF-ground reaction force- the intensity and duration of stress the body is subjected to during contact with the ground.

Hamstring/Quadriceps ratio- hamstring strength divided by quadriceps strength

Healthy- no history of cardiovascular, metabolic, neurological, pulmonary or other medical condition; a nonsmoker

Isokinetics- a type of resistive exercise that involves providing accommodating resistance to muscular torque development during muscle contraction.

KT-1000®- trade name of a knee arthrometer designed by MEDmetric Corp, used to assess knee joint anterior/posterior displacement.

Low intensity- using Rate of Perceived Exertion (RPE) Revised Scale--subjective report of "1" on level of exertion. (2)

Moderate intensity- using Rate of Perceived Exertion (RPE) Revised Scale--subjective report of "3" on level of exertion. (2)

No history of lower extremity injury within the past one year- no injury to either leg, hip, knee, ankle, or foot joint in the past one year that kept her out of practice or a game for more than three days.

Non-athlete- person who attends a class A, B, C, and D school system, but does not participate in organized school/recreational sports or other organized physical activities.

Peak torque- single highest force generated by a muscle group through its range of motion.

Q-angle- angle formed by a line connecting the anterior superior iliac spine to the mid-patella and the line connecting the mid-patella to the middle of the anterior tibial tuberosity measured in standing to reflect functional weight bearing position.

Squinting patella- condition of patella facing medially reflecting femoral anteversion.

Time to peak torque- time required for a muscle to generate its maximum force.

Torque at 0.2 second- time rate of tension development the muscle group is able to produce at 0.20 second after the muscle contraction begins.

CHAPTER 1
INTRODUCTION

Women's athletics has seen astounding progress in recent years with increasing opportunities for women at all levels. There is wide agreement that this transformation is due to passage of Title IX of the Educational Amendment of 1972 which prohibits gender discrimination in educational institutions that receive federal funds. Expanded media coverage of female athletic competition in response to viewer demand has further sparked interest in participation. Participation in organized sports and intensity of play for girls and young women has increased. (3) Incidence of injury to female athletes has escalated as well. (4) Collectively, these trends lead to a heightened interest into possible causes of these injuries. (5)

Considering all sports, the most common injuries for both males and females occur at the knee. (4) The knee joint connects the distal femur and proximal tibia. Structures providing stability to the joint include: distal femur and proximal tibia geometry, joint capsule, ligaments, menisci, and isometric and dynamic contraction of lower extremity musculature crossing the knee joint. (6) The anterior cruciate ligament (ACL) is a major stabilizer of the knee, it connects tibia to femur. (7) Injuries to the ACL tend to be severe, often requiring surgical intervention to restore knee joint stability. Wilk, 1993, states "ACL injury is one of the most commonly treated problems in orthopedic and sports physical therapy." (8) Knee injury data collected previously suggests that females are more likely to sustain an ACL injury when compared to their male counterparts. (9)

Basketball, soccer, and gymnastics show the highest incidence of non-contact ACL injuries for women. (4) The common mechanism by which most females experience an ACL injury involves deceleration and a change of direction. (9) Basketball demands the ability to quickly change direction during both offensive and defensive play.

Factors considered as potential causes of ACL injuries in females include: inadequate training, decreased intercondylar notch size, a smaller ACL, increased Q-angle, increased joint laxity due to an interaction of estrogen and collagen, excessive imbalance between hamstrings and quadriceps strength, and an altered neuromuscular firing pattern. (4,9-18) Poor physiological preparation in female athletes has previously been correlated to incidence of knee injury. (4) Females tend to have increased joint laxity and musculotendinous flexibility when compared to males. Research has shown that female athletes have less joint laxity than non-athletic females, but more than male athletes and non-athletes. (10,11)

There is contradictory information in the literature regarding the relationship between joint laxity and occurrence of injury. Muscle imbalance has been investigated with positive results regarding its connection to knee joint injury. Knapik et al. (19) suggested that a positive relationship exists between incidence of injury and a decreased hamstrings to quadriceps muscle strength ratio. The activity of the hamstrings muscles is balanced by the quadriceps muscle. Quadriceps strength is often 50% to 100% greater than that of the hamstrings. Concentric contraction of the quadriceps weakly opposed by eccentric contraction of the hamstrings may result in excessive anterior tibial translation and subsequent ACL strain or failure. (11) Solomonow et al. (20) studied the normal interaction between the ACL and the hamstrings muscles. The hamstrings muscles potentially relieve strain on the ACL during deceleration or lateral blows to the knee. (11) The interaction between the injured ACL and muscle strength/action has also been studied. (21,22) However, limited information is available regarding any relationships between anterior knee joint laxity without injury and muscle strength/ action. The purpose of this study was to compare anterior knee joint displacement and eccentric hamstrings time to peak torque in healthy, uninjured athletes and non-athletes.

This study is significant because it investigated the relationship between joint laxity and hamstrings time to peak torque in female athletes and non-athletes aged 14-18. This study provides a basis for further study into the relationships of joint laxity, time to peak torque of eccentric hamstrings, exercise and joint laxity, and ACL injuries. Information generated in this study contributes to the current research base. Findings may also benefit athletes, coaches and clinicians in designing approaches for injury prevention and rehabilitation.

CHAPTER 2
LITERATURE REVIEW

Historical Perspective

Women's participation in sport has undergone some dramatic changes in the last 100 years. The introduction of basketball in 1891, by James Naismith sparked interest in intercollegiate team competition. By 1925, twenty-two percent of American colleges offered intercollegiate women's competition. (23) The "golden era" between 1925-1935 saw growing popularity of individual and team sports and the organization of sports governing bodies. Controversy arose regarding the Victorian ideal of womanhood and participation in sports. (24) Female participation in the Olympics began in 1912 with some non-contact sports. With the passage of time, women have made their way into many competitive sports arenas. The social role of women began to change perhaps because of women's suffrage, but more likely because of ambitious, women adventurers of the early 20th century. (24) Stereotypes and attitudes have changed slowly. A major victory for female participation in sport was won in 1972 as the result of the passage of Title IX of the educational amendment. Title IX stated "sex discrimination was prohibited in any educational program or activity receiving federal financial assistance". This legislation further required educational institutions to afford women equal opportunities in athletics and to award athletic scholarships in proportion to their participation (3).

Since that time the participation of women in organized sports has dramatically increased. (3) In 1972, only seven percent of interscholastic athletes were female contrasted with thirty-seven percent in 1992. (25) Female intercollegiate participation increased from fifteen percent of college athletes to thirty-four percent during the same time span. (26) These statistics are somewhat deceptive however, since much of the increase came during the late seventies and early eighties. Increases have been marginal since that time with decreases seen during some years. With the increased visibility of women in the Olympics (thirty-seven percent of Olympic athletes in 1992) and the advent of women's professional sports, they are presented challenges at levels never before encountered. (27) An increase in participation has also increased awareness of health issues and concerns of the female athlete. (15) It has become apparent that there is a lack of information about the female athlete and the challenges she faces. (5)

Increased risk of injury unfortunately accompanies this increase in participation. While it is widely accepted that injuries are more sport specific than sex specific, the incidence of knee injuries among men and women participating in jumping and pivoting sports has recently been discussed. (15) Researchers have shown an increase in incidence of ACL injuries in female basketball players when compared to their male counterparts. (4,11,15)

Before Title IX, it was difficult to study incidence of injury in the female athlete due in part to the small number of participants as well as inadequate injury surveillance systems. With the ensuing increase in participation, data collection of injury statistics for female sports began around 1973. (28) Data from Ciullo (29) showed that most injuries were sustained in track and field, basketball, field hockey, gymnastics, and softball. From analysis of this data, Ciullo (29) stated that injury in sport varies little between genders but was more sport specific. There is some evidence though that knee and ankle injuries may be more common in female athletes. (4,15,29,30) Many investigators have demonstrated an increased susceptibility to ACL injuries in females when compared to matched-sport male counterparts. (15)

Knee Joint Characteristics

The knee is comprised of two units, the distal femur and proximal tibia. Movements occurring at the knee include flexion, extension, and rotation. Arthrokinematically, the condyles of the femur both roll and glide on the tibial condyles. Stability of the joint is provided by many joint features: the geometry of the distal femur and proximal tibia, menisci, joint capsule, collateral and cruciate ligaments, and dynamic muscle contraction. (6)

ACL Injuries and Contributing Factors

Increased participation has led to a host of other problems for the female athlete. A greater number of female participants in many sports have resulted in an increased incidence of injuries for this population. Of particular concern is the increased incidence of ACL injuries among female athletes. (31,32) According to Emerson (9), basketball may present the greatest risk for ACL injuries due to the repetitive nature of running, jumping, pivoting, change of direction, and deceleration in the sport. Unfortunately, ACL injuries are a relatively common occurrence in basketball players. (31) Hutchinson and Ireland (4) have found that women participating in basketball are at a particularly high risk for ACL injury. A very high prevalence of non-contact mechanism of injury in female participants was found in intercollegiate basketball. (30) According to a 100%

consensus of participants at the American Orthopedic Society for Sports Medicine "there is a greater incidence in females than males of knee injury involving the ACL in basketball." (5) In contact and ballistic sports, the rate of female ACL injury is nearly equal to that of their male counterparts in matched sport. (29) Results from Arendt's (15) five year evaluation of collegiate men's and women's soccer and basketball programs, showed a significantly higher female ACL injury rate in both sports compared to males in these sports. ACL injuries may occur with or without external or internal rotation of the tibia in the presence or absence of hyperextension. (9) Cutting, defined as an abrupt change of direction, has been described as the most hazardous movement for ligaments of the knee. (33)

Researchers have described many factors that may contribute to ACL injuries in females. They can be divided into intrinsic and extrinsic factors. (15) Intrinsic factors include joint laxity, limb alignment, and notch dimensions. Extrinsic factors involve muscular strength, physiologic training/adaptation to exercise, and sport demands. (15)

Intrinsic Factors

Ligament Laxity

The concept of ligament laxity as a possible factor predisposing athletes to knee injury has been studied previously with inconclusive results. Nicholas (12) showed a strong association between "indices of looseness" and likelihood of knee ligament rupture. In his study of 139 professional football players (playing between 1963-68) indices of looseness were measured and tallied. Thirty-nine players had three of five indices of looseness of which 28 (72%) subsequently ruptured knee ligaments. This study, though significant, may not be generalized to the population at large. A follow-up study in 1975 by Godshall (34) using the same indices failed to replicate Nicholas' results. Curiously, he found that as athletes matured their joints tightened. Grana and Moretz (10) also did a study using the same methods of determining tightness versus looseness as Nicholas: upper extremity rotation, lower extremity rotation, palms-to-floor, genu recurvatum, and the lotus position. The subjects in this study included 672 male and female public high school students (282 athletes and 390 non-athletes) with an average age of 15.9 years. Results showed no correlation between ligament laxity and injury, refuting the prognostic importance of ligamentous laxity testing in athletes.

Grana and Moretz (10) indicated that female athletes have greater ligament laxity than males (athletes and non-athletes), but less laxity than female non-athletes. A study by Huston and Wojtys (11) yielded similar results. Hutchinson and Ireland (4) stated that females tend to have increased joint laxity compared to their male counterparts. In the study by Huston and Wojtys (11) there was no difference between male athletes and non-athletes. Female athletes however, had tighter joints than their non-athletic counterparts. Studies by other investigators demonstrated no significant differences between anteroposterior laxity of males and females. (35-38) Although Oliver et al. (38) reported no significant differences between males and females for ligamentous laxity, they noted a trend for the males to have less laxity than females in their study.

Cyclical hormones may play a role in ligamentous laxity. This is currently under investigation using rabbit ACL fibroblast (in culture). (39) In the presence of the hormone estrogen, collagen synthesis and fibroblast proliferation were inhibited. This may contribute to weaker ACL's in females due to fluctuating hormonal patterns. Further studies are needed to explore this phenomenon.

Limb Alignment

Limb alignment has been implicated as a reason for discrepancy in numbers of ACL injuries between genders. The wider female pelvis creates a valgus orientation to the knee with relative internal rotation of the femur. The compensatory external tibial tubercle rotation and hindfoot pronation leads to increased Q-angle. The resultant "squinting patella" or "miserable malalignment syndrome" does not necessarily interfere with athletic performance. (29) In a retrospective study, data from one sports medicine clinic revealed no relationship between tibio-femoral alignment, Q-angle and knee injury in a sample of seventy-six female basketball players with ACL injury. (13,30) A ten degree Q-angle is considered to be the most efficient line of pull for the quadriceps femoris muscle. (32,40) The Q-angle is typically greater in females than males with average values of seventeen and fourteen degrees respectively. (33) In a study by Lyon et al., Q-angle was examined as a possible factor affecting peak torque in knee extension. (16,31) Three sets of subjects, grouped according to Q-angles (group1:<11 degrees, group 2:13-17 degrees, group 3:>17), were evaluated at three speeds (30, 60, and 180 degrees per second) using the Cybex II® Isokinetic Dynamometer. Results suggested there was no significant difference in angle of peak torque in knee extension between the three groups at any of the test speeds. In this investigation, the amount of Q-angle did not appear to affect the angle at which peak extension torque occurred, demonstrating minimal functional differences between knees with varying Q-angles. These researchers recognized a limitation of their study as assessment of knee extension peak torque in a seated position. A more accurate functional assessment could possibly be obtained with subjects in a weight-bearing position. (16,31) Shambaugh (14) however, showed a strong relationship between structural measures, such as Q-angle, and lower extremity injury. This is certainly an area that requires further investigation.

Notch Dimensions

Research into the possible relationship between intercondylar notch stenosis and ACL injuries has recently been investigated. The intercondylar notch is the tunnel through which the ACL passes connecting the tibia anteriorly to the femur posteriorly. In two prospective studies, notch dimensions were determined using a tunnel view radiograph of bilateral knees of participants and of some cadaveric specimens. (17,18) In Souryal and Freeman (18), notch width index was defined as the ratio of the intercondylar notch width to the distal femur width at the popliteal groove level.

Souryal and Freeman (18) gathered data on 902 athletes with a two year follow-up to document injuries and correlate these with notch width index. Their results showed a larger notch width index for men when compared to women. Further, they showed an increase of non-contact ACL injury in participants with a narrower intercondylar notch (notch width index of one standard deviation below the mean). They concluded that intercondylar notch stenosis significantly increases the risk of non-contact ACL injury. A later study by LaPrade and Burnett (17) reviewed data from 213 athletes and found no statistical difference in notch width index or ACL injury between genders. They were in agreement with Souryal and Freeman's (18) findings of increased risk of non-contact

ACL injury with intercondylar notch stenosis. A review of literature by Arendt (15) found the evidence inconclusive concerning gender differences. Efforts must be made to standardize intercondylar notch measurement and examine size of ACL in reference to notch dimension. (15)

Extrinsic Factors

Sport Demands

The game of basketball involves the following typical moves: running, cutting, starting, stopping, jump shot takeoff, jump shot landing, lay-up takeoff, lay-up landing, vertical jump takeoff, vertical jump landing and shuffle. McClay et al. (41) have shown the forces that occur at the knee during these typical maneuvers are considerably greater than previously thought. These tremendous forces focus attention to the injury risk potential in basketball. (41) Several studies have shown a large percentage of non-contact mechanism of ACL injuries. (11,15,42) Noyes et al. (43) described 78% of all ACL injuries as non-contact injuries. Most ACL injuries occurred from cutting, sudden deceleration or landing from a jump. These motions may damage the ACL by rotational stress or by hyperpronation or excess femoral valgus positioning. (44) Huston & Wojtys (11) have investigated the physiologic differences in men and women that may contribute to higher number of ACL injuries in females. They include knee joint laxity, lower extremity strength, endurance, muscle recruitment order, and muscle reaction time. They compared elite male and female athletes and their non-athletic gender matched controls. In this study, isokinetic concentric testing found female athletes slower in time to peak torque of the hamstrings compared to male athletes. Muscle recruitment during passive tibial translation was also found to be different in female athletes in comparison to all other groups. The firing pattern of the female athlete was quadriceps-hamstrings-gastrocnemius, as other test groups used hamstrings-quadriceps-gastrocnemius (male athlete, male non-athlete, female non-athlete). This suggests a need to redesign athletic programs and training with consideration of female physiology. (11)

Muscular Strength

Muscular weakness has long been suspected as a predisposing factor to ACL injury. Muscular strength is necessary to provide dynamic joint stability in the demanding movements of sports today. (45) A study by Moore & Wade (44) showed women's relative quadriceps strength to be 70% of men's strength. Women's hamstrings strength was found to be 63% of men's strength. The female hamstrings/quadriceps ratio was less than males as well. Hamstrings strength, particularly eccentric strength, is proposed to be important in preventing ACL strain in potential injury situations such as sudden deceleration. (11) During eccentric contraction of the hamstrings, the muscle lengthens providing an active stabilizing force to complement the passive strength of the ACL in restricting excessive anterior translation of the tibia. Huston (11) stated "the balance of power between the quadriceps and the hamstrings is crucial to normal knee function". The quadriceps can produce enough force to damage knee ligaments if hamstrings strength supplies insufficient restraint.

Training/Physiologic Adaptation

Training/physiologic adaptation and skill have also been considered variables in the ACL injury disparity between males and females. (15) Lack of muscle training has been described as a primary factor in higher injury rate in female basketball players. (44) With rapid increase in the number of participants, perhaps teams are utilizing less conditioned, less skilled athletes for competition. (15) Poorly conditioned female athletes and incidence of concurrent knee injury has been documented. (4) Improved pre-season training programs are therefore necessary not only to enhance performance but also to possibly reduce the incidence of injury in females. (4)

As many researchers continue to investigate the predisposing factors, it is evident that all may influence ACL injury rate. Further research must be done to determine the extent to which these risk factors could be modified.

Joint Forces

The knee is a complex system that is subjected to a wide range of forces relative to various levels of activity and the corresponding gravitational forces. A combination of musculotendinous and ligamentous structures work to maintain stability of the knee under conditions of varied levels of activity and mechanical stress. (46) McClay et al. (41) conducted a study on 24 professional male basketball players to determine ground reaction forces encountered during characteristic movement patterns performed in basketball. "Ground reaction forces (GRFs) indicate the intensity and duration of stress the body is subjected to during contact with the ground." (41) Results were displayed in units of body weight (bw) and Newton seconds. Body weight (bw) is a measure of force described as a percentage of a person's body weight. GRFs were described for three components: the vertical (V), anteroposterior (AP), and mediolateral (ML). The AP component of the GRFs were also separated into braking versus propulsion forces. Mean braking GRFs of selected moves are listed in Table 1.

Table 1.--Mean Braking Ground Reaction Forces

Activity	**Maximum AP braking (bw)**	**AP impulse braking (N•s)**
Running	0.4	21.5
Cutting	1.1	69.6
Stopping	1.3	109.9
Shuffling	0.3	30.0
Lay-up takeoff	1.0	111.7
Lay-up landing	2.5	128.3

AP=anterior-posterior
bw=percentage of body weight
N•s=Newton seconds
Table is modified from McClay et al. (41)

McClay et al. (41) also stated "these high forces from landing not only were associated with large (GRF) impulses but also had short rise times to the high peaks immediately after impact (29ms for lay-up landing)". Forces build up quickly; therefore, it could be concluded that muscle torque responding to these forces must also rise quickly.

A study by Nyland et al. (47) produced GRFs for a run and rapid stop, with subjects in conditions of unfatigued and fatigued. Their subjects included 19 female collegiate athletes with a mean age of 20.8 ± 1.8 years. Results showed peak braking forces of 1.35 bw and 1.57 bw for the unfatigued and fatigued conditions respectively. This study also noted, via electromyography (EMG) readings, a delayed onset of muscle activation during the fatigued trials as compared to the unfatigued trials. This study demonstrated greater forces with increased time to muscle activation under the fatigued condition. To delay/prevent fatigue the proposed study included rests between test speeds and as few practice trials as is necessary for subject learning.

Schot et al. (33) stated, "The unique stresses incurred during change-of-direction locomotion have been identified as potentially dangerous to the knee joint." These authors performed a study that analyzed two change of direction maneuvers, a 45 degree and 90 degree cutting pattern. Subjects in this study included six men and six women with an average age of 26.2 ± 6.6 years. Speed of subject approach was not controlled and was sacrificed for accuracy of the cutting maneuver. No gender differences were observed relative to the cutting pattern. Average braking forces of 4.9 Newton/kg body mass for the 45 degree maneuver and 6.8 Newton/kg body mass for the 90 degree cutting maneuver were recorded. As demonstrated by the three studies above, the knee incurs tremendous AP stresses associated with braking and deceleration moments (those also seen in the cutting maneuver). Ligaments alone without the eccentric role of muscles cannot maintain knee integrity, especially under extreme conditions, such as deceleration and/or cutting. (46)

Anterior Knee Joint Displacement

Controversy exists regarding the incidence of greater joint laxity in females compared to males. A paucity of normative data exists concerning knee joint laxity between males and females and athletes compared to non-athletes (male or female), especially young males and females under the age of 18 years. Studies testing the reliability of different knee ligament arthrometers have produced data concerning joint laxity.

Knee arthrometers have been established as generally reliable for intratester measures of passive anterior and posterior laxity on the same day, but not for intertester measures. (48,49) Ballantyne et al. (49) determined reliability of the KT-1000® among experienced and inexperienced male and female testers for the passive, active and manual anterior drawer test. Their results suggested that intratester reliability was moderate to good, intertester reliability was poor, and tester experience may be more important than gender in influencing reliability.

Daniel et al. (35) performed in vitro and in vivo studies with the KT-2000® knee arthrometer. The in vivo study included 338 normal subjects (188 male and 150 female) ages 15 to 45 years. Test position included: subject in supine, knees supported in 20 ± 5 degrees flexion, and feet supported in external rotation of zero to ten degrees. Eighty-nine Newtons of passive anterior and posterior force resulted in a range of three to seventeen millimeters of displacement, mean of 8.4 ± 2.2 millimeters. The mean anterior displacement for normal right knees was 5.5 ± 1.8 mm and 5.8 ± 1.9 mm for normal left knees. No significant differences were reported between right and left legs.

Oliver et al. (38) used the Genucom Knee Analysis System to measure passive anterior and posterior displacement at 90 degrees of knee flexion with a 90 Newton (N) force level. The test was performed in three modes: no tibial rotation, 15 degrees of internal tibial rotation, and 15 degrees of external tibial rotation. One hundred subjects, 75 male and 25 female, with a mean age of 30.2 years were tested. A mean anterior displacement of 6 ± 4 mm was recorded for the neutral AP test at 90 N for the uninjured male knees. The uninjured female knees demonstrated a mean anterior displacement of 9 ± 3 mm. Both internal and external rotation of the tibia caused a significant decrease in anterior laxity at the 90 N force level for uninjured knees of both males and females. All subjects in this study had sustained a knee injury of some type to one of their knees. Daniel et al. (35) noted that the mean anterior laxity of the uninjured knee in patients with unilateral ACL disruption was greater than those in the non-injured subjects. Oliver et al. (38) did not include non-injured subjects their study; therefore, no comparison was made concerning subjects who had sustained injuries versus those who had never sustained a knee injury. Harter et al. (50) studied 51 male and female subjects aged 19 to 49 years with a mean age of 27.3 ±7.5 years who had undergone ACL reconstruction on one of their knees. The KT-1000® was used to passively measure anterior tibial displacement with a 20 pound load (just under 90 N). A mean anterior displacement of 6.2 ± 2.1 mm was reported for the non-injured/healthy knees of their subjects. These results compared favorably with the results of Daniel et al. (35)

Knee Joint Laxity and Exercise

Exercise increases circulation to soft tissue and warms it. Soft tissue has increased extensibility after it has been warmed or heated. "Connective tissue yields more easily to passive stretch if the tissue is warm." (51) Based on this information, it would seem logical to expect that exercise could increase anterior knee joint displacement compared to a measure taken before any exercise activities.

Sakai et al. (52) studied 11 semi-professional female basketball players to record the effect physical activity had on anterior tibial displacement. Their results showed no change in anterior knee laxity with sedentary work or after warm up prior to practice, but a significant increase with exercise/game style practice. They also reported that the increased laxity was still significant 1½ hours post-exercise, and did not recover completely until five hours post-exercise.

Exercise-related fatigue has been studied to determine its effects on knee joint laxity, under the premise that fatigue may cause laxity and lead to ligamentous injury. (53) Skinner et al. (53) studied 10 Navy SEALS, to determine the effect exercise-induced fatigue had on anterior knee displacement. Subjects performed isokinetic exercise (35 knee flexion/extension repetitions at 180°/second), on the right leg only, and ran to attain the fatigued state. Laxity testing was performed before and after all exercise. Results showed a significant difference for anterior knee joint displacement between right and left legs post-exercise, and between left legs pre and post-exercise. Thus, the leg subjected to both running and isokinetic exercise did not show a significant difference in anterior displacement as did the leg that was subjected to the running exercise only. This leads to a question concerning the effect isokinetic exercise has on the knee complex. This study looked at pre and post-exercise measurements of anterior tibial displacement and compared them to other similar studies.

ACL and Hamstrings Relationship

Anterior tibial forces at the knee are resisted both passively, by non-contractile soft tissue, and dynamically, by contractile soft tissue. The ACL, which is attached to the anterior tibia and posterior part of the inner aspect of the lateral femoral condyle, provides the primary source of passive stability against anterior shear forces at the knee. (6,7) Dynamically, the ACL and hamstrings have been shown to work in a complementary manner resisting anterior tibial forces. (7,20,21,45,46,54)

Interest in the relationship between the ACL and hamstrings has become more prominent since the identification of four categories of sensory nerve endings in the cruciate ligaments were documented. (55) Studies of ligament innervation began in the 1940s by Gardner, who first identified sensory endings in the knee joint capsule, ligaments, and menisci of cats and then humans. (55) Evidence of Ruffini and Golgi receptors in the ACL leads to speculation of reflex sensory information possibly requesting muscle assistance to maintain joint stability in conditions when the ligaments are loaded at levels near physiological capacity. (20)

Beard et al. (21) conducted a study comparing reflex hamstrings contraction latency to ACL deficiency. Forty-three male and 7 females were included in their study. A testing apparatus was designed and constructed for their study. Using EMG surface electrodes placed on the posterior thigh, hamstrings activity was measured for time of activation in response to a 100N posteroanterior shear force. The 51 normal knees tested in this study demonstrated a mean reflex hamstrings contraction latency (RHCL) of 47.9 milliseconds. The mean RHCL for the ACL deficient knees tested showed a statistically significant difference at 90.4 milliseconds. The ACL deficient knees in this study had arthroscopically determined ACL damage. This study identified a difference between muscle activation times between individuals with no injury and those with ACL injury. No comparison was made however concerning any knee ligament laxity within their uninjured subject population. In our study, we wanted to compare anterior knee joint displacement, in the absence of injury, to eccentric hamstrings time to peak torque.

Kramer et al. (56) studied the ACL operated and non-operated knees of 15 males and 15 females. The purpose of their study was to determine interrelationships among knee stability, strength, and current level of activity. Knee flexor and extensor concentric and eccentric muscle strength (peak torque) was assessed using the Kinetic Communicator®, an isokinetic dynamometer. Peak torque was measured at 60 and 180 degrees per second. The KT-1000® arthrometer was used to measure passive anterior displacement of the tibia relative to the femur in response to an 89 N force.

Results from the Kramer et al. (56) study reported significantly greater knee flexor torque for the non-operated knee compared to the operated knee for both concentric and eccentric muscle actions. Knee extensor torque was significantly greater for the non-operated knee for concentric muscle contractions only. As angular velocity increased, peak torque for concentric muscle contractions decreased significantly and did not change or increase for eccentric muscle contractions. Mean anterior displacement was 12.3 ± 2.2 mm and 9.7 ± 2.6 mm for the operated and non-operated knees respectively. Most patients in their study identified participation in a variety of noncompetitive to competitive activities. (56)

Kramer et al. (56) reported a moderate correlation between current activity level and strength (knee extensors greater than knee flexors), a poor correlation of current activity level to anterior displacement, and a poor correlation between strength and anterior displacement. The authors identified test specificity of the passive KT-1000® test performed in the supine position as the major factor contributing to the poor correlation between strength and anterior displacement, and anterior displacement and current activity level.

Isokinetics

Hislop and Perrine (57) first described isokinetic exercise in 1967. Isokinetic machines control speed of joint movement and provide resisting force proportional to muscular effort generated. (57) They enable evaluation and training of muscular strength under conditions of constant angular velocity. (58) Cybex® (Ronkonkoma, New York, NY) patented the isokinetic testing and assessment concept. Other isokinetic machines followed Cybex's® patent expiration (Ariel®, Biodex®, KIN COM®, LIDO®, MERAC®). (42,47)

Biodex® System 2 was used in this study based on its reliability and availability to researchers. Reliability of Biodex® machines has been proven by research. (56,59-62) Parameters of peak torque (PT), angle of peak torque (APT), and total work (TW) have been proven reliable at speeds of:

a) 60°/second, PT r = 0.91 - 0.95, TW r = 0.95 (60, 62),

b) 180°/second, PT r = 0.96, TW r = 0.97 (62),

c) 240°/second, PT r = 0.95, TW r = 0.96 (62)

d) 300°/second, PT r = 0.97, TW r = 0.95 (62), and

e) 450°/second, PT r = 0.05 - 0.82, APT r = 0.15 - 0.82 (60)

Isokinetic dynamometers supply mechanical resistance to moving body extremities and trunk proportional to forces provided by the subject using the equipment. Concentric, muscle shortening, and eccentric, muscle lengthening, can be performed and measured on most isokinetic equipment (56,59,63). Velocity, which is preset and measured in degrees/second, cannot be exceeded by the subject's effort against the machine's electrically braked force arm. Muscles thus, can be contracted to maximum capacity, by a motivated subject, at all points in their range of motion. (51)

Dynamometer machine velocities range from 1 - 1000 degrees per second. (42) Literature reveals a variety of isokinetic dynamometer testing speeds for concentric and eccentric hamstrings and quadriceps peak torque, 0 - 450 degrees per second (22,60,63-67) and 30 - 180 degrees per second (63, 64) respectively. Reliability of data collected at higher speeds tends to decline. (8,60,61) The ability of a muscle to generate force varies at different testing velocities. The general rule is that the greatest force is generated at the slowest angular velocities and least force at the fastest velocities during a concentric contraction. (56,63,65-69) Eccentric force generation in the lower limb can decrease (70), but it usually increases (56,64,65,69) or remains constant when velocity is increased. (63)

Various functional and sporting activities have angular velocities estimated to range from 700 - 2000 degrees per second. (65) In a study done by McClay et al. (71), with professional basketball players, knee flexion velocities were recorded for eleven moves found characteristic of basketball. This study looked at the moves most common to cause ACL injuries during basketball game play: cutting, stopping and, shuffling. Maximum knee flexion velocity for cutting was 358.9°/second, 500.9°/second for stopping, and 337°/second for shuffling. (71) The McClay et al. (71), data were generated from professional male basketball players. This data cannot be generalized to high school female athletes and non-athletes. Their data suggests potential physiological speeds that occur during typical basketball moves however these speeds are not safely reproduced or appropriate for this study's research population. The Biodex® System 2 is capable of maximum eccentric speed in passive mode of 150°/second. For convenience, this study included eccentric testing speeds of 90°/second and 150°/second.

Eccentric Testing Speeds

Eccentric testing speeds used are generally 60, 120, and 180 degrees/second. These speeds are considered slow when compared to speeds of functional activities. (69,72,73) Speeds of 120°/second and 180°/second are recommended by Hageman and Sorenson (74) as the maximum test speeds for the general population and athletic populations respectively. Speeds of less than 60°/second have been found to correlate with delayed onset muscle soreness. (72)

Delayed Onset Of Muscle Soreness

Associated with eccentric muscle action is delayed onset of muscle soreness (DOMS). DOMS results most likely from structural damage in skeletal muscle. (63, 75) It occurs within 24 to 48 hours of strenuous eccentric muscle loading or strenuous endurance events such as marathon and triathlon events and peaks from 48 to 72 hours after the event. (76) Indirect indications of muscle damage include reduced range of motion, prolonged strength loss and elevated creatine kinase in the blood. (75,76) Biopsy of gastrocnemius from runners immediately and 12 weeks post marathon showed sarcomere tearing at the Z-band and movement of fluid into muscle cells. (75) Symptoms may include feeling of pain, tenderness, swelling, stiffness and deep ache in muscles which dissipates anywhere from 48 hours to two weeks. (70,76) Volunteers from the Kramer et al. study of continuous concentric-eccentric knee flexors and extensors, found one third of the male and one half of the female participants reported perceptible, but not limiting soreness within 48 hours of eccentric testing. This soreness did not interfere with second and third testing sessions. (56) A study by Rodenburg et al. (77) with forearm flexors exercising eccentrically for 30 minutes, reported a small preventative effect for DOMS by doing a warm-up, stretching prior to testing, and doing massage after testing.

Torque

The ability of a force to cause rotation of a lever is called torque. Torque is the product of the magnitude of applied force and the distance the force lies from the axis of rotation. (78) For isometric dynamometers, increasing the force of muscular contraction does not change the angular velocity of contraction but is translated into increased torque. (67) Torque values can be expressed in terms of ratios between agonist and antagonist (63,65,68) or for comparison of contraction types (concentric to eccentric) within the same muscle. (60,67) In this study, time to peak torque values for both subject groups was measured. Time to peak torque is "the time interval between the start of muscle contraction and the point in the ROM of highest torque. This measurement provides an indication of the muscle's (or muscle group's) ability to produce torque quickly. An injured joint has a longer time to peak torque than does a healthy joint." (79) Huston and Wojtys (11) studied concentric time to peak torque in males and females. Their results showed female athletes had slower concentric time to peak torque than male athletes, but female athletes showed no significant differences in concentric time to peak torque when compared to female non-athletes. Beyond the Huston and Wojtys (11) research, time to peak torque information is limited in the literature.

Stabilization

In reviewing biomechanical factors affecting force output, Nosse (80) observed with the Cybex® isokinetic dynamometer, that the stabilization technique was the most influential variable affecting torque output. Inadequate stabilization allows subjects to use other body movements to influence force generated which does not accurately reflect the effort of the specific muscle or muscle group wanted. Smidt and Rogers (81) said to isolate a muscle or muscle group for testing, stabilization was necessary. Varying levels of stabilization produce recordings of muscle strength variations. (81)

Using a KIN/COM® system, Hanten et al. (82) showed that the maximal isokinetic torque generated by the quadriceps femoris muscle during concentric and eccentric contractions at velocities of 30 60, 90, 120, 150, 180 and 200 degrees per second was not significantly affected by the stabilization procedures. Minimum stabilization in this study consisted of the support of the KIN/COM® with a backrest and subjects gripping the sides of the test table. Maximum stabilization included support of the testing table with a backrest, a stabilization strap across the thorax which also encircled the backrest, a second strap positioned inferior to the anterior superior iliac spines, and the third strap positioned proximal to the superior border of the patella. (82)

Hart et al. (83) studied the effect of trunk stabilization on torque generated by the quadriceps muscle group. Their results showed that a strap positioned across the hips and straps crossing the trunk with a backrest, thigh cuff proximal to the patella with the subject gripping the sides to the testing table produced a significantly greater torque regardless of velocity. These results disagree with those of Hanten. (82)

Biodex® recommends stabilization with straps placed around the thigh, waist, and trunk with arms folded across the chest. (84) In this study, subjects were stabilized according to Biodex® recommendations.

Warm Up And Rest Intervals

Before eccentric isokinetic exercise begins, warm-up activities should be performed. (72) Assorted warm up combinations have been used before eccentric testing on isokinetic dynamometers. Several authors have used a combination of passive stretches to muscles used for testing plus stationary cycling at a moderate pace for five or less minutes. (22,59,85,86). Others have used only stationary cycling. (60,63) Various combinations of submaximal and maximal repetitions, ranging from one to three submaximal and one to two maximal contractions on the isokinetic machine, have been used as warm-ups. A two minute rest interval between speeds for eccentric isokinetic testing has been used in research. (69,86,87)

In this study subjects completed a five minute warm-up on an Airdyne® bicycle at a moderate level followed by self-stretching of quadriceps, hamstrings, and gastronemius muscle groups. Subjects were then given a verbal description of both concentric and eccentric muscle actions, followed by several low intensity eccentric practice trials against the researcher's manual resistance. Verbal explanations and manual resistance have been used to increase subjects understanding of what to expect during testing on isokinetic machines. (56,86) Directly after manual eccentric training, subjects performed, at each test speed, two submaximal and five maximal eccentric contractions on the Biodex® System 2. A two minute rest period followed a change between speeds.

Steiner et al. (86) found that incorporating a same-session learning component gave moderate to excellent (ICC 0.58 - 0.96) data for measurements of average peak torque, total work, and power for quadriceps and hamstrings eccentric muscle action. Subjects were allowed to repeat practice sets of three submaximal and three maximal contractions as often as needed to ensure they had correct eccentric motor activity sufficient to complete the test. No subject performed more than two practice sets. Perrin (88) suggested that three submaximal and three maximal repetitions are adequate to secure reliable measurements of isokinetic peak torque, work,and power. In this study, manual training plus machine learning trials of two submaximal and five maximal repetitions were performed at 90°/second and 150°/second to enhance subjects understanding and performance of eccentric contractions.

Gravity Correction

Isokinetic testing that involves movement in the vertical plane has muscular and gravitational forces acting on the limb-lever system. These forces are generated by the mass of both the limb and the lever arm of the isokinetic dynamometer. (89) All torques need to be gravity corrected. The Biodex® computer software performs this function (84). The maximum torque due to the dead weight of the limb is subtracted from the torque generated by muscle groups during testing. Torque registered by the dynamometer reflects the true exertion of the muscle group being tested. (79)

Test Repetitions

To ensure reliability measures, a range from three to six repetitions are needed for eccentric isokinetic testing at a specific speed. (72) Maximal repetitions vary with different eccentric isokinetic studies: three maximal repetitions were done in studies by Ghena et al. (69) and Bishop et al. (90); four maximal repetitions were performed in Strauss et al. (87) and Kramer et al. (22); five maximal repetitions were done by Young and Brooks (59) and Hopkins et al. (73); while six maximal repetitions were done by Steiner et al. (86)

Subject Testing Position

Young and Brooks (59) conducted an isokinetic knee flexion and extension study to determine the effect of supine, five degrees of hip flexion, and sitting, 90 degrees of hip flexion, positions on quadriceps and hamstrings eccentric muscle strength. Results indicated a decrease in strength values for both muscle groups in supine, with hamstrings group showing a greater deficit. (59) Worrell's et al. (68) study on hip position, seated at 110 degrees hip flexion and supine10 degrees hip flexion, for quadriceps and hamstrings found a significant decrease in peak torque values for knee extension in supine compared to sitting. Hamstrings and quadriceps torque was greatest when in a sitting position. (68) Hopkins et al. (73) studied isokinetic eccentric testing of quadriceps and hamstrings. They reported significantly greater peak torque and hamstrings to quadriceps ratios in sitting and 110 degrees hip flexion, compared to the supine position and 10 degrees hip flexion. (73)

For consistency of measurement in our testing, the shin pad was placed with its inferior border two inches above the distal tip of the medial malleolus. (65) Biodex® System 2 Applications/Operations Manual suggests the knee attachment length be such that the calf pad placement is proximal to the malleoli and below the prominent calf muscles. (84)

"The axis for flexion and extension at the tibiofemoral joint passes through the femoral condyles at an angle to the mechanical and anatomic axes." (78) The seat of the Biodex® was adjusted such that the dynamometer axis was aligned with the anatomical/mechanical axis of the knee joint as described in the Biodex® System 2 Application/Operations Manual. (65,84)

Summary

A 100% consensus of participants at the American Orthopedic Society stated that females have a greater incidence of knee injuries that involve the ACL in basketball compared to males. (5) Many factors were suggested as potential causes of ACL injuries in females. Intrinsic factors included ligament laxity, limb alignment, and notch dimensions. Extrinsic factors included sport demands, muscular strengthening, and training. This study considered two factors, (3) ligamentous laxity at the knee and (4) time to hamstring eccentric peak torque. Anterior tibial forces at the knee are resisted both passively by non-contractile soft tissue and dynamically by contractile soft tissue.

Dynamically, the ACL and hamstrings have been shown to work in a complementary manner to resist anterior tibial forces. (7, 20, 21,45, 46, 54)

The KT-1000® was used to measure the passive resistive properties of the knee. Exercise increases circulation to soft tissue and warms it. When soft tissue is warmed or heated it has increased extensibility. (51) Sakai et al. (52) studied eleven semi-professional female basketball players and recorded the effect physical activity had on anterior tibial displacement. Their results showed no change in anterior laxity with sedentary work, but a significant increase with exercise. This study tested the effects of warm-up, eccentric hamstrings isokinetic exercise, and cool-down on anterior tibial displacement.

The Biodex® System 2 isokinetic dynamometer was used to measure the time it takes the hamstrings to reach a peak eccentric contraction at speeds of 90°/second and 150°/second. Hageman and Sorenson (74) recommend eccentric speeds of 120°/second and 180°/second as the maximum test speeds for the general population and athletic populations respectively. Eccentric speeds correlated with delayed onset of muscle soreness are those less than 60°/second. (72) Test speeds of 90°/second and 150°/second were chosen for safety and convenience.

Grana and Moretz's (10) study on ligament laxity suggested female athletes had more laxity than males (athletes and non-athletes), yet had less laxity than female non-athletes. To test the idea that female athletes have less ligament laxity than female non-athletes, this study included female basketball players and female non-athletes ages 14 - 18 years old.

This study provided a basis for further study into the relationships of joint laxity, time to peak torque of eccentric hamstrings, exercise and joint laxity, and ACL injuries. Information generated in this study contributed both to the current research base and to athletes, coaches, and clinicians in designing approaches for injury prevention and rehabilitation. The following hypotheses were tested:

1. there will be no statistical difference ($p \leq 0.05$) in passive knee joint displacement (in mm) between athletic and non-athletic females aged 14 - 18 years.

2. there will be no statistical difference ($p \leq 0.05$) in eccentric hamstring time to peak torque (in seconds) at speeds of 90°/second and 150°/second between athletic and non-athletic females aged 14 - 18 years.

3. there is a positive relationship ($p \leq 0.05$) between passive anterior knee joint displacement (measured in mm) and eccentric hamstring time to peak torque (measured in seconds) at speeds of 90°/second and 150°/second in female athletes aged 14 - 18 years.

4. there is a positive relationship ($p \leq 0.05$) between passive anterior knee joint displacement (measured in mm) and eccentric hamstring time to peak torque (measured in seconds) at speeds of 90°/second and 150°/second in female non-athletes aged 14 - 18 years.

CHAPTER 3
MATERIALS AND METHODS

Subjects

Sixty healthy female volunteers (30 athletes and 30 non-athletes) age 14-18 years were tested in this study. Subjects were females with no history of lower extremity injury within the past one year, and no acute pathologies. Athletes were basketball players who attended a class A, B, C or D school system. Non-athletes were defined as persons who attended a class A, B, C or D school system, but did not participate in organized school/recreational sports or other organized physical activities. These populations were obtained by contacting guidance counselors, physical education teachers, athletic directors, athletic trainers and/or coaches from high schools within a 60 mile radius of Grand Rapids, Michigan.

Volunteers completed a pre-assessment questionnaire. Exclusion criteria included: (a) history of cardiovascular, neurological, rheumatological, or other medical conditions (b) pregnancy or suspicion thereof (c) smokers (d) inability to extend the knees, in sitting, from 90 to 0 degrees (e) history of back or lower extremity injury, within the past one year, that kept her out of practice, a game, or other activities for more than three days. All participants signed a consent form with a parent signature if they were under 18 years, before proceeding with the testing. Parents were encouraged to attend the testing session. All participants received an identification number for purposes of confidentiality and neutrality, that were used throughout the study. To ensure unrestricted movement during testing, subjects wore socks, shorts, and T-shirts during testing.

Study Site

All testing was performed at one facility, Butterworth Rehabilitation Clinic located at 2312 28th street, SE, Grand Rapids, Michigan. This site was equipped with the materials used in this study.

Materials

A Schwinn Airdyne® exercise bike was used for warm-up prior to testing. The KT-1000® knee arthrometer was used to measure passive anterior tibial translation. The KT-1000® was designed to measure passive anterior and posterior joint laxity. (91) The KT-1000® arthrometer has previously been determined as reliable for intratester measures. (48,49) The Biodex® System 2 isokinetic dynamometer was used, in the passive mode, to measure eccentric hamstrings time to peak torque. Biodex® isokinetic testing provides an objective and quantitative measure of dynamic muscle activity including eccentric time to peak torque. (84) The reliability of the Biodex® dynamometer for use in isokinetic testing has been established by previous research. (56,59-62) The same KT-1000® and Biodex® machines were used for all testing in this study. The Biodex® was calibrated according to the operator's manual on each day of testing.

Test-retest

Two pilot studies were performed to determine the reliability of test equipment and procedures. Five non-study volunteers participated in each pilot study. The first test-retest evaluated both the KT-1000® arthrometer and Biodex® System 2 dynamometer. Changes were made to both isokinetic testing verbal instructions and practice repetitions. The second test-retest evaluated the Biodex® only.

Procedure

Each subject received a testing number and reviewed her consent form and pre-test questionnaire with the research supervisor. Participants were encouraged to ask any questions they had related to the research or participation. Each subject chose one of two cards marked right and left to determine order of leg testing. Subjects were measured for height and weight. Leg dominance was determined by asking each subject to kick a ball between two stationary objects five feet apart from a distance of ten feet away. The KT-1000® was used, according to testing order determined earlier, to measure passive anterior drawer on subjects bilaterally. The passive anterior drawer was performed supine according to the manufacturers' recommendations. The KT-1000® was calibrated for each subject prior to data collection. Three measurements of passive anterior displacement were recorded and averaged for each subject. Thirty pounds of anterior force was used for all measurements.

Next, each subject performed a five minute warm-up on the Schwinn Airdyne® exercise bike, at a moderate (modified rate of perceived exertion = 3) intensity level. For consistency, seat height was adjusted to approximately 15 degrees of knee flexion with the foot and pedal closest to the floor. Following the five minutes on the bike, subjects performed self-stretching of their quadriceps femoris, hamstrings, and gastrocnemius muscles. (See Appendix G) Two repetitions, held for 30 seconds each, were performed for each muscle group (quadriceps femoris, hamstrings, and gastrocnemius).

Following the warm-up and stretching, subjects were tested for eccentric hamstrings time to peak torque on the Biodex® System 2 isokinetic dynamometer, in the limb order previously determined. Subjects were given a verbal description of both concentric and eccentric muscle actions. Prior to stabilization on the Biodex®, submaximal and maximal eccentric practice trials were performed against the tester's manual resistance.

For reliability purposes, the same three examiners performed all Biodex® testing and calibrations. Each subject was seated on the Biodex® with the back adjusted to ensure 90 degrees of hip flexion, as measured by a standard goniometer. Stabilization straps were applied to the trunk, waist, and thigh according to the Biodex® operator's manual. The seat was adjusted to ensure the dynamometer powerhead was placed at the anatomical axis of the knee joint, which corresponds to an imaginary line passing through the center of the femoral condyles in the coronal plane. In accordance with the Biodex® protocol for stabilization and for purposes of consistency, the shin pad's inferior border was placed two inches above the distal tip of the medial malleolus. Subjects were instructed to keep arms crossed against chest throughout testing and exert maximal effort for each repetition. Gravity correction was done by the Biodex® computer which weighed each lower extremity prior to data collection.

At each test speed (90°/second and 150°/second), subjects performed two submaximal repetitions and five maximal practice repetitions for eccentric hamstrings contractions. A one minute rest was given between the practice and test trials. Five maximal repetitions were recorded following the one minute rest at each practice speed. A two second pause was given between each test repetition. A two minute rest period was given between test speeds. Tests were performed from 90 to 0 degrees of knee flexion at 90°/second and 150°/second. Following Biodex® testing, each subject performed three minutes of stationary cycling at a low intensity for cool down. After the cool down period, subjects were tested again for passive anterior tibial displacement with the KT-1000®.

Data Analysis

The $\alpha = 0.05$ level was used to determine statistical significance. SPSS for MS WINDOWS was used to analyze the data collected in this study. The Pearson Product Moment correlation test was used to evaluate the test-retest reliability of the KT-1000® arthrometer and Biodex® System 2 isokinetic dynamometer. Descriptive statistics were analyzed based on subject's pre-test questionnaire for comparisons of height, weight, age, sport level, and school classification. The paired, two-tailed *t*-test was used to compare right and left legs for time to peak torque and anterior tibial displacement. The paired, two-tailed *t*-test was used to compare pre and post-exercise anterior tibial displacement. The independent, two-tailed *t*-test was used to determine differences between athletic and non-athletic females for passive anterior tibial displacement, and time to peak torque. The Pearson Product Moment correlation was used to describe the relationship between eccentric hamstrings time to peak torque and active anterior knee joint laxity. (92)

CHAPTER 4
RESULTS

A convenience sample of 63 subjects was tested. Two subjects were excluded due to lack of pre-test questionnaire information confirming appropriate inclusion criteria. A third subject was excluded due to participation in basketball in previous years, but not in the fall 1997 season. The remaining subjects in this study included 30 female athletes and 30 female non-athletes. All subjects were between 14 and 18 years of age. Athletes in this study played basketball during the fall 1997 basketball season. The non-athletes participated in no more than three hours of physical activity per week and did not participate in organized school athletic activities during the fall 1997 or winter 1997/98. All participants were healthy and had not been limited from physical activity for more than three days due to a knee injury.

Upon arrival subjects chose one of two cards to randomize first leg tested. They were weighed and measured for height and leg dominance was determined. Anterior knee joint displacement was measured followed by a warm-up prior to eccentric hamstrings testing. Time to peak torque was measured bilaterally at two speeds, 90°/second and 150°/second. Following isokinetic testing, a cool down and a post-test of anterior knee joint displacement was performed.

Tables 2-4 include all data analyzed in two pilot studies of five subjects. These were conducted prior to data collection to determine the reliability of the testing equipment and procedures. The Pearson Product Moment correlation test was used to analyze the test-retest reliability of anterior knee joint displacement and eccentric hamstrings time to peak torque measures. (92) One tester performed all KT-1000® measurements of anterior knee joint displacement. KT-1000® results, displayed in Table 2, showed a strong correlation between the test-retest data.

Table 3 displays the time to peak torque results from pilot 1 and Table 4 shows time to peak torque results from pilot 2. The eccentric hamstrings Biodex® testing showed no reliability after the first pilot with five subjects. A second pilot of five subjects was conducted following revisions to both the isokinetic verbal instructions and practice repetitions. The second pilot showed improved correlation between the test-retest data for time to peak torque, however, results were not statistically significant at $p \leq 0.05$.

Table 2.--KT-1000® Test-retest Analysis for Reliability

	Correlation Coefficient	**p value**
KT-1000® Pre (R) Day 1 to Day 2 n=5	0.9682	0.007
KT-1000® Pre (L) Day 1 to Day 2 n=5	0.8878	0.044
KT-1000 Post (R) Day 1 to Day 2 n=5	0.9650	0.008
KT-1000® Post (L) Day 1 to Day 2 n=5	0.8335	0.079

(R)=right
(L)=left
$p \leq 0.05$

Table 3.--Time to Peak Torque Test-retest Pilot 1

	Correlation Coefficient	p value
Pilot 1 TTPT 90°/sec (R) Day 1 to Day 2 n=5	0.2047	0.741
Pilot 1 TTPT 90°/sec (L) Day 1 to Day 2 n=5	0.5120	0.378
Pilot 1 TTPT 150°/sec (R) Day 1 to Day 2 n=5	0.0773	0.902
Pilot 1 TTPT 150°/sec (L) Day 1 to Day 2 n=5	-0.3713	0.538

TTPT=eccentric hamstrings time to peak torque
(R)=right
(L)=left
$p \leq 0.05$

Table 4.--Time to Peak Torque Test-retest Pilot 2

	Correlation Coefficient	p value
Pilot 2 TTPT 90°/sec (R) Day 1 to Day 2 n=5	0.8145	0.093
Pilot 2 TTPT 90°/sec (L) Day 1 to Day 2 n=5	-0.1907	0.759
Pilot 2 TTPT 150°/sec (R) Day 1 to Day 2 n=5	0.8148	0.093
Pilot 2 TTPT 150°/sec (L) Day 1 to Day 2 n=5	-0.8127	0.095

TTPT=eccentric hamstrings time to peak torque
(R)=right
(L)=left
$p \leq 0.05$

Independent *t*-tests were used to compare the two groups in this study. Table 5 results showed comparisons between athletes and non-athletes for age, height, and weight. Results revealed no statistical difference between the athletes and non-athletes for theses measures. Information was also collected on each subject for school classification, level of athletic participation, leg dominance, and first leg tested. Table 6 displays the frequency of these measures.

Table 5.--Demographic Comparisons

	Mean	Std. Dev.	p value
Age			
NA n= 30	16.03 years	0.999 years	
A n= 30	15.53 years	1.279 years	0.097
Height			
NA	65.67 inches	2.294 inches	
A	66.56 inches	2.812 inches	0.180
Weight			
NA	143.03 lbs	28.76 lbs	
A	136.16 lbs	23.67 lbs	0.317

NA=non-athlete
A=athlete
Std. Dev.=standard deviation
p value≤0.05

Table 6.--Frequencies

	Frequency	Percent
School Class n=60		
A	18	30.0
B	35	58.3
C	6	10.0
D	1	1.7
Level of Play n=60		
Varsity	12	20.0
Junior varsity	10	16.7
Freshman	3	5.0
8th grade	5	8.3
NA	30	50.0
Leg Dominance n=60		
Right	56	93.3
Left	4	6.7
First leg tested n=60		
Right	26	43.3
Left	34	56.7

NA=non-athlete

Addressing the first hypothesis, Table 7 shows results of KT-1000® measures of anterior knee joint displacement. Anterior knee joint displacement was measured bilaterally before and after all exercise. The paired *t*-test was used to compare right to left and pre to post test measurements. The independent *t*-test was used to compare anterior knee joint displacement between athletes and non-athletes. There was no statistical difference between the pre and post KT-1000® measurements or between anterior knee joint displacement for the right and left legs at $p \leq 0.05$. Since there was no difference between right and left, and pre and post KT-1000® values, all correlations were made with the right pre KT-1000® values only. Based on the anterior knee joint displacement results, we were unable to reject the null hypothesis that there is no statistical difference in passive knee joint displacement between athletic and non-athletic females aged 14-18 years.

Table 7.--Results of KT-1000® Measurements

	Mean (mm)	Std. Dev. (mm)	p value
KT-1000® (Right)			
Pre n=60	6.167	1.509	
Post n=60	6.050	1.358	0.211
KT-1000® (Left)			
Pre n=60	5.916	1.430	
Post n=60	6.016	1.372	0.260
KT-1000® (Pre)			
Right	6.167	1.509	
Left	5.916	1.430	0.129
KT-1000® (Right/Pre)			
NA	6.467	1.332	
A	5.867	1.634	0.125

NA=non-athlete
A=athlete
Std. Dev.=standard deviation
p value≤0.05

Addressing our second hypothesis, Table 8 represents the results of eccentric hamstrings time to peak torque measures. Eccentric time to peak torque (TTPT) of the hamstrings was measured for both legs at two speeds, 90°/second and 150°/second. Paired *t*-tests showed a significant difference between right and left legs at the slower

90°/second, but not at the faster 150°/second speed. Independent *t*-tests were used to compare athletes and non-athletes TTPT at each speed. No significant difference was demonstrated between the two groups at either speed. We were unable to reject the null hypothesis that there will be no statistical difference in eccentric hamstrings time to peak torque between athletic and non-athletic females aged 14-18 years.

Table 8.--Time to Peak Torque Results and Comparisons

	Mean (sec)	**Std. Dev. (sec)**	**p value**
TTPT at 90°/sec			
right n=60	787.25	128.15	
left n=60	824.77	138.98	0.052
TTPT at 150°/sec			
right n=60	525.38	74.79	
left n=60	531.28	80.83	0.643
TTPT at 90°/sec Right			
NA n=30	781.53	117.91	
A n=30	792.97	139.43	0.733
TTPT at 90°/sec Left			
NA	808.26	157.86	
A	841.27	117.52	0.362
TTPT at 150°/sec Right			
NA	517.73	78.39	
A	533.03	71.51	0.433
TTPT at 150°/sec Left			
NA	518.67	86.68	
A	543.90	73.81	0.230

TTPT= time to peak torque
NA=non-athlete
A=athlete
Sec=seconds
Std. Dev.=standard deviation
p value≤0.05

The Pearson Product Moment correlation is based on covariance. A positive relationship indicates that as one continuous measure increases a second continuous variable would also increase. A negative relationship indicates that as one continuous measure increases the second continuous variable would decrease. (92)

The Pearson Product Moment correlation was used to compare the relationship between time to peak torque (TTPT) and anterior knee joint displacement. Correlation coefficient values measure the strength of association of two variables. Little to no relationship is indicated with correlation coefficients ranging from 0.00 to 0.25, 0.25 to 0.50 suggest a fair degree of relationship, and 0.50 to 0.75 indicate a moderate to good relationship. (92) Values above 0.75 are considered good to excellent. (22, 92)

Table 9 displays the results of Pearson Product Moment correlation tests for anterior knee joint displacement and eccentric hamstrings time to peak torque. Table 9 addresses the third and fourth hypotheses, and displayed that no relationship between TTPT, at both speeds, and anterior knee joint displacement for either the athletic nor non-athletic populations studied.

Table 9.--Pearson Product Moment Correlations Right Pre KT-1000® Measures Compared to Biodex® Eccentric Hamstrings Time to Peak Torque

Variables (n=60)	**Correlation Coefficients**	**p Value**
AKJD to (R) TTPT @90°/sec	-0.0199	0.880
AKJD to (L) TTPT @90°/sec	0.0412	0.754
AKJD to (R) TTPT @150°/sec	0.0382	0.772
AKJD to (L) TTPT @150/sec	-0.1697	0.195

AKJD=anterior knee joint displacement pre exercise for right legs
TTPT=time to peak torque
(R)=right
(L)=left
sec=second
p value≤0.05

Although not directly related to the hypotheses, other data were collected and analyzed including: coefficient of variance, torque @ 0.2 second, weight, and height. Table 10 displays coefficient of variance results from eccentric hamstrings testing on the

Biodex® System 2 dynamometer. Coefficient of variance is a measure of relative variation and is expressed as a percentage. It is based on the size of the standard deviation relative to the mean. (92) The coefficient of variance (CoV) of eccentric hamstrings testing was analyzed for each group using independent and paired *t*-tests with the alpha level for rejection of the null hypotheses at $p \leq 0.05$. Paired *t*-tests revealed no significant difference in coefficient of variance for right and left legs at either speed. Independent *t*-tests showed no significant difference between athletes and non-athletes for CoV at both speeds.

Table 10.--Coefficient of Variance (CoV) for Eccentric Hamstrings Measurements

	Mean (%)	Std. Dev. (%)	p value
CoV at 90°/sec			
Right n=30	24.645	11.265	
Left n=30	25.033	14.158	0.849
CoV at 150°/sec			
Right	28.200	19.780	
Left	27.455	18.321	0.797
CoV at 90°/sec			
NA (Right) n=30	25.530	12.107	
A (Right) n=30	23.760	10.486	0.547
CoV at 150°/sec			
NA (Right)	28.693	23.863	
A (Right)	27.707	15.035	0.849

NA=non-athlete
A=athlete
Std.Dev.=standard deviation
sec=second
p value≤0.05

Table 11 describes the torque (in foot-pounds) subjects were able to produce at 0.2 second during their peak torque trial. Paired *t*-tests showed no significant difference between right and left legs at either the slow or fast speeds, 90°/second and 150°/second respectively. Independent *t*-tests also showed no significant difference between the torque produced by athletes and non-athletes at both speeds.

Table 11.--Torque at 0.2 second

Torque at 0.2 sec	Mean (ft-lbs)	Std. Dev. (ft-lbs)	p value
90°/sec			
Right n=60	7.77	6.66	
Left n=60	8.85	7.66	0.387
150°/sec			
Right n=60	13.20	11.19	
Left n=60	15.24	11.03	0.217
90°/sec (Right)			
NA n=30	7.43	5.73	
A n=30	8.11	7.57	0.695
150°/sec (Right)			
NA n=30	12.94	9.83	
A n=30	13.45	12.57	0.863

NA=non-athlete
A=athlete
sec=second
ft-lbs=foot pounds of force
Std.Dev.=standard deviation
p value≤0.05

Comparisons of torque @ 0.2 second, weight, and height to anterior knee joint displacement and/or eccentric hamstrings time to peak torque were also analyzed. Table 12 displays the results of anterior knee joint displacement and torque @ 0.2 second. Results revealed no relationship at the slow 90°/second speed, but a fair negative relationship between anterior knee joint displacement and torque at 0.2 second at the 150°/second testing speed.

Table 12.--Pearson Product Moment Correlations Anterior Knee Joint Displacement to Torque @ 0.2 second

Variables (n=60)	**Correlation Coefficient**	**p Value**
AKJD to (R) Torque @ 0.2sec at 90°/sec	-0.1686	0.198
AKJD to (R) Torque @ 0.2sec at 150°/sec	-0.3595	0.005

AKJD=anterior knee joint displacement
sec=second
R=right leg
p value≤0.05

Table 13 represents results of weight compared to eccentric hamstrings measures and anterior knee joint displacement. Table 14 displays height compared to eccentric hamstrings measures and anterior knee joint displacement. Weight showed no relationships to anterior knee joint displacement and torque at 0.2 second at both speeds. Weight showed a fair positive relationship to eccentric hamstrings time to peak torque at 90°/second for the left leg only. All other measures of time to peak torque showed no relationship to weight. Height showed no relationship to time to peak torque at both speeds and to torque at 0.2 second for 90°/second. A fair negative relationship was demonstrated at the $p \leq 0.05$ level for height and anterior knee joint displacement, and a fair positive relationship between height and torque at 0.2 second for the faster 150°/second speed.

Table 13.--Pearson Product Moment Correlations Weight Compared to Biodex® Eccentric Hamstrings Measures and Anterior Knee Joint Displacement

Variables (n=60)	**Correlation Coefficient**	**p value**
(R) TTPT @90°/sec to weight	0.0027	0.984
(L) TTPT @90°/sec to weight	0.2875	0.026
(R) TTPT @150°/sec to weight	-0.1445	0.270
(L) TTPT @150°/sec to weight	0.0693	0.599
(R) Torque @ 0.2 sec @90°/sec to weight	0.0505	0.702
(R) Torque @ 0.2 sec @150°/sec to weight	0.0681	0.605
AKJD to weight	-0.0209	0.874

TTPT=time to peak torque
AKJD=anterior knee joint displacement
(R)=right
(L)=left
sec=second
p value≤0.05

Table 14.--Pearson Product Moment Correlations Height Compared to Biodex® Eccentric Hamstrings Measures and Anterior Knee Joint Displacement

Variables (n=60)	**Correlation Coefficient**	**p value**
(R) TTPT @90°/sec to height	0.0372	0.778
(L) TTPT @90°/sec to height	-0.0323	0.806
(R) TTPT @150°/sec to height	-0.1732	0.186
(L) TTPT @150°/sec to height	0.0401	0.761
(R) Torque @ 0.2 sec @90°/sec to height	0.1818	0.164
(R) Torque @ 0.2 sec @150°/sec to height	0.4257	0.001
AKJD to height	-0.3353	0.009

TTPT=time to peak torque
AKJD=anterior knee joint displacement
(R)=right
(L)=left
sec=second
p value≤0.05

CHAPTER 5
DISCUSSION AND IMPLICATIONS

Pilot Study

The initial test-retest analysis demonstrated a good to excellent correlation and was statistically significant for KT-1000® measures. The same experienced tester performed all anterior knee joint displacement measures with the KT-1000®. The reliability demonstrated in this study is supported by Ballantyne et al. (49) who suggested all KT-1000® measurements be performed by an experienced tester for intratester reliability.

The initial test-retest failed to demonstrate reliability for isokinetic testing of eccentric hamstrings time to peak torque. Reliability of Biodex® machines has been proven by research for parameters of peak torque, angle of peak torque and total work. (56, 59-62) There is no research regarding reliability of eccentric hamstrings time to peak torque tested in the passive mode on the Biodex® System 2 published in the literature.

Another possible factor affecting the initial isokinetic test-retest reliability was testing methods. After the first pilot, the test design was modified to include a greater number of maximal practice repetitions and fewer submaximal repetitions. The goal was to promote better understanding of effort desired during actual testing. Changes were also made to the verbal instructions to emphasize the maximum effort desired and the importance of quickness of response. New directions stated "pull as hard and as fast as you can when you feel the bar begin to move". Steiner et al. (86) found that incorporating a same session learning segment including verbal commands for encouragement yielded moderate to excellent reliability using the LIDO® for eccentric isokinetic lower extremity testing of peak torque, power, and total work. The Steiner et al. (86) study did not evaluate time to peak torque.

Attention and concentration level of participants may have been a limiting factor in this first test-retest study. During the isokinetic testing it was noted that some participants were distracted by activity in the testing area. In the revised test instruction participants were encouraged to "please concentrate and give your best effort" and "this is the actual test" to enhance attention to the task. After revising the methods for the isokinetic testing, a second test-retest on five different individuals was performed for isokinetic eccentric hamstrings time to peak torque. Results demonstrated improved correlation coefficients between day one and day two testing, however this was not significant at $p \leq 0.05$.

Hypotheses

This study considered anterior knee joint displacement and eccentric hamstrings time to peak torque. Previous research has shown that female athletes have less ligament laxity than female non-athletes. (10,11) Results of this study do not support the findings of the above studies. This study found no significant difference in passive anterior knee joint displacement between female basketball players and female non-athletes. We were unable to reject the null hypothesis that there is no statistical difference in passive knee joint displacement between athletic and non-athletic females aged 14-18 years. The findings of this study agree with Kramer et al. (56) who found a "poor correlation between current activity level and anterior knee joint displacement" measured passively with the KT-1000®.

In this study eccentric hamstrings time to peak torque was measured at two speeds, 90°/second and 150°/second. Results from this study suggest there is no difference in the amount of time it takes female athletes and non-athletes to produce eccentric hamstrings time to peak torque. We were unable to reject the null hypothesis that there will be no statistical difference in eccentric hamstrings time to peak torque between athletic and non-athletic females. Huston and Wojtys (11) provided the only other study to consider time to peak torque. They compared concentric time to peak torque between elite female athletes and non-athletes,and found no significant difference between these groups for this measure.

Increased tibial displacement and dynamic activity of the hamstrings muscles may play a role in ACL protection and injury. Previous research by Beard et al. (21) demonstrated a relationship between arthroscopically diagnosed ACL deficient knees and reflex hamstrings contraction latency measured by EMG in fifty-one patients. The Beard et al. (21) study demonstrated a difference in muscle activation times between individuals with no injury and those with ACL deficiency.

The purpose of this study was to determine if there is a relationship between anterior knee joint displacement and eccentric hamstrings time to peak torque in healthy females aged 14-18 years old. The results of this study did not suggest a relationship between anterior knee joint displacement and eccentric hamstrings time to peak torque in female athletes or non-athletes aged 14-18 years.

Eccentric time to peak torque was measured to assess hamstrings ability to react and produce force against a knee extension moment. This measure may be more specific to recruitment of muscle fibers over time rather than the ability of the hamstrings to react quickly and produce force in response to an extension moment. A different measurement or method such as torque at a given amount of time or use of electromyography may be more appropriate. Time to peak torque is the time required for a muscle to generate its greatest force. (84) Time to peak torque can not be considered a measure of reaction.

Discussion of Other Data Analyzed

During eccentric hamstrings isokinetic testing, the Biodex® Advantage software also collected data for torque at 0.2 second. Torque at 0.2 second is defined as the time rate of tension development produced after the test muscle group begins to contract. (84) Results of this study indicated a fair negative relationship between anterior knee joint displacement and torque at 0.2 second at 150°/second with a p value of 0.005. This suggests that as anterior knee joint displacement increases torque at 0.2 second decreases.

The decrease in ability to produce torque at 0.2 second may be due to slower activation of the hamstrings muscles in individuals with increased tibial displacement. Beard et al. (21) identified increased latency of reflex hamstrings contraction in an ACL deficient population. Previous research has shown that the ACL and hamstrings work together to resist anterior tibial forces. (7,20,21,45,46,54) Solomonow et al. (20) concluded that a fast-to-respond reflex arc exists from mechanoreceptors in the ACL to the hamstrings muscles. Ruffini endings, Pacinian corpuscles, Golgi tendon organlike endings, and free nerve endings have been identified in human ACLs. (55) Pacinian corpuscles are rapidly adapting, have low thresholds, and are activated with acceleration and deceleration. (55) Kinesthetic mechanoreceptors, such as Pacinian corpuscles, may be stimulated more quickly in individuals who demonstrate less tibial displacement than those who have greater laxity.

Johansson et al. (55) discussed the assumption, given the cruciate ligaments are taut in different situations, that the knee joint ligaments provide the central nervous system with varied receptor input for each individual situation. If an individual demonstrates increased anterior knee joint displacement, then it is possible that their central nervous system receives different receptor input in many situations as that of an individual who demonstrates less anterior knee joint displacement. With less central nervous system input it seems reasonable to assume that a person is less likely to react quickly and produce torque as compared to those with less anterior knee joint displacement.

Comparisons of height and weight to anterior knee joint displacement, eccentric hamstrings time to peak torque, and torque at 0.2 second at both speeds were also performed. Weight showed no relationship to anterior knee joint displacement nor torque at 0.2 second. Results did show a fair positive relationship between weight and time to peak torque at 90°/second for the left leg only. Weight did not show a correlation to time to peak torque at 150°/second or 90°/second for the right leg. These results could be due to the lack of significance in the reliability of the Biodex® measures in the passive mode demonstrated by our test-retest results.

Height showed no correlation to eccentric hamstrings time to peak torque at both speeds and to torque at 0.2 second for 90°/second. A fair positive relationship was demonstrated at the $p \leq 0.05$ level for height and torque at 0.2 second at 150°/second. These results suggest that as height increases, the ability to produce torque at 0.2 second also increases.

Wilk and Andrews (8) studied different pad placement sites distal to the knee joint and their effect on ability to produce torque. Results from their study suggest a more proximal pad placement minimizes the ability to produce torque. They reported a significant difference between pad placement and peak torque at two speeds, 60°/second and 180°/second. Their results showed no significant difference between pad placement and peak torque at 300°/second. They did not measure torque at 0.2 second.

In this study pad placement was standardized for each subject at two inches above the distal tip of the medial malleolus. The distance between the knee joint axis of rotation and the pad was different for every subject. This could be a possible source of difference among subjects. The length of the lever arm was not standardized for each subject. A longer lever arm may give the taller subject a mechanical advantage over the shorter subject who has a shorter lever arm to work against.

Measurements of anterior knee joint displacement were taken before and after all exercise. Results of this study indicated no difference between pre and post activity anterior knee joint displacement. Research by Sakai et al. (52) demonstrated a significant difference in anterior knee joint laxity pre exercise compared to post exercise. The exercise in their study consisted of basketball game style practice of one hundred fifty minutes.

Sakai et al. (52) studied eleven semiprofessional basketball players. They found no change in anterior knee joint laxity after a full day of sedentary work or after a sixty minute warm-up prior to practice. The level of physical activity demanded of our participants did not approach that of the Sakai et al. (52) study. Our study consisted of approximately 45 minutes of physical activity and is most appropriately compared to the Sakai et al. (52) study of anterior knee joint displacement after 60 minutes of warm up activities. Our study demonstrated similar results of no change in anterior knee joint displacement after limited physical activity.

Results of this study also found no difference between right and left legs for anterior knee joint displacement. All subjects in this study were healthy and had no previous knee injuries. Thirty pounds of force was used to measure anterior knee joint displacement. Subjects were tested in approximately 20 degrees of knee flexion. All subjects fell between four and ten millimeters of anterior displacement. The mean was 6.167mm$\pm$ 1.509mm for right legs and 5.916mm$\pm$ 1.430mm for left legs.

Results from Daniel et al. (35) reported similar results with no significant difference between right and left legs. They tested 338 normal subjects with a range of 3-17 mm of anterior knee joint displacement. Oliver et al (38) tested 25 females with one injured and one uninjured leg. They tested subjects in 90 degrees of knee flexion and reported a mean anterior displacement of 9$\pm$ 3mm for the uninjured legs.

A significant difference was found for eccentric hamstrings time to peak torque between left and right legs for athletes and non-athletes combined at 90°/second. In this study the right legs were faster at reaching peak torque with a mean time to peak torque of 787.25 ±128.15 seconds compared to 824.77 ±138.98 seconds for left legs at the p value 0.052. This may have something to do with leg dominance. Ninety three percent of all subjects tested in this study were right leg dominant as measured by the leg used to kick a ball. This was not the case at the higher speed. Hageman et al. (63) studied leg dominance and torque finding no significant difference between these variables for eccentric and concentric muscle contractions. Their study did not consider time to peak torque.

The faster speed of 150°/second showed no significant difference between right and left legs. Differences between speeds or between legs at the slower speed may be due to lack of significance in reliability of Biodex® eccentric hamstrings time to peak torque measures in the passive mode. The results of the second test-retest for time to peak torque demonstrated an improved relationship between eccentric hamstrings time to peak torque measures, but this improvement was not significant at the $p \leq 0.05$ level.

<u>Strengths</u>

Test-retest for intrarater measures of anterior knee joint displacement using the KT-1000® was found to be reliable at the $p \leq 0.05$. Refer to Table 2. Test-retest for eccentric hamstrings time to peak torque measured using the Biodex® System 2 dynamometer in the passive speed was first found to be unreliable. After changes were made to the procedure and verbal instructions, reliability of eccentric hamstrings time to peak torque measures improved. The improvement was not statistically significant at $p \leq 0.05$ (Refer to Tables 3 and 4).

This study included the KT-1000® arthrometer and the Biodex® System 2 dynamometer which have been used in previous research and were documented reliable and valid. The same tester performed all anterior knee joint displacement measurements. The same three testers performed all eccentric hamstrings testing on the Biodex® System 2 dynamometer. The Biodex® System 2 dynamometer was calibrated at the beginning of each testing day.

Limitations

One limitation of this study was the post season status of our female basketball player population. It is possible that a greater discrepancy could have existed between the athletes and non-athletes if the basketball players had been tested during the basketball season when they were at peak muscle performance. This could have affected all stated hypotheses. Further confounding results, some of the non-athletic participants admitted to exercising regularly. They, however, fit the non-athlete acceptance criteria of less than three hours of activity per week. A physical activity test or questionnaire was not administered to the subjects; therefore, the degree of difference between the two groups, relative to physical activity at the time of testing, was unknown. A basketball player who did not participate in sport or physical activity after the basketball season may not have been in the same physical condition she was in during the basketball season.

Another potential source of limitation within this study was the lack of equal representation of school class (A,B,C,D) and level of play (varsity, junior varsity, freshman, and eighth grade). Class B was represented twice that of Class A and three times that of Class C. Only one participant was from a Class D school. Varsity and junior varsity levels were represented almost equally. Although freshman and eighth grade were nearly equal, they were less than half the number of varsity and junior varsity participants. A larger sample size may have increased equality between classes and levels of play. This would have made the study's significant results more applicable to the general population.

Motivation of individual participants during isokinetic testing may have been a limiting factor. The test was performed in a gym where other people were exercising and this could have been a source of distraction. Attempts were made during practice trials to increase motivation and understanding of testing procedure with verbal commands. During test trials, however, no verbal instructions were given. Reading scripted instructions could have been a source of variation in consistent delivery to each subject. Tone of voice and inflection may have varied. Also, rapport may have been different between some subjects and testers.

Stabilization on the Biodex was attempted with waist, thigh, and two shoulder straps. Participants were also asked to cross arms over their chest and grab the shoulder straps during testing to prevent use of other muscles during the test. Some substitution may have resulted in spite of stabilization efforts.

Speculation has been made about the influence of female cyclical hormones and their effect on ligament laxity. (39) This study did not attempt to control for time in menstrual cycle. Cyclical hormone influence could have been a possible factor in amount of passive laxity demonstrated and subsequent proprioceptive ability during time to peak torque testing.

Lower extremity functional activities have a significant closed chain component. This study assessed lower extremity function in a seated open kinetic chain position. Until closed kinetic chain equipment or testing procedures become more accessible, this will continue to be a limitation to lower extremity strength testing.

Further Research

A suggestion for research is to replicate the present study including an activity questionnaire to further stratify the population. Performing test procedures on college and professional level female basketball players with their comparable age non-athletes would add to the literature and may demonstrate different results. Reproduction of this study with ankle pad placement varied by either percentage of tibia length or equal pad placement distal to knee joint for all subjects would limit mechanical advantage of taller participants. It would be of interest to develop normative data for eccentric time to peak torque in passive mode on an isokinetic machine for this population. A longitudinal study after testing to follow injuries in the female basketball population would also provide more information concerning those factors that may influence injury.

Conclusion

The purpose of this study was to compare anterior knee joint laxity and eccentric hamstrings time to peak torque in female athletes and non-athletes ages 14 –18 years. Data collected showed no significant correlation between these variables. Results also showed no significant differences between populations studied for anterior knee joint displacement or eccentric hamstrings time to peak torque.

Data collected for eccentric hamstrings torque at 0.2 second, at 150°/second, revealed a positive correlation to height. A negative correlation was found to exist between torque at 0.2 second and anterior knee joint displacement. Based on these results, more research is warranted to further clarify the relationship between ability of the hamstrings to quickly produce torque and anterior knee joint displacement.

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Appendix A

Contact Letter

Dear Principal, Superintendent, Athletic Director, Coach, Athletic Trainer, Guidance Counselor,

As third year physical therapy students at Grand Valley State University we are seeking 60 female volunteers for completion of our required masters degree research project. Our project involves testing two anatomical factors, anterior cruciate ligament (ACL) and hamstring muscle group strength. Weakness in either of these factors individually have been postulated to cause ACL injuries. Research has shown that female athletes experience more ACL injuries than their male counterparts. Our research hopes to determine if a correlation exists between ACL laxity and the time it takes for the hamstrings to reach their highest force. Information gained by this study will benefit coaches, athletes, and clinicians in planning programs for injury prevention and rehabilitation.

Our specific research population requires 30 female eighth grade, ninth grade, JV and/or varsity level basketball players ages 14-18 years old and 30 non-athletic females ages 14-18 years old. Participants will be required to travel to Butterworth Rehabilitation Clinic, 2312 28th St., Grand Rapids, MI.

At this site ACL laxity will be measured with a KT-1000® arthrometer and hamstring strength will be measured on the Biodex® System 2 isokinetic dynamometer. All testing will be carried out by student physical therapists and supervised by a licensed physical therapist. Testing sessions will be approximately 60-70 minutes in length. There is no cost involved for the testing. All results will be confidential.

Sincerely,

Julie Clark S.P.T.
Maureen Godfrey S.P.T.
Noreen LaBorde S.P.T.
Jolene Bennett M.A., P.T., A.T.C.

Appendix B

Parent Contact Letter

Dear Parent(s)/Guardian(s),

Your daughter has expressed an interest in participating in a research project being conducted by three third year students from Grand Valley State University. Our specific research population requires 30 female eighth grade, ninth grade, JV and/or varsity level basketball players ages 14-18 years old and 30 non-athletic females ages 14-18 years old.

Our project involves testing two anatomical factors, anterior cruciate ligament (ACL) and hamstring muscle group strength. Weakness in either of these factors individually have been postulated to cause ACL injuries. Research has shown that female athletes experience more ACL injuries than their male counterparts. Our research hopes to determine if a correlation exists between ACL laxity and the time it takes for the hamstrings to reach their highest force.

Participants will be required to travel to Butterworth Rehabilitation Clinic, 2313 28th St., Grand Rapids, MI. At this site ACL laxity will be measured with a KT-1000 arthrometer and hamstring strength will be measured on the Biodex System 2 Isokinetic dynamometer. All testing will be carried out by student physical therapists and supervised by as licensed physical therapist. Testing sessions will be approximately 60-70 minutes in length. There is no cost involved for the testing. All results will be confidential.

We are currently scheduling appointments for testing on Mondays, Wednesdays, and Fridays, from 3:00-6:00 PM and Saturdays form 9:00 AM- 5:00 PM, January through the first week of February.

Please find enclosed consent form and pretest questionaire. **These forms must be completed and returned on you daughter's scheduled test day. Both forms are necessary for participation in this research study.** We appreciate you letting your daughter participate in this research study.

Sincerely,

Julie Clark S.P.T.
Maureen Godfrey S.P.T.
Noreen LaBorde S.P.T.
Jolene Bennett M.A., P.T., A.T.C.

Appendix C

INFORMED CONSENT

TITLE OF STUDY
"The Relationship of Eccentric Hamstrings Time to Peak Torque and Anterior Knee Joint Displacement".

INVESTIGATORS
This research is being carried out under the supervision of Jolene Bennett MA, PT, ATC at the Butterworth Rehabilitation Clinic located at 2312 28th Street SE, Grand Rapids, Michigan.

PURPOSE OF STUDY
The purpose of this study is to identify a relationship between time to peak torque of the hamstrings and anterior knee joint displacement. The isokinetic testing will be performed on the Biodex® machine. You will be asked to resist knee extension in 13 repetitions at two speeds. The anterior knee laxity will be assessed using the KT-1000®, performing a passive anterior drawer test. Subjects will be thirty athletes and thirty non-athletes between the ages of fourteen and nineteen. They must have no history of low back or lower extremity injury within the previous year. The knowledge obtained from this study will assist physical therapists, athletic trainers and coaches in planning programs for injury prevention and rehabilitation.

STUDY PROCEDURES
Should you choose to participate in this study you will be one of sixty participants. You will be asked to complete a pre-test questionnaire including personal information, medical history, medications, athletic participation, and current activity level. Exclusion criterion for this study include: (1) any back or lower extremity injury in the past year that prevented participation in practice, a game, or other activities for more than three days, (2) inability to obtain hip flexion of 90 degrees, knee flexion of 90 degrees and knee extension of 0 degrees, (3) any history of neuromuscular, rheumatological, or cardiovascular disease, (4) if subject is or suspects she may be pregnant.

Knee joint laxity will be assessed followed by a five minute warm-up on the Airdyne® exercise bike and stretching of the quadriceps femoris and hamstring muscles. Following the period of stretching, isokinetic testing will be performed. A cool down of three minutes on the Airdyne exercise bike will be required. A second measure of knee joint laxity will be performed after cool down is complete.

Page 1 of 3 Parent initials________Participant initials________

Anterior knee joint laxity will be assessed using the KT1000® arthrometer. This device will be used to determine the amount of movement the anterior cruciate ligament allows between the femur (thigh) and tibia (lower leg). The arthrometer will be strapped to your lower leg with a contact point at the patella. Laxity will be determined passively.

Isokinetic testing will be performed on the Biodex® System 2. Trial repetitions will precede data collection as well as a manual trial so that you understand the movement and resistance desired. Testing will include thirteen repetitions at two speeds, 90 and 150 degrees per second. Each testing segment will include two submaximal efforts and five maximal efforts, a one minute rest period, followed by five maximal efforts from which the data will be collected. A two minute rest will be observed between speeds.

Your participation in this study will require approximately one hour of your time.

RISKS, BENEFITS, PRECAUTIONS

At any time during the testing you may elect to discontinue the testing.

Eccentric contraction of the hamstrings is the focus of investigation in isokinetic testing. You may experience delayed onset of muscle soreness due to this activity.

Participation in this study does not preclude unpredictable risks that may result from stretching and exercise. If any risks are noted by researchers you will be informed of them and given the option of withdrawing from the study.

The results/explanation of strength testing and anterior tibial displacement will be provided to each participant.

PRIVACY

If you agree to participate in the study you will be assigned a testing number which will be used throughout the study ensuring anonymity and confidentiality to the extent limited by law. Data from this study will be available to researchers, Butterworth Hospital and the Food and Drug Administration.

If the results of this study are published in a professional journal or used for other educational purposes your identity will remain anonymous.

		Parent initials_______Participant initials_______

FINANCIAL COMPENSATION
In the event of resulting injury from testing, first aid treatment will be provided by researchers and/or physicians at the Butterworth Med Center. Butterworth Hospital may not be held liable for injuries and will not provide care without cost.

CONTACTS
This study is directed by Jolene Bennett MA, PT, ATC. If you have any questions she may be reached at Butterworth Rehabilitation Center (616) 391-7791.

The following is a contact person for information regarding your rights as a participant in this research:

Linda Pool
Butterworth Hospital
100 Michigan NE
Grand Rapids, MI 49503
(616) 391-1291

VOLUNTARY PARTICIPATION
Participation in this study is on a voluntary basis from which you may withdraw at any time during the testing. You will be provided a signed copy of this consent form.

STATEMENT OF OBTAINING INFORMED CONSENT
I acknowledge that I have read and have had my questions answered about the study and I voluntarily give my consent to participate in this study.

__________________________ ________________
Signature of participant Date

I acknowledge that I have read and have had my questions answered about the study and I give my parental consent, allowing my daughter/dependent to participate in this study.

__________________________ ________________
Signature of parent/guardian Date
(if participant is < 18 years old)

__________________________ ________________
Witness Date

Appendix D

Pre-test Questionnaire

Date:____________ Test#:_________________________

Subject'sName:____

Address:____

____

Age:_______ Date of Birth:_________________________

Last grade completed: 7 8 9 10 11 (Circle one)

Do you play basketball at any of the following levels:
(Circle all that apply)

Eighth grade Freshman JV Varsity yes or no?

If NO above, do you participate in other organized school/recreational sports or physical activities such as dance, karate, or gymnastics?

yes or no

If yes please describe____

____

School size Classification: A B C D (Circle one)

Have you experienced an injury to any of the following joints in the past one year that kept you out of practice, a game, or other physical activities for more than three days? (Circle *yes* or *no*)

A. foot	yes	no
B. ankle	yes	no
C. knee	yes	no
D. hip	yes	no
E. back	yes	no

Have you ever fractured either your legs or feet? Yes or No?

Have you ever had surgery on either knee? Yes or No?

Do you have previous experience with isokinetic testing? Yes or No?

Are you currently experiencing any medical condition/problem for which you have or have not seen a doctor? (Circle *Yes* or *No*)

Neuromuscular disease	yes	no
Joint/Rheumatological disease	yes	no
Heart/cardiovascular disease	yes	no
Pregnancy	yes	no
Other________________	yes	no

If yes, please explain ____

____

Did you pass your high school physical for the 1997-98 school year?

Yes or *No* or *Did not have a Physical* (Circle one)

Do you have regular menses? Yes or No?

Are you a smoker? Yes or No?

List any medications you currently take.________________________________

____

____

______________________ Participant signature

______________________ Parent/Guardian signature

______________________ Date

______________________ Date

Appendix E

Data Collection Sheet

Date:_____________ Test #:_____________________________________

Age:_____________ Date of Birth:__________________________________

Time in sport: NA In-season (beginning middle end) Post-season

Height:__________ Weight:__________

Leg dominance:____________
First leg tested ____________
KT-1000 passive anterior knee joint displacement data 1 (millimeters)

Right	_______	_______	_______	**Ave:**_______
Left	_______	_______	_______	**Ave:**_______

First leg tested __________
Biodex eccentric hamstring test data at 90°/sec
Time to peak torque (seconds)

	Right		**Left**
	_______		_______
Coefficient of Variance (CoV)	_______	CoV	_______

First leg tested __________
Biodex eccentric hamstring test data at 150°/sec
Time to peak torque (seconds)

	Right		**Left**
	_______		_______
CoV	_______	CoV	_______

First leg tested __________
KT-1000 anterior knee joint displacement data 2 (millimeters)

Right	_______	_______	_______	**Ave:**_______
Left	_______	_______	_______	**Ave:**_______

Appendix F

Instruction for Testing Joint Laxity

"This is a test of knee joint laxity. During most of the procedure you will be asked to simply relax. You will be instructed when active movement is required. If at any time you experience discomfort during the procedure please indicate to us and the test will be discontinued. This test will performed on both legs. Do you have any questions before we begin?"

1. Participant will lay supine on table with hands over mid section and head on pillow.
2. Place thigh support under both legs proximal to popliteal space; knee flexion should be between 20-35 degrees of flexion.
3. Place foot support under both feet distal to lateral malleolus.
4. Place thigh strap around thighs to prevent external rotation.
5. Position arthrometer on anterior aspect of tibia lining up joint line arrow with knee joint line.
6. Adjust and calibrate arthrometer according to KT1000® manual.
7. Tell participant *"The straps should be snug but not too tight" "Completely relax your leg and look up toward ceiling."*

Ensure relaxation by palpating quadriceps for contraction, oscillating calf, and checking tension in patellar tendon.

Proceed to passive drawer test.

"At this point I will apply some pressure to the instrument which you will feel in joint. Do you feel any discomfort? You will hear six successions of beeps as I apply pressure down through handle indicating the amount of force applied. Continue to remain relaxed as testing continues."

Repeat *"relax"* as often as necessary as tightening of musculature may skew results.

Perform sequence on contralateral limb.

Appendix G

Instruction for Isokinetic Testing

1. HELLO. I'M _____________.

2. THE NEXT PART OF THE TEST WILL BE OVER HERE.

3. THIS IS THE BIODEX MACHINE.

4. THIS MACHINE WILL BE MEASURING THE TIME IT TAKES YOUR HAMSTRING MUSCLES, WHICH ARE IN THE BACK OF YOUR LEG, TO REACH THEIR GREATEST FORCE.

5. YOU WILL BE SEATED THROUGHOUT ALL TESTING.

6. WE WILL SECURE YOU TO THE SEAT WITH THESE STRAPS:
    - ONE OVER YOUR THIGH
    - TWO ACROSS YOUR CHEST
    - AND ONE WILL ALSO GO AROUND YOUR WAIST.

7. THESE STRAPS ARE TO PREVENT YOU FROM USING OTHER MUSCLES TO HELP YOU DURING THE TEST.

8. THIS BAR HERE, THE KNEE ATTACHMENT, WILL MOVE UP AND DOWN. IT WILL STRAIGHTEN AND BEND YOUR KNEE. YOUR JOB WILL BE TO PULL AGAINST THE BAR WHEN IT STRAIGHTENS YOUR LEG.

9. DO YOU HAVE ANY QUESTIONS?

10. THIS IS ---------------. SHE WILL OPERATE THE COMPUTER.

11. THE COMPUTER COLLECTS ALL THE DATA FROM YOUR TEST.

12. WE WILL BE WORKING TOGETHER TO COORDINATE THE COMPUTER SETUP AND TEST INSTRUCTIONS. SO WE WILL BE TALKING TO ONE ANOTHER DURING THE TEST PROCESS.

13. PLEASE SEAT YOURSELF ON THE MACHINE AND WE WILL BEGIN.

14. WE NEED TO ADJUST THE SEAT, SO YOUR KNEE IS LINED UP WITH THIS BLACK KNOB.

15. WE ALSO NEED TO ADJUST THE BACK OF THE SEAT.

16. IF YOU'RE READY WE CAN PUT THE STRAPS ON NOW. THE STRAPS SHOULD BE SNUG BUT NOT TOO TIGHT.

17. YOU SHOULD BE ABLE TO BREATH COMFORTABLY. IF YOU FEEL COMFORTABLE WE CAN BEGIN THE PRACTICE WITHOUT THE KNEE ATTACHMENT.

18. I AM GOING TO STRAIGHTEN AND BEND YOUR LEG LIKE THE MACHINE IS GOING TO DO. JUST RELAX YOUR LEG.

19. I'M GOING TO ASK YOU TO CROSS YOUR ARMS AND HOLD ONTO THE CHEST STRAPS DURING THE TESTING OK?

20. DURING THE TEST, WHEN YOU FEEL THE BAR BEGIN TO STRAIGHTEN YOUR LEG WE WILL ASK YOU TO PULL AGAINST IT. **THE KEY IS NOT TO PULL AGAINST IT UNTIL YOU FEEL THE MOVEMENT.**

21. DON'T TRY TO PREPARE TO PULL. WAIT UNTIL YOU FEEL THE BAR MOVE AND THEN PULL AGAINST THE BAR THROUGHOUT THE ENTIRE MOTION.

22. NOW WE WILL PRACTICE LIKE YOU WILL BE DOING ON THE MACHINE. REALIZE YOU WILL BE ABLE TO STOP ME WHEN I STRAIGHTEN YOUR LEG BUT YOU WON'T BE ABLE TO STOP THE MACHINE.

23. LET'S TRY IT ONE TIME.

24. PULL AGAINST ME A LITTLE BIT AS I STRAIGHTEN YOUR LEG. PULL THE WHOLE TIME I AM STRAIGHTENING. RELAX ON THE WAY DOWN.

25. LETS TRY IT TWO MORE TIMES.

26. SO YOU UNDERSTAND WHAT WE ARE DOING WE WANT YOU TO KNOW THAT AS YOU RESIST THE STRAIGHTENING OF YOUR KNEE, YOUR HAMSTRING MUSCLES ARE LENGTHENING. THIS IS CALLED AN ECCENTRIC MUSCLE CONTRACTION. A CONCENTRIC CONTRACTION SHORTENS THE MUSCLE.

27. IN THIS TEST WE DON'T WANT YOU TO PREPARE BUT TO PULL AGAINST THE BAR ONCE YOU FEEL IT START TO STRAIGHTEN YOUR LEG.

28. DO YOU HAVE ANY QUESTIONS BEFORE WE GO ON?

29. OK! WE ARE GOING TO STRAP THE BOTTOM PAD ON YOUR LEG. WE ARE MEASURING TO MAKE SURE IT IS AT THE RIGHT HEIGHT ABOVE YOUR ANKLE. IS THE STRAP COMFORTABLE? CAN YOU MOVE YOUR FOOT UP AND DOWN?

30. BEFORE WE GO ON, I WANT TO SHOW YOU THIS RED BUTTON. IF AT ANY TIME YOU WANT TO DISCONTINUE PARTICIPATION IN THIS STUDY, FOR ANY REASON, HIT THAT RED BUTTON AND IT WILL IMMEDIATELY STOP THE MACHINE.

31. DO YOU HAVE ANY QUESTIONS BEFORE WE BEGIN THE TEST?

32. FIRST WE WILL SET THE LIMIT FOR HOW FAR YOUR LEG WILL GO UP AND DOWN. SEE HOW YOU CAN MOVE YOUR LEG FREELY? JUST RELAX WHILE I STRAIGHTEN IT OUT. DOES THAT FEEL OK? NOW I WILL BRING IT DOWN.

33. HOLD YOUR LEG UP AGAINST THAT BOTTOM STOP. THANK YOU.

34. NEXT THE MACHINE NEEDS TO WEIGH YOUR LEG SO JUST RELAX AS THE MACHINE STRAIGHTENS YOUR LEG.

35. NOW RELAX WHILE YOUR LEG GOES BACK DOWN.

36. WE ARE ABOUT TO START THE PRACTICE AND TESTING. YOU WILL DO THIS TWICE, ONCE FOR A SLOW SPEED AND ONCE FOR A FAST SPEED. THEN WE WILL SWITCH TO THE OTHER CHAIR TO TEST YOUR OTHER LEG.

37. REMEMBER TO KEEP YOUR ARMS CROSSED DURING THE TESTING.

38. NOW WE WILL DO THE SLOW SPEED PRACTICE . WE WANT YOU TO GIVE HALF EFFORT FOR THE FIRST TWO FOLLOWED BY FIVE MAXIMAL EFFORTS. **WHEN I SAY MAXIMAL, I MEAN AS HARD AND AS FAST AS YOU CAN.**

39. **REMEMBER THE KEY IS NOT TO PULL AGAINST THE BAR UNTIL YOU FEEL IT STRAIGHTENING YOUR LEG. ALWAYS RELAX ON THE WAY DOWN.**

40. READY?

41. DON'T PULL UNTIL YOU FEEL THE MACHINE BEGIN TO STRAIGHTEN YOUR LEG. PULL ALL THE WAY UP AND REST. THAT'S ONE SUBMAX. NOW TWO SUBMAX, REST. YOU ARE GOING TO DO 5 MAXIMAL TRIALS NOW. **DON'T START UNTIL YOU FEEL THE MACHINE MOVE YOU FIRST. PULL AS HARD AS YOU CAN ALL THE WAY UP AND RELAX ON THE WAY DOWN.** THAT'S ONE MAX, REST. TWO MAX, REST. THREE MAX, REST. FOUR MAX, REST. FIVE MAX AND REST.

42. YOU HAVE FINISHED THE PRACTICE FOR THE SLOW SPEED. NOW YOU GET A 0NE MINUTE REST BEFORE YOU DO THE ACTUAL TEST.

43. **YOU WILL RIDE THE FIRST ONE UP AND DOWN THEN THE 5 MAXIMAL EFFORTS WILL BEGIN.** THIS IS THE ACTUAL TEST WE WILL BE COLLECTING DATA ON. WE WILL NOT TALK YOU THROUGH THE TEST. JUST REMEMBER TO RIDE THE FIRST THEN START PULLING AGAINST THE MACHINE ON THE SECOND ONE. PULL WHEN YOU FEEL THE MACHINE BEGIN TO STRAIGHTEN YOUR LEG. REST ON THE WAY DOWN. **PLEASE CONCENTRATE AND GIVE YOUR BEST EFFORT.** DON'T WORRY ABOUT COUNTING. THE COMPUTER WILL COUNT FOR YOU.

44. DO YOU HAVE ANY QUESTIONS?

45. REMEMBER TO RELAX AND RIDE THE FIRST ONE AND START THE MAXIMAL EFFORTS ON THE SECOND ONE. **PULL AS HARD AND AS FAST AS YOU CAN.**

46. ARE YOU READY? OK THEN WE WILL BEGIN.

47. YOU ARE DONE WITH THE SLOW SPEED. NOW WE WILL GO ON TO THE FAST SPEED.

48. YOU HAVE A 2 MINUTE REST BEFORE WE GO ON SO JUST RELAX.

49. WE WILL NOW DO THE PRACTICE FOR THE FAST SPEED. IT IS THE SAME AS BEFORE: 2 HALF EFFORTS, FOLLOWED BY 5 MAXIMAL TRIALS.

50. CROSS YOUR ARMS AGAIN AND HOLD ONTO THE CHEST STRAPS.

51. **THE BAR WILL MOVE MUCH QUICKER NOW** BUT DON'T WORRY, YOU WILL DO JUST FINE.

52. PULL WITH 1/2 EFFORT WHEN YOU FEEL THE MACHINE BEGIN TO STRAIGHTEN YOUR LEG. RELAX. THAT WAS SUBMAX 1. TWO SUBMAX. THE NEXT FIVE WILL BE MAXIMUM EFFORT. THAT'S ONE MAX. PULL AGAINST THE MACHINE ONLY WHEN IT MOVES YOUR LEG, NOT BEFORE. TWO MAX. RELAX. THREE MAX. RELAX. FOUR MAX. RELAX. FIVE MAX, AND RELAX.

53. YOU HAVE FINISHED THE PRACTICE FOR THE FAST SPEED. YOU WILL NOW HAVE A ONE MINUTE REST BEFORE DOING THE ACTUAL TEST.

54. **YOU WILL RIDE THE FIRST ONE UP AND DOWN THEN THE 5 MAXIMAL EFFORTS WILL BEGIN.** THIS IS THE ACTUAL TEST WE WILL BE COLLECTING DATA ON. WE WILL NOT TALK YOU THROUGH THE TEST. JUST REMEMBER TO RIDE THE FIRST THEN START PULLING AGAINST THE MACHINE ON THE SECOND ONE. PULL WHEN YOU FEEL THE MACHINE BEGIN TO STRAIGHTEN YOUR LEG. REST ON THE WAY DOWN. **PLEASE CONCENTRATE AND GIVE YOUR BEST EFFORT.** DON'T WORRY ABOUT COUNTING. THE COMPUTER WILL COUNT FOR YOU.

55. DO YOU HAVE ANY QUESTIONS?

56. REMEMBER TO RELAX AND RIDE THE FIRST ONE AND START THE 5 MAXIMAL EFFORTS ON THE SECOND ONE. PULL AS HARD AND AS FAST AS YOU CAN WHEN THE BAR BEGINS TO MOVE.

57. ARE YOU READY? OK THEN WE WILL BEGIN.

58. YOU ARE DONE WITH THE FAST SPEED. NOW WE WILL GET YOU UNSTRAPPED AND SWITCH TO THE OTHER SIDE.

59. ARE YOU OK WITH EVERYTHING SO FAR?

60. PLEASE SEAT YOURSELF ON THE MACHINE AND WE WILL GET STARTED.

61. WE NEED TO ADJUST THE SEAT, SO YOUR KNEE IS LINED UP WITH THIS BLACK KNOB.

62. WE ALSO NEED TO ADJUST THE BACK OF THE SEAT.

63. IF YOU'RE READY WE CAN PUT THE STRAPS ON NOW. THE STRAPS SHOULD BE SNUG BUT NOT TOO TIGHT.

64. IS THE STRAP COMFORTABLE AROUND YOUR LEG? CAN YOU MOVE YOUR FOOT UP AND DOWN?

65. OK, IF YOU'RE COMFORTABLE WE CAN BEGIN.

66. NEXT THE MACHINE NEEDS TO WEIGH YOUR LEG SO JUST RELAX AS THE MACHINE STRAIGHTENS YOUR LEG.

67. NOW RELAX WHILE YOUR LEG GOES BACK DOWN.

68. WE ARE ABOUT TO START THE PRACTICE AND TESTING. YOU WILL DO THIS TWICE, ONCE FOR A SLOW SPEED AND ONCE FOR A FAST SPEED.

69. REMEMBER TO KEEP YOUR ARMS CROSSED DURING THE TESTING.

70. NOW WE WILL DO THE SLOW SPEED PRACTICE . IT WILL BE THE SAME AS BEFORE: 2 HALF EFFORTS, FOLLOWED BY 5 MAXIMAL REPETITIONS.

71. **REMEMBER THE KEY IS NOT TO PULL AGAINST THE BAR UNTIL YOU FEEL IT STRAIGHTENING YOUR LEG. ALWAYS RELAX ON THE WAY DOWN.**

72. READY?

73. DON'T PULL UNTIL YOU FEEL THE MACHINE BEGIN TO STRAIGHTEN YOUR LEG. PULL ALL THE WAY UP AND REST. THAT'S ONE SUBMAX. NOW TWO SUBMAX, YOU ARE GOING TO DO 5 MAXIMAL TRIALS NOW. **DON'T START UNTIL YOU FEEL THE MACHINE MOVE YOU FIRST. PULL AS HARD AND FAST AS YOU CAN, RELAX ON THE WAY DOWN.** THAT'S ONE MAX, REST. TWO MAX, REST. THREE MAX, REST. FOUR MAX, REST. FIVE MAX AND REST.

74. YOU HAVE FINISHED THE PRACTICE FOR THE SLOW SPEED. NOW YOU WILL HAVE A ONE MINUTE REST BEFORE DOING THE ACTUAL TEST.

75. **YOU WILL RIDE THE FIRST ONE UP AND DOWN THEN THE 5 MAXIMAL EFFORTS WILL BEGIN.** THIS IS THE ACTUAL TEST WE WILL BE COLLECTING DATA ON. WE WILL NOT TALK YOU THROUGH THE TEST. JUST REMEMBER TO RIDE THE FIRST THEN START PULLING AGAINST THE MACHINE ON THE SECOND ONE. PULL WHEN YOU FEEL THE MACHINE BEGIN TO STRAIGHTEN YOUR LEG. REST ON THE WAY DOWN. **PLEASE CONCENTRATE AND GIVE YOUR BEST EFFORT.** DON'T WORRY ABOUT COUNTING. THE COMPUTER WILL COUNT FOR YOU.

76. DO YOU HAVE ANY QUESTIONS?

77. REMEMBER TO RELAX AND RIDE THE FIRST ONE AND START THE 5 MAXIMAL EFFORTS ON THE SECOND ONE. **PULL AS HARD AND AS FAST AS YOU CAN.**

78. ARE YOU READY? OK THEN WE WILL BEGIN.

79. YOU ARE DONE WITH THE SLOW SPEED. NOW WE WILL GO ON TO THE FAST SPEED.

80. YOU HAVE A 2 MINUTE REST BEFORE WE GO ON SO JUST RELAX.

81. WE WILL NOW DO THE PRACTICE FOR THE FAST SPEED. IT IS THE SAME AS BEFORE: 2 HALF EFFORTS, FOLLOWED BY 5 MAXIMAL TRIALS.

82. CROSS YOU ARMS AGAIN AND HOLD ONTO THE CHEST STRAPS.

83. **THE BAR WILL MOVE MUCH QUICKER NOW** BUT DON'T WORRY, YOU WILL DO JUST FINE.

84. PULL WITH 1/2 EFFORT WHEN YOU FEEL THE MACHINE BEGIN TO STRAIGHTEN YOUR LEG. RELAX. THAT WAS SUBMAX 1. TWO SUBMAX. THE NEXT 5 WILL BE MAXIMAL EFFORTS. THAT'S ONE MAX. PULL AGAINST THE MACHINE ONLY WHEN IT MOVES YOUR LEG, NOT BEFORE. TWO MAX. RELAX. THREE MAX. RELAX. FOUR MAX. RELAX. FIVE MAX AND RELAX.

85. YOU HAVE FINISHED THE PRACTICE FOR THE FAST SPEED. YOU WILL NOW HAVE A ONE MINUTE REST BEFORE DOING THE ACTUAL TEST.

86. **YOU WILL RIDE THE FIRST ONE UP AND DOWN THEN THE 5 MAXIMAL EFFORTS WILL BEGIN.** THIS IS THE ACTUAL TEST WE WILL BE COLLECTING DATA ON. WE WILL NOT TALK YOU THROUGH THE TEST. JUST REMEMBER TO RIDE THE FIRST THEN START PULLING AGAINST THE MACHINE ON THE SECOND ONE. PULL WHEN YOU FEEL THE MACHINE BEGIN TO STRAIGHTEN YOUR LEG. REST ON THE WAY DOWN. **PLEASE CONCENTRATE AND GIVE YOUR BEST EFFORT**. DON'T WORRY ABOUT COUNTING. THE COMPUTER WILL COUNT FOR YOU.

87. DO YOU HAVE ANY QUESTIONS?

88. REMEMBER TO RELAX AND RIDE THE FIRST ONE AND START THE 5 MAXIMAL EFFORTS ON THE SECOND ONE. **PULL AS HARD AND FAST AS YOU CAN.**

89. ARE YOU READY? OK THEN WE WILL BEGIN.

90. YOU ARE DONE WITH THE BIODEX TESTING. WE WILL GET YOU UNSTRAPPED AND YOU CAN GO OVER TO THE BIKE TO PERFORM THE COOL DOWN. THANKS FOR YOUR EFFORT DURING THESE TESTS TODAY.

APPENDIX H

STRETCHING (93, 94)

1. GOALS FOR STRETCHING

A. Increase general flexibility of quadriceps and hamstring muscle groups prior to eccentric isokinetic testing.

B. Prevent or minimize the risk of musculocutaneous injuries related to eccentric exercise.

2. STRETCHING PROCEDURE

A. Standing Ballet Stretch for Quadriceps

a. Stand on left leg.

b. Use left arm to balance against chair/wall/plinth.

c. Bend right leg back and pull right ankle up toward right buttock.

d. With right hand, pull up on ankle so that the knee points down and until you feel a point of tension, a sense of pulling or tightness of structures being stretched, but, not pain.

e. Spend 15 seconds in an easy stretch. Silently count the seconds for each stretch.
No bouncing. Relax as you hold the stretch. Do not hold your breath.

f. The feeling of tension should decrease as you hold the position. If it does not, decrease back off slightly and find an amount of tension that is comfortable for you. The easy stretch lessens muscular tightness and prepares the tissues for the developmental stretch.

g. Move slowly into the developmental stretch. Move a fraction of an inch more into the stretch, until you again feel a mild tension. Hold for 15 seconds. Tension should decrease; if does not, back off the stretch slightly and find an amount of tension that is comfortable for you. The developmental stretch increases flexibility.

h. Repeat on the other side.

B. Seated Pike Hamstring Stretch for Hamstrings

a. Sit with legs outstretched, ankles together, toes pointed upwards.

b. Place hands on floor by thighs.

c. Looking straight ahead, gently slide hands forward.

d. Keeping back and knees straight, try to bring chest as close as possible to knees and thighs.

e. Go to the point of mild tension, but no pain, behind the knees and thighs.

f. Spend 15 seconds in an easy stretch. Silently count the seconds for each stretch.
No bouncing. Relax as you hold the stretch. Do not hold our breath.

g. The feeling of tension should decrease as you hold the position. If it does not, decrease, back off the stretch slightly and find an amount of tension that is comfortable for you. The easy stretch lessens muscular tightness and prepares the tissues for the developmental stretch.

h. Move slowly into the developmental stretch. Move a fraction of an inch more into the stretch, until you again feel a mild tension. Hold this position for 15 seconds. Tension should decrease; if it does not decrease, back off the stretch slightly and find an amount of tension that is comfortable for you. The developmental stretch increases flexibility.

C. Gastrocnemius Stretch

a. Use both arms to balance against chair/wall/plinth.

b. Keeping your back straight, with your heel on the floor and your toes turned slightly outward, lean into the chair/wall/plinth until you feel a point of tension, a sense of pulling or tightness of structures being stretched, but, not pain.

c. Spend 15 seconds in an easy stretch. Silently count the seconds for each stretch.
No bouncing. Relax as you hold the stretch. Do not hold your breath.

d. The feeling of tension should decrease as you hold the position. If it does not decrease, back off slightly and find an amount of tension that is comfortable for you. The easy stretch lessens muscular tightness and prepares the tissues for the developmental stretch.

e. Move slowly into the developmental stretch. Move a fraction of an inch more into the stretch, until you again feel a mild tension. Hold for 15 seconds. Tension should decrease; if it does not, back off the stretch slightly and find an amount of tension that is comfortable for you. The developmental stretch increases flexibility.

f. Repeat stretch on same side a second time.

g. Repeat stretch on the other side.

APPENDIX I

LETTER OF VOLUNTEER PARTICIPATION

This is to verify that ______________________________ participated as a volunteer subject in the physical therapy masters degree research project entitled **THE RELATIONSHIP OF ECCENTRIC HAMSTRINGS TIME TO PEAK TORQUE AND ANTERIOR KNEE JOINT DISPLACEMENT.** Total time spent was ______________ hours. This study was approved by both Butterworth Hospital and Grand Valley State University.

Julie Clark S.P.T   Maureen Godfrey S.P.T.   Noreen LaBorde S.P.T.