ANAEROBIC FATIGUE AND ITS EFFECT ON KINEMATIC AND KINETIC VARIABLES ASSOCIATED WITH IMPACT DURING VERTICAL JUMPING

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DEDICATION

This work is dedicated to my wonderful and loving wife, Michelle Ann Robinson. She has been by my side from the beginning and she has never let the dream die. During periods of stress and self-doubt, she has always provided an ear to listen and a reassuring hug. She has provided me with two beautiful children, Kelsey Elise and Brodie Allan, that I love dearly and are the lights of my life. I hope in the future, that my children will realize the hard work and dedication that their father endured.

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Kinematic and kinetic variables associated with impacts during non-fatigued and fatigued vertical jumping was examined. The purpose of this study was to investigate fatigue and its effect on anterior/posterior shear forces, compression forces, and flexion/extension moments at the ankle, knee, and hip during an impact from vertical jumping. Twenty unskilled untrained females were tested isokinetically at 60 and 180 deg/s for leg extension and flexion strength. Leg strength was examined then retested two days later immediately following the Wingate Anaerobic Power test. This data was compared and used to quantify the amount of fatigue that would occur following the Wingate test. Non-fatigued and fatigued conditions were compared and significant differences ($p < .01$) were present for peak torque at 60 and 180 deg/s during both leg extension and flexion. Significant differences ($p < .01$) also occurred during the 25th repetition of leg extension and flexion at 180 deg/s. Non-fatigued and fatigued vertical jumps were performed approximately one week after the isokinetic leg testing.

Non-fatiqued countermovement vertical jumps were performed first with the fatigued jumps occurring second. The fatigued jumps were conducted immediately following the Wingate test. No differences were present for anterior/posterior shear forces, compression forces, and flexion/extension moments for the ankle, knee, and hip. There was a significant decrease (p <.01) in vertical jump height. It was concluded that kinetic changes in the joint did not occur because of a decrease in jump height. This was attributed to the lower extremity muscles being fatigued and as a result, the lower extremity muscles were unable to produce enough force to displace the body of the individual into the air for the same distance.

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CHAPTER I

INTRODUCTION

Recreational and elite athletes perform jumps in numerous sport activities such as volleyball, basketball, football, and gymnastics. Other activities such as dance and aerobic dance contain a jumping component. In each of these activities, the performer jumps, becomes airborne, and eventually must return to the ground. The return to the ground is commonly called an impact. During this impact, the body must react to the force generated by the acceleration of the body toward the ground during the landing. The force experienced during landing is absorbed by the muscles, ligaments, and bones of the lower extremities. This force absorption may be inconsequential or may result in an injury to the performer.

In a survey of 76 female basketball players, injuries were documented for a 30-month period. Seventy-two percent of all injuries occurred to the knee and 58% of all injured players were landing from a jump at the time of their reported injury (Gray et al., 1985). Gray et al. (1985) concluded that weak quadricep and hamstring muscles may have been a possible factor contributing to the joint laxity and instability. Many other researchers (Henry, Lareau, & Neigut, 1982; Zelisko, Noble, & Porter, 1982) have reported similiar injury sites during basketball but did not document the cause of the injury. However, the assumption was made that the landings were the primary cause of the injuries. Zelisko et al. (1982) examined the injuries sustained by men and women professional basketball players. The body part most frequently injured by players on both teams was the ankle followed by the knee. Women had 1.4 times as many knee injuries as the men. It was postulated that the lack of strength conditioning of the women may have contributed to weaker quadricep and hamstring muscles which provide dynamic stability to the passive protection offered by ligamentous structures at the ankle and knee joints.

Henry et al. (1982) reviewed 7 years of medical injuries to players of a professional basketball team. It was observed that 69% of all basketball players were injured and that 94% of all games missed were a result of ankle and knee injuries. Sixty percent of these injuries occurred during the 2nd and 4th periods of games. This may support the idea that weak and fatigued muscles of the lower extremities may contribute to the increased chance of injury of the ankle and knee during the impact phase of a jump.

Another area of concern is hip pain associated with repeated impacts. Fullerton and Snowdy (1988) reported a high incidence of femoral neck stress fractures in military personel during basic training at Infantry and Officers Training School. The soldiers participated in a 14-week basic training course with an increase in intensity and a change in the type of training occurring at the 6th and 8th week. The increase in training progressed from marching to running with increases occuring in the weekly training mileage. Following the increased training, there was an increase in the reported incidence of hip pain. The investigators attributed this to muscle fatigue and the subsequent loss of the muscles' ability to absorb shock during an impact condition. It was also postulated that this increased the compression loading and shear forces on the femoral neck. Fullerton (1990) also examined athletes and reported that at the onset of training or near the time of a significant change in the activity intensity, there was an increase in the reported incidence of hip pain. Muscle fatigue and the loss of the muscles ability to absorb force during impacts were thought to be responsible.

As a result of these findings, two questions were raised: (a) How do the lower extremities absorb ground reaction forces during impact from a vertical jump; and (b) How does fatigue change the body's ability to attenuate the forces that are generated during that impact?

Purpose of the Study

The purpose of this study was to compare the differences between selected mechanical parameters in vertical jumping in both a non-fatigued and fatigued state. More specifically, the purpose of the study was to investigate the changes in anterior/posterior shear forces; compression force; and flexion/extension moments at the ankle, knee, and hip during impacts from a vertical jump in both a non-fatigued and fatigued state.

Problem of the Study

The problem of the study was to analyze lower extremity biomechanical variables during vertical jumping in a non-fatigued and fatigued state. The participants consisted of 20 unskilled untrained college-aged females, 18 to 35 years with no history of orthopaedic problems to the ankle, knee, or hip joints.

Each participated in three testing sessions. The first session was used to obtain health history information, anthropometric measures, and to familiarize the participant with the cycle ergometer, vertical jumping, and testing protocol. Muscular strength and muscular endurance were assessed by testing lower extremity extension and flexion isokinetically.

Following muscular strength and endurance testing, a Wingate anaerobic power test was performed. This was immediately followed by lower extremity extension and flexion isokinetic testing. These data were used to substantiate the amount of fatigue that occurred to each participant following the Wingate test.

Vertical jumping during a non-fatigued state and fatigued state was conducted during the third session. The non-fatigued vertical jump was conducted first with the fatigued jump occurring second. Each jump was performed with the hands on the hips. Each participant performed a self-selected countermovement before each jump. The fatigued jump was preceeded by a Wingate anaerobic test with the jump being performed immediately following the Wingate test. During this session, the movement patterns of the vertical jump were recorded by the Peak5 video analysis system, and the ground reaction forces were determined through the utilization of an AMTI force platform. Shear and compression joint forces and flexion/extension moments at the ankle, knee, and hip were calculated from anthropometric, video, and force data.

Comparison of the joint forces and joint moments that occurred during the landing phase of the vertical jump in both a non-fatigued and fatigued state followed. A multivariate Hotelling's T^2 with repeated-measures was used to analyze the impact forces at the ankle, knee, and hip. Vertical jump height during a non-fatigued and fatigued condition was analyzed with a paired t-test and comparison of torque production that occurred during lower extremity isokinetic testing in both a non-fatigued and fatigued state was also analyzed by a paired *t*-test.

Hypotheses

The following hypotheses were tested at the .01 level of significance:

1. There is no difference in peak knee extensor strength during a non-fatigued and fatigued condition at 60 deg/s.

2. There is no difference in peak knee flexor strength during a non-fatigued and fatigued condition at 60 deg/s.

3. There is no difference in peak knee extensor strength during a non-fatigued and fatigued condition at 180 deg/s.

4. There is no difference in peak knee flexor strength during a non-fatigued and fatigued condition at 180 deg/s.

5. There is no difference in knee extensor muscular endurance (25th repetition) during a non-fatigued and fatigued condition at 180 deg/s.

6. There is no difference in knee flexor muscular endurance (25th repetition) during a non-fatigued and fatigued condition at 180 deg/s.

7. There is no difference in knee extensor muscular endurance (50th repetition) during a non-fatigued and fatigued condition at 180 deg/s.

8. There is no difference in knee flexor muscular endurance (50th repetition) during a non-fatigued and fatigued condition at 180 deg/s.

9. There is no difference in the compression joint reaction force, posterior/anterior shear joint reaction force, and flexion/extension moment at the ankle between non-fatigued and fatigued subjects performing vertical jumps.

10. There is no difference in the compression joint reaction force, posterior/anterior shear joint reaction force, and flexion/extension moment at the knee between non-fatigued and fatigued subjects performing vertical jumps.

11. There is no difference in the compression joint reaction force, posterior/anterior shear joint reaction force, and flexion/extension moment at the hip between non-fatigued and fatigued subjects performing vertical jumps.

Operational Definitions

The following definitions have been established for use in this study.

Anterior/posterior joint reaction forces: A force that travels in a horizontal direction and it travels along the y-axis.

Compression joint reaction forces: A force that travels in a vertical direction and travels along the z-axis.

<u>Countermovement vertical jump</u>: A jump performed with a self-selected preparatory bend in the knees which is immediately followed by a vertical jump.

<u>Fatigue:</u> The inability to maintain the required or expected force leading to the reduced performance of a given task (Sahlin, 1992).

<u>Fatigue Index:</u> A numerical value that represents the amount of power reduction that occurs during the Wingate Anaerobic Power Test. It is determined by dividing the least amount of pedal revolutions that occur during a five second period by the peak amount of pedal revolutions that occur during a five second period. This will then be subtracted from one and expressed as a percentage.

<u>Flexion/Extension moment:</u> A force that produces a moment about the x-axis with the axis located at the joint center of the ankle, knee, and hip.

<u>Jump height:</u> The difference between the greater trochanter height at a standing position and the greater trochanter at the maximum jump height. This will be measured in cm during both a non-fatigued and fatigued condition.

<u>Mechanical work:</u> The application of force through a distance (Winter, 1988).

<u>Moment:</u> A force that produces a rotary motion about a point or axis.

<u>Non-fatigued participants:</u> Individuals who have not participated in any aerobic and/or anaerobic training or exercise testing for the previous 48 hours prior to the testing session.

<u>Peak torque:</u> The maximum amount of torque produced during one of the four maximal voluntary contractions performed during isokinetic testing at 60 deg/s.

<u>Thornstensson and Karlsson Analysis:</u> The average peak torque of contractions 48-50 divided by the average peak torque of contractions 1-3 and expressed as a percentage (Thornstensson & Karlsson, 1976). The 50 isokinetic contractions were performed at 180 deg/s. This analysis procedure was modified by using the average torque values of contractions 48-50 and comparing the values in both a non-fatigued and fatigued state.

<u>Unskilled participants:</u> Individuals who have not participated in high school or collegiate athletic events involving a vertical jumping component.

<u>Untrained:</u> Individuals who participate in physical activity on the average of 1 day per week or less.

<u>Wingate Anaerobic Power Test:</u> A 30-s supramaximal cycle ergometer test with a resistance of 0.09 kg/kgBW. The Wingate test was used to fatigue the working muscles that provide stability for the ankle, knee, and hip (Bar-Or, 1987).

Delimitations

This study was subject to the following delimitations.

1. Twenty individuals were randomly selected from a pool of students from Texas Woman's University.

2. Wingate Anaerobic Power Test was used to produce fatigue rather than an athletic event with vertical jumping as one of its components.

3. Age, gender, skill, and training level of the participants were pre-determined.

4. Laboratory observations were used for data collection rather than actual observations of vertical jumping during athletic events.

5. All body segments were assumed to be rigid.

6. Joints were considered to be hinge or ball and socket joints.

7. Joint friction was assumed to be negligible.

8. The length of each segment remains constant during the movement.

Limitations

The study was subject to the following limitations.

1. The movement of the markers attached to the skin could have caused inaccurate coordinate readings.

2. The ability of the investigator to correctly locate anatomical landmarks of body segments could be a limitation.

3. The joint centers were estimated using a series of prediction equations.

4. The reliability of the investigator when collecting anthropometric measurements of the participants could be a limitation.

5. The relationship between anaerobic fatigue and alterations in impact forces associated with countermovement vertical jumping may be limited to this lab situation.

CHAPTER II

REVIEW OF THE RELATED LITERATURE

The purpose of this study was to compare the differences between selected mechanical parameters during impact from vertical jumping in both a non-fatigue and fatigued state. The sections of this review include: (a) Supportive Structures of the Ankle, Knee, and Hip, (b) Energy Systems, (c) Fatigue, (d) Wingate Anaerobic Power Test, (e) Isokinetic Testing, (f) Impacts Associated with Countermovement Vertical Jumps (CMJ), and (g) Summary.

Supportive Structures of the Ankle, Knee, and Hip

The joints of the lower extremities (hip, knee, and ankle) are unlike the joints that are associated with the upper extremities. The major function of the upper extremity joints is manipulation whereas the lower extremity function is weight-bearing. The lower extremity joints must support the weight of the head, upper extremities, and the trunk. The lower extremity joints also provide mobility by allowing movement about the joint when forces are generated by the surrounding musculature. A review of the ligamentous and muscle tissues that provide support and mobility for the hip, knee, and ankle follow.

The Hip

The hip joint is the area of interface between the pelvis and the femur. The socket of the hip joint is located on the pelvis and is constructed in such a way as to grasp the head of the femur (Gray, 1977). The motion allowed by the hip are flexion, extension, and hyperextension in the sagittal plane, abduction and adduction in the frontal plane, and to a lesser extent external and internal rotation in the transverse plane.

The main ligaments that connect the head of the femur to the pelvis are the iliofemoral, pubofemoral, and ischiofemoral ligaments. The iliofemoral ligament is shaped like the inverted letter Y. The apex of the ligament is attached to the anterior iliac spine and the two arms of the Y attach to the greater trochanter and lesser trochanter of the femur. The pubofemoral ligament arises from the anterior aspect of the pubic ramus and passes to the anterior surface of the intertrochanteric fossa. The ischiofemoral ligament attaches to the posterior surface of the pelvis and spirals around the femoral neck (Norkin & Levangie, 1988).

The iliofemoral ligament is the strongest ligament and limits hip hyperextension. The pubofemoral ligament limits hip abduction and extension and the ishiofemoral ligment also limits hip hyperextension (Norkin & Levangie, 1988).

The muscles surrounding the hip joint are divided into two categories: flexors and extensors. The hip flexors consist of eleven muscles: iliopsoas (psoas major and iliacus), pectineus, tensor fasciae latae, adductor brevis, rectus femoris, sartorius, adductor magnus, adductor longus, and the gracilis with the rectus femoris, sartorius, and gracilis being the only two-joint muscles. The hip extensors consist of seven muscles, four are one-joint muscles and the remaining three are two-joint muscles. The one-joint muscles are the gluteus maximus, gluteus minimus, posterior fibers of the gluteus medius, and the superior fibers of the adductor magnus. The two-joint muscles, commonly called the hamstring group, are the long head of the biceps femoris, semitendinosus, and semimembranosus. These muscles orginate above the hip and descend to below the knee and are the the muscles that extend the hip and flex the knee.

The major functions of the muscles and ligaments of the hip are to provide stability and support to the pelvis which in turn supports the upper portion of the body (Norkin & Levangie, 1988). In order for stability to occur, the hip and pelvis must work in conjunction with the lumbar spine. The supportive musculature is relatively inactive during upright stance but when the line of gravity is anterior to the hip joint, the hamstrings and gluteus maximus are required to prevent anterior tilting of the pelvis (Nordin & Frankel, 1989). This movement in the sagittal plane occurs during vertical jumping, meaning that the hamstrings and the gluteus maximus play an important role in preventing excessive anterior tilting of the pelvis.

The Knee

The knee is a complex system of ligaments and muscles that provides stability and mobility between the two largest bones in the body, the femur and tibia. In addition to providing mobility and stability, the knee also absorbs shock during dynamic situations (Lees, 1981; Mizrahi & Susak, 1982)

The ligaments and muscles of the knee are categorized as static or dynamic stabilizers. The ligaments of the knee provide static stability. The primary medial-lateral static stabilizers are the medial and lateral collateral ligaments. The medial collateral ligament attaches to the medial aspect of the femoral epicondyle and inserts into the medial aspect of the proximal tibia. The lateral collateral ligament attaches to the lateral femoral epicondyle and inserts into the head of the fibula.

The anterior-posterior static stabilizers consist primarily of the cruciate ligaments. The anterior cruciate ligament attaches to the anterior surface of the tibia and arises superiorly and posteriorly to attach to the posterior part of the lateral femoral condyle. The posterior cruciate ligament arises from the posterior aspect of the tibia and inserts anteriorly to the medial femoral epicondyle (Norkin & Levangie, 1988).

The dynamic stabilizers consist of flexor and extensor muscles that not only stabilize the knee during movement but also provide the mechanism for force production that causes lower extremity mobility. The flexors of the knee consist of the hamstring group (semitendinosus, semimembranosus, and biceps femoris) and the sartorius, gracilis, and gastrocnemius. All of the flexor muscles are two-joint muscles. The semitendinosus, gracilis, and sartoris join tendons to form the pes anserinus. This tendon attaches to the anterior medial surface of the tibial shaft posterior to the tibial tuberosity. The semimembranosus also attaches to this area and in conjunction with the pes anserinus provide medial stability to the knee. Lateral stability is provided by the biceps femoris and popliteus muscles. The biceps femoris inserts on the lateral epicondyle of the tibia and the head of the fibula. The popliteus is a small muscle that originates on the posterior side of the lateral epicondyle of the femur and crosses posteriorly to attach to the medial aspect of the tibia. The major function of the popliteus is to unlock the knee during the initial phase of movement (Norkin & Levangie, 1988).

The gastrocnemius and plantaris are the only muscles that extend from above the knee to below the ankle. The gastrocnemius acts in conjunction with the biceps femoris, semimembranosus, and popliteus to provide posterior stability to the knee. Anterior stability is provided primarily by the patella and by the extensor retinaculum (Norkin & Levangie, 1988).

The quadricep muscle group is the primary extensor of the knee. This muscle group is comprised of the rectus femoris, vastus intermedius, vastus lateralis, and vastus medialis. The rectus femoris is the only portion of the quadriceps that crosses two joints. The rectus femoris originates on the anterior inferior spine of the ilium while the other three originate on the anterior femur and attach to the base of the patella. The vastus medialis and vastus lateralis also insert directly into the medial and lateral aspects of the patella (Norkin & Levangie, 1988).

The quadricep group provides extension at the knee by concentric contraction and controlled flexion by eccentric contraction (McNitt & Gray, 1989). This group also provides an even distribution of force on the articular cartilage by controlling patellar tracking (Nordin & Frankel, 1989).

During relaxed upright standing, the quadricep muscles provide minimal force for support because the center of gravity of the body is above the knee. During dynamic activities, such as jumping, knee flexion increases and the center of gravity shifts away from the midline of the body. The quadriceps group must provide greater force production to stabilize the knee. When this occurs, the joint reaction force becomes greater (McNitt & Gray, 1989). This places stress on the articular cartilage and menisci. Acute or chronic stresses may be harmful to both the articular cartilage and menisci of the knee (Nordin & Levangie, 1988).

The Ankle

The ankle joint complex is composed of three joints; the tibiotalar, fibulotalar, and distal tibiofibular (Gross & Nelson, 1998). These joints have a dual role. The first function is to be rigid enough for stability by providing support for the body in static posture and by acting as a lever for push-off during movement. The second function is to be flexible enough to absorb the shock during dynamic activities (Nordin & Frankel, 1989). The dorsiflexors act as a damping mechanism for the absorption of force during vertical jumping (Gross & Nelson, 1988). These authors go on to report that jumpers who make heel contact first produce 22% higher vertical ground reaction forces than jumpers who landed with metatarsal contact first.

The ligaments of the tibiofibular joint are stabilizing fibers that run oblique for a short distance between the distal protion of the tibia and fibula. They consist of the crural tibiofibular interosseous and the anterior posterior tibiofibular ligaments (Nordin & Frankel, 1989).

The ligaments that provide stability for the remaining ankle joint are the medial and lateral collateral ligaments. The medial ligament is a fan shaped ligament that arises from the borders of the tibial malleolus and inserts on the anterior portion of the navicular, on the talus, and on the distal and posterior portion of the calcaneous. This ligament provides medial support. The lateral ligament consists of three bands; the anterior and posterior talofibular, and the calcaneofibular ligaments. These ligaments provide lateral support. The lateral collateral ligaments are much smaller and weaker than the medial ligament making these ligaments more prone to injury (Norkin & Levangie, 1988).

The range of motion of the ankle joint is primarily restricted to plantar flexion and dorsiflexion. Medial and lateral rotation as well as pronation and supination are restricted by the medial and lateral collateral ligaments. The muscles that control movement are classified according to function; plantar flexors and dorsiflexors. The primary plantar flexors are the gastrocnemius and soleus. The gastrocnemius arises from two heads on the condyles of the femur and inserts via the calcaneal (Achilles) tendon to the calcaneous. Other less prominent plantar flexors are the flexor digitorum longus, tibialis posterior, and flexor hallicus longus. The prominent dorsiflexors are the tibialis anterior, extensor digitorum longus, extensor hallucis longus and peroneus tertius. These muscles provide limited stability for the ankle and are able to generate force for mobility (Norkin & Levangie, 1988).

Energy Systems

Energy can be defined as the capacity or ability to perform work (Fox, Bowers, & Foss, 1993; McArdle, Katch, & Katch, 1986). Chemical energy is derived from food which in turn fuels the body when performing mechanical work. Mechanical work is defined as the application of force through a distance (Winters, 1988). Mechanical work is performed by the contraction of muscles and the subsequent production of force. The purpose of this section is to briefly review the different energy systems within the body and their role in energy production during certain activities.

Chemical energy liberated during the breakdown of food is not directly used to perform work. It is used to produce another chemical compound called adenosine triphosphate (ATP). ATP is utilized for all the energy requiring processes of the cell. ATP is made up of adenosine and three phosphate groups. The two terminal phosphate groups are called high-energy bonds. These bonds can be broken down in the presence of water through a process called hydrolysis. During hydrolysis, the outermost phosphate bond is broken and energy is released with adenosine diphosphate (ADP) and an inorganic phosphate being formed (Fox, Bowers, & Foss, 1993).

Once the ATP stored in the muscles is broken down, it must be resynthesized. This is accomplished by three common energy-yielding systems: (A) the ATP-PC or phosphagen system, (B) the anaerobic glycolysis system, and (C) the oxidative system. The oxidative system consists of two parts: the oxidation of carbohydrates (aerobic glycolysis), and the oxidation of fatty acids and amino acids.

The ATP-PC and anaerobic glycoysis systems make up anaerobic metabolism. Anaerobic metabolism refers to the resynthesis of ATP through chemical reactions that do not require the presence of oxygen (Fox et al., 1993). During the phosphagen system, ATP is formed by the breakdown of phosphocreatine (PC). Creatine phosphate prevents the rapid depletion of ATP by providing a readily available supply of high-energy phosphates for the resynthesis of ATP (Murray, Granner, Mayes, & Rodwell, 1990). Creatine phosphate is similiar to ATP in that when its phosphate group is removed, a large amount of energy is liberated. ADP and a high energy phosphate forms a new ATP by the energy liberated during the breakdown of PC. The phosphagen system can only provide energy for about 10 s of high intensity activities because of the limited amount of stored phosphagens in the muscles (Margaria, Cerretelli, & Mangilli, 1964)).

Glucose is catabolized through anaerobic glycolysis for the purpose of rapid energy release. In the body, carbohydrates are converted to glucose and stored in the liver and skeletal muscle as glycogen. Anaerobic glycolysis involves 12 seperate but sequential reactions. During anaerobic glycolysis, glucose is chemically broken down into lactic acid and energy is released to resynthesize ATP. This system provides enough energy for high-intensity activities lasting 1 to 3 min (Fox et al., 1993; Murray et al., 1990).

Aerobic glycolysis is the complete breakdown of glucose. This system is the same as anaerobic glycolysis except that in the presence of oxygen lactic acid does not build up because its removal rate equals its rate of production. When oxygen is present, pyruvic acid enters the Kreb's Cycle in the form of acetyl Co-A. Once in the Kreb's Cycle, two further chemical events take place. These events are the release of carbon dioxide, which is eliminated from the body by the lungs, and the removal of hydrogen and electrons which enter the electron transport system. After entering the electron transport system, the hydrogen compounds are carried through a series of enzymatic reactions, with the end product being water. The energy released during this process is used to resynthesize ADP and phosphate (Fox et al., 1993; McArdle et al., 1986; Murray et al., 1990).

Fats can also be aerobically broken down to carbon dioxide and water, releasing energy for ATP resynthesis. Fatty acid molecules undergo transformation to aceyle-CoA by a series of reactions called beta oxidation before entering the Kreb's Cycle and the electron transport system. Fats are capable of supplying greater amounts of energy for ATP resynthesis than carbohydrates. Aerobic metabolism of fats and carbohydrates supply energy needed during activities that can be performed for relatively long periods of time but which require submaximal effort (Fox et al., 1993; Murray et al., 1990).

Fatique

Fatigue is of critical importance to performance and has been the subject of numerous investigations. Fatigue has been defined in many ways. For the purpose of this review, it will be defined as a failure to maintain the required or expected force leading to a reduced performance of a given task (Sahlin, 1992). Fatigue has been attributed to central and/or peripheral causes. With central fatigue, the impairment is located in the central nervous system, and with peripheral fatigue, the impairment is located at the peripheral nerve, neuromuscular junction, and/or the contracting muscle (Sahlin, 1992).

Central fatigue appears to be mediated by motivation, impairment of transmission down the spinal cord, and impaired recruitment of motor neurons (Gibson & Edwards, 1985; Sahlin, 1992). Central fatigue plays a major role during prolonged exercise in which perceptions of pain and discomfort may cause the early cessation of exercise. In well-motivated normal subjects, central fatigue appears to play only a minor role in the cessation of exercise (Gibson & Edwards, 1985)

Impairment of transmission down the spinal cord and impaired recruitment of motor neurons occurs during maximum voluntary contractions when performing isometric exercises and may occur during certain neurological disorders (Gibson & Edwards, 1985). However, some metabolic disturbances may be induced during prolonged exercise such as hypoglycemia and increased plasma ammonia levels, which could impair central nervous system function (Sahlin, 1992) and may, in turn, be a minor contributor to fatigue.

The primary contributor to fatigue occurs in the periphery with the major area of fatigue occurring at the muscle level (Sahlin, 1992). Limited research exists in the area of peripheral nerve fatigue and neuromuscular junction fatigue is only prevelant during prolonged maximum voluntary contraction during isometric contractions (Bigland-Ritchie, Furbush, & Woods, 1986).

Several factors have been implicated in fatigue of the contractile mechanism itself. They consist of lactate accumulation, depletion of ATP and PC stores, and depletion of muscle glycogen stores. Lactate accumulation can hinder two physiological mechanisms. With an increase in lactate, hydrogen ion concentration increases and pH decreases (Vollestad & Sejersted, 1988; Sahlin, 1986; Sahlin, 1992) When hydrogen ion concentrations increase, the excitation-coupling of actomyosin filaments are hindered by a decrease in the amount of calcium released by the sarcoplasmic reticulum and interfering with the calcium-troponin binding capacity. Increased hydrogen ions also inhibit the activity of phosphofructokinase (PFK). PFK is a key enzyme involved in anaerobic glycolysis. This inhibition slows anaerobic glycolysis which reduces the availability of ATP for energy (Roberts & Smith, 1989; Sahlin, 1986; Sahlin, 1992; Vollestad & Sejersted, 1988)

ATP is a direct source of energy during muscular contraction, with PC being used for the immediate resynthesis of ATP. Intramuscular depletion of these phosphagens during activities at intensities greater than 90% VO_2 max could result in fatigue. Most of the energy requirements during high intensity activities are supplied by anaerobic metabolism. Some researchers have found that minimum values observed at exhaustion are 70% of resting ATP and 10% of resting PC (Gollinick & Hermansen, 1973; Karlsson, 1971). Gollinick and Hermansen (1973) and Karlsson (1971) concluded that the intramuscular stores are never fully depleted, meaning that this could not be the reason for fatigue. Others believe that only the ATP local to the active crossbridges are depleted while the ATP in the cell as a whole remains fairly high (Roberts & Smith, 1989; Wenger & Reed, 1976). The enzymes responsible for ATP transport (ATP translocases) can become saturated, and thus may be unable to replenish the locally depleted ATP at a high enough rate (Wenger & Reed, 1976).

During prolonged exercise at intensities between 50-90% of VO_2 max, fatigue is associated with depleted stores of muscle glycogen (Gollnick & Hermansen, 1973; Karlsson, 1971). Low or depleted muscle glycogen stores cause a drop in ATP production capacity which subsequently causes a loss of force generating capacity. When the force levels drop below the levels required to meet the demand of a certain exercise, the onset of fatigue occurs.

In summary, fatigue has been recognized as the inability to maintain force which in turn leads to the reduced performance of a given task. Fatigue can occur centrally or peripherally during muscle contractions. Central fatigue is apparent during long term exercise and is related primarily to a lack of motivation and to a lesser extent to metabolic changes. During peripheral fatigue, metabolic changes are generally observed with the pattern being different after short term exercise (lactate accumulation, ATP and PC depletion) than after prolonged exercise at moderate intensities (glycogen depletion). A common metabolic denominator is that during a fatigued state, the muscle has the decreased capacity to generate ATP. Whatever the cause, fatigue can be explained by the inability to generate sufficient force to perform the desired activity or a decline in force production during a given task.

Wingate Anaerobic Power Test

The Wingate Anaerobic Power Test became popular during the mid- and late-1970s. It fulfilled the need for a short, simple, non-invasive, and inexpensive test of anaerobic fitness. The test has been reported to be reliable (test-retest reliability of r =.95 to .97) and valid (Bar-Or, Dotan, & Inbar, 1977). The test is performed on a bicycle ergometer and requires a resistance based upon the subject's body weight. A resistance of 0.075 kg/kg of body weight was recommended in the original research by Bar-Or et al. (1977). The recommended resistance was modified to 0.090 kg/kg of body weight for non-athletes and 0.100 kg/kg of body weight for athletes (Bar-Or, 1987). The force is predetermined to yield a supramaximal mechanical power (equivalent to 2 to 4 times the maximal aerobic power) and to induce a noticable fatigue (i.e., drop in mechanical power) within the first few seconds (Bar-Or, 1987). The participants performs a 30-s timed ride with the predetermined resistance applied after initial inertia and unloaded frictional resistance have been overcome.

Three indices are normally provided as a result of the Wingate test. These are: (a) peak anaerobic power, the highest mechanical power in any 3- to 5-s period; (b) mean anaerobic power, the average power sustained throughout the test; and (c) fatigue index, the power decline during the test relative to peak power (Bar-Or, 1987).

Peak anaerobic power mostly reflects the participant's ability to utilized the phosphagen energy system. Mean anaerobic power reflects the ability to derive energy from the combination of anaerobic glycolysis and the phosphagen system. The contribution of anaerobic glycolysis is evidenced by blood lactate values ranging from 9.54 to 12.60 mmol/l in subjects following Wingate tests (Perez et al., 1986; Tamayo et al., 1984; Withers et al., 1991). The phosphagenic contributions to the Wingate test was substantiated by Jacobs et al. (1982), who reported that female subjects reduced their ATP stores by 34%, PC stores by 60%, and glycogen stores by 34%. Withers et al. (1991) found similiar values for male participants. They depleted their ATP stores by 41% and their PC stores by 69% following a similiar 30-s supramaximal bicycle test.

Based on these observations, the Wingate Anerobic Power Test appears to markedly tax the anaerobic energy pathways in both males and females. These observations further support the idea that fatigue is experienced as a result of the depletion of phosphagens (ATP and PC) stored within the muscle. When this depletion occurs, muscle force production decreases with a concomitant decrease in the revolutions per minute produced during the Wingate Anaerobic Power Test. Based on this evidence, the Wingate test can be used as a fatiguing mechanism of the anaerobic energy pathways.

Isokinetic Testing

Isokinetic testing devices have been used to assess muscular performance for diagnostic, therapeutic, experimental, and/or training purposes (Appen & Duncan, 1986; DiBrezzo, Gench, Hinson, & King, 1985; Jacobs, Hermiston, & Symons, 1991; Jenkins, Thackaberry, & Killian, 1984). The major values used to evaluate muscular performance on isokinetic devices are peak torque, average peak torque, and fatigue index. Peak torque and average peak torque have been used to assess muscular strength while the fatique index has been used to assess muscular endurance. There is no universal agreement about the definition of these three variables and no generally accepted isokinetic testing protocol.

Various protocols have been used to determine the three factors. Maximal torque has been determined as the peak torque in the first two contractions (DiBrezzo et al., 1985), first three contractions (Aspen & Duncan, 1986; Housh, Thorland, Tharp, Johnson, & Cisar, 1984), first five contractions (Jenkins et al., 1984) and first six contractions (Baltzopoulos, Eston, & MacLaren, 1988). Others have used the average peak torque in the first five contractions (Patton & Duggan, 1987; Stratford, Bruulsema, Maxwell, Black, & Harding, 1990).

The fatigue index has been interpreted in various ways. It has been expressed as the average peak torgue of contractions 48 to 50 divided by the average peak torque of contractions 1 to 3 and expressed as a percentage (Thornstensson & Karlsson, 1976) while Burdett & Swearington (1987) expressed fatigue as the number of contractions performed before peak torque falls to 50% of the intial peak torque. Barnes (1981) expressed fatigue as a percentage of the initial peak torque. The 10 contractions following peak torque was expressed as a percentage of the initial peak torque. Patton, Hinson, Arnold, and Lessard (1978) characterized fatigue as the time it takes to reach volitional exhaustion.

The speed of contraction for isokinetic testing has also varied with speeds of 30 deg/s to 300 deg/s being reported (Appen & Duncan, 1986; Barnes, 1981; Gleeson & Mercer, 1991; Jenkins et al., 1984). An inverse relationship exists between speed of contraction and force production with the greatest amount of force being produced at slower speeds (Appen & Duncan, 1986; Barnes, 1981; Jenkins et al., 1984) Because of this relationship, slower speeds with fewer contractions (2 to 6 repetitions) have been used to access muscular strength, and faster speeds with a larger number of contractions (10 to 50 repetitions) have been used to access muscular endurance.

Isokinetic testing is a valid and reliable form of measure of muscular performance. Johnson and Siegel (1978) examined leg extension/flexion on three consecutive days with six trials each day. Their subjects performed four maximal efforts at 180 deg/s. Reliability coefficients ranging from .93 to .97 were reported. Clarkson et al. (1982) reported similiar results when measuring at a variety of speeds (0, 30, 180, 240 deg/s). These investigators concluded that the reliability was high for the torque output at all four speeds (r's = .97 to .99).

Stratford et al. (1990) examined the reliability of two separate protocols, one at 60 deg/s with no rest between the five maximum contractions and the second at 60 deg/s with 30-s rest between each of the five contractions. High correlations between both protocols with the rest protocol having a reliability of .99 and the no rest protocol having a reliability of .96 were reported.

In summary, isokinetic testing of muscular function has a high test-retest reliability (Clarkson et al., 1982; Johnson & Siegel, 1978; Stratford et al., 1990). Slow speeds of 30-90 deg/s with fewer contractions (2 to 6) may be used to assess muscular strength. Fast speeds of 180 to 300 deg/s at 10 to 50 contractions can be used to assess muscular endurance. Binder-Macleod and Snyder-Mackler (1993) stated that in the clinical rehabilitation environment, the most widely used protocol to assess muscular fatigue is the Thorstensson and Karlsson method (1976).

Based on the aforementioned literature, the evaluation of muscular strength will be determined by the peak torque performed during four maximal contractions at 60 deg/s. Muscular endurance will be determined by the Thorstensson and Karlsson protocol (1976). A comparison of the average torque of repetitions 48 to 50 divided by the average torque of repetitions 1 to 3 and then expressed as a percentage will not be used. A statistical analysis of the absolute values of the 25th and 50th repetition during a non-fatigued and fatigued condition will be used because of the inability to apply the fatigue index to this experimental design.

Impacts Associated with Vertical Jumping

Many sports and movement activities contain a vertical jumping component which is followed by a landing. Sports such as volleyball, basketball, football, gymnastics, and aerobic dance contain the vertical jumping component and subsequent landing phase. Forces are generated at the ankle, knee, and hip during the landing phase of vertical jumping. The forces that are generated at these joints are a result of the deceleration of the body during the landing. Winter (1984) suggest that the flexion/extension joint moments of force, representing the net rotatory effect of all forces on a joint, is the desired component to evaluate at the joint during the landing phase of a vertical jump. Vaughan, Davis, and O'Connor (1992) state that compression and anterior/posterior shear forces as well as flexion/extension joint moments are helpful in evaluating the force dissipation that occurs during impacts involved with vertical jumping.

The purpose of this section was to review articles that have examined forces generated during the landing phase of vertical jumping.

Until recently, most of the information concerning impacts generated from vertical jumping focused on the kinematics and ground reaction forces associated with the landing phase of vertical jumping. Few landing studies have been reported in which inverse dynamic methods have been employed to analyze joint moments at the ankle, knee, and hip.

Researchers have identified two primary foot contact patterns associated with impacts during vertical jumping. The two patterns are the toe-heel and flat-foot techniques with the former being the most widely used (Steele & Milburn, 1987; Valiant & Cavanagh, 1985). Additional techniques observed less frequently include toe-only and heel-only styles (Steele & Milburn, 1987). The flat-foot, toe-only, and heel-only landing techniques elicit a unimodal vertical ground reaction force-time history. The toe-heel landing elicits a bimodal force-time history with the first peak being the toe contact and the second and largest peak being the heel contact. Valiant and Cavanagh (1985) simulated a basketball rebound activity and reported that participants who landed with the toe-heel technique had vertical ground reaction forces of 1.3 BW during the first peak and 4.1 BW during the second peak. Paricipants who landed with the flat-foot technique had vertical ground reaction forces of 6.0 BW. The toe-heel landing not only produced less ground reaction force but also elicited more absorption of the force generated during the landing.

The idea of greater absorption of force with a flexed knee was supported by Dufek, Schot, and Bates (1990). They examined three participants during the landing phase of a vertical fall of 40 and 100 cm. Participants were examined under a stiff, slightly flexed, and fully flexed landing condition. The investigators found that the 100 cm vertical fall produced the greatest peak flexor joint moments of -3.3, -1.8, and -12.1 Nm/kg for the ankle, knee, and hip, respectively. The corresponding peak extensor joint moments were 2.4, 9.3, and 10.7 Nm/kg for the ankle, knee, and hip, respectively. Analysis of the landing technigues revealed peak flexor and extensor joint moment values at all joints for the stiff landing were 2.8 and 2.4 times the fully flexed values; 67% of the minimum peak flexor and extensor joint moments were observed for the slightly flexed technique. It was concluded that the stiff landings may be potentially dangerous because of the earlier occurrence and greater magnitude of peak joint moments of force values at the ankle, knee, and hip.

The idea of stiff landings being dangerous was further supported by Devita and Skelly (1992). They examined eight female intercollegiate basketball and volleyball players during the landing phase of a vertical fall of 59 cm. The players were examined under soft and stiff landing conditions. The stiff landing averaged 117 deg of knee flexion and the soft landing averaged 77 deg. The stiff landing had larger vertical ground reaction forces but only the ankle plantarflexors produced a larger moment (0.185 vs 0.232 N•m•s•/kg). The hip and knee muscles absorbed more energy in the soft landing, whereas the ankle muscles absorbed more in the stiff landing. Overall, the muscular system absorbed 19% more of the body's kinetic energy in the soft landing when compared to the stiff landing. This resulted in a reduction of impact stress on other body tissues such as bones and ligaments.

Based on this brief review of the literature, the potentially dangerous nature of stiff knee joint landings as indicated by the greater and earlier peak joint moments of force values at the ankle, knee, and hip is evident. Stiff landings produce greater forces on the supportive structures of the lower extremities which in turn may increase the chance for injury.

Summary

The supportive structures of the lower extremities consist of dynamic stabilizers in the form of muscles and passive stabilizers in the form of ligaments and bone. These dynamic and static stabilizers provide support for the trunk, upper extremities, and head. If the dynamic stabilizers are unable to generate a sufficient amount of force in the form of muscle contractions for the support for the trunk, upper extremities, and head, then the passive structures must provide the support. In turn, they may become weakened and injuries may result. These injuries may range from minor joint ligament damage to stress fractures of the bones in the feet, shank, thigh, or hip.

Fatigue may be defined as the inability to maintain the required or expected force leading to the reduced performance of a given task (Sahlin, 1992). If fatigue occurs, then the supportive musculature becomes weakened and may not be able to provide support for the body during certain activities.

One activity that is prevalent in many sports is vertical jumping. The impact forces experienced during landing from a rebound in basketball have been recorded to be two to six times a person's body weight (Valiant & Cavanagh, 1985) with 15.1 BW experienced during a double back somersault in gymnastics (Panzer, Wood, Bates, & Mason, 1988). The lower extremities are able to attenuate and absorb this force during normal non-fatigued conditions. But will they be able to absorb this force when the dynamic stabilizers become fatigued? The purpose of this research was to examine what may happen to the joint reaction forces that are generated at the ankle, knee, and hip during a fatigued state. The premise was that the joint reaction forces and moments should be greater during a fatigued state because the lower extremities would be more rigid during the landing.

CHAPTER III

METHOD

The purpose of this study was to compare differences between selected mechanical parameters during impact from vertical jumping in both a non-fatigued and fatigued state. A description of the experimental equipment and procedures used to accomplish this purpose are contained in this chapter. This chapter is divided into the following sections: (a) Pilot Studies, (b) Description of Participants, (c) Desciption of Data Collection, (d) Data Reduction and Analysis, and (e) Statistical Analysis.

Pilot Studies

This section is divided into pilot studies for isokinetic testing reliability, anthropometric measurement reliability, and Wingate induced fatigue. An initial investigation was conducted to determine the reliability of the investigator during isokinetic testing. The isokinetic device used for the investigation was a Cybex II leg extension and flexion machine. Twenty participants (16 females and 4 males) participated in the Cybex II reliability pilot study. Two parameters were tested. These parameters were peak torgue for leg extension and flexion which was measured at a speed of 60 deg/s and fatigue index which was measured at a speed of 180 deg/s. The initial data were collected and compared to scores obtained during the following week. An analysis of variance (ANOVA) with repeated measures was used to determine the intraclass correlation between the two testing days. The reliability coefficients for extension and flexion at 60 deg/s were r =.83 and .87, respectively. The reliability coefficients for extension and flexion at 180 deg/s were r =.85 and .83, respectively.

A second pilot study was conducted to determine the reliability of the investigator during anthropometric measurements. Anthropometric measurements of 5 participants were collected on two successive weeks. Lower extremity characteristics of each participant were determined by 11 anthropometric measurements. The measurements taken of the right side of the body consisted of thigh length, midthigh circumference, calf length, calf circumference, knee diameter, foot length, malleolus height, malleolus width, and foot breadth. The total body mass, and the distance between the left and right anterior superior iliac spine (ASIS) of each subject was also determined. The methods and procedures for measuring each of the above variables are located in Table 3. An analysis of variance (ANOVA) with repeated measures was used to determine the intraclass correlation between the two testing days (see Table 1). The reliability coefficients ranged from .89 for midthigh circumference to .99 for body mass.

Table 1

Reliability Coefficients for Anthropometric Measurements

Measurements	r
Body mass	.99
ASIS breadth	.95
Thigh length	.91
Midthigh circumference	.89
Calf circumference	.90
Calf length	.92
Knee diameter	.95
Foot length	.98
Malleolus height	.97
Malleolus diameter	.97
Foot breadth	.92

A third pilot study was used to determine if there was a decrease in muscular strength and muscular endurance following a Wingate Anaerobic Power Test. Isokinetic tests were performed on five female subjects. Two days later, the participants performed the Wingate Anaerobic Power Test which was immediately followed by isokinetic testing. These data were compared to the initial data to determine if there was a significant decrease in torque output between the variables measured. A paired dependent t-test was used to analyze the difference between the non-fatigued and fatigued conditions.

The variables measured were peak torque for flexion and extension at 60 deg/s, peak torque for flexion and extension at 180 deg/s and torque of repetitions 25 and 50 at 180 deg/s (see Table 2).

Table 2

Pilot Study: Isokinetic Knee Extension and Flexion

Variable	p
60 deg/s, peak torque	
extension	
NFT	.008*
FT	
flexion	
NFT	.012*
FT	
180 deg/s, peak torque	
extension	
NFT	.018*
FT	
flexion	
NFT	.025*
FT	
180 deg/s, 25th rep	
extension	
NFT	.042*
FT	
flexion	
NFT	.048*
FT	
180 deg/s, 50th rep	
extension	
NFT	.058
FT	
flexion	
NFT	.079
FT	

Note. Non-fatigued (NFT), Fatigued (FT)
* Significance was at the $p < .05$.

An alpha level of $p < .05$ was used during the pilot study for isokinetic testing because of the limited sample size. An alpha level of $p < .01$ was used for the actual study. Significant differences were observed for peak torque values for flexion and extension at 60 and 180 deg/s. Significant differences were also observed for torque values of the 25th repetition for flexion and extension at 180 deg/s.

Description of Participants

Prior to data collection, approval for the use of human subjects was received from the Texas Woman's University Human Subject Review Committee. Participants were informed and consent was obtained prior to data collection. A copy of this Informed Consent Form can be found in Appendix A. A proposal was developed and permission for data collection was obtained from the dissertation committee.

The participants of the study were volunteers from the student body of Texas Woman's University. Selection of the subjects resulted from advertisements around the University campus and from announcements to various University activity classes. The respondents were selected based on responses obtained on the Medical History Questionnaire and Physical Activity Readiness Questionnaire (PAR-Q). Both questionnaires are included in Appendix A. Twenty participants were randomly selected from a pool of 30 respondents who fit the profile of healthy, untrained, unskilled females between the age of 18 and 35 years with no prior history of lower extremity injuries or abnormalities. This age range was selected for the purpose of decreasing the chance for joint injuries in the underdeveloped adolescent and to prevent any added stress to the physical deterioration of the joints associated with the aging process. Untrained was defined as individuals who engage in physical activity on the average of 1 day per week or less.

Description of Data Collection

This section contains the data collection procedures used to determine if anaerobic fatigue would alter mechanical parameters associated with vertical jumping. The data collection period were divided into three sessions.

Before the first session, all potential participants completed the health history questionaire and PAR-Q to determine if they were suitable for the research study. All potential participants were then placed in a subject pool. Each participant was then randomly chosen to participate. A description of the methods and procedures were given during the first data collection period. Each participant read and signed an informed consent form before proceding further. Anthropometric measurements were also taken during the first session and each participant was familiarized with the equipment. After the participants were familiarized with the Monark cycle ergometer and isokinetic equipment, each was given a lower extremity isokinetic test to determine muscular strength and muscular endurance during a non-fatigued state.

The second data collection period occurred at least 48 hrs after the initial testing session. This period consisted of a Wingate Anaerobic Power Test on a Monark bicycle ergometer. The Wingate test was used to fatigue the anaerobic energy systems (phosphagen system and anaerobic glycolysis). Immediately following the Wingate test (within 10 s), muscular strength and endurance were assessed on the right and left leg, respectively, by isokinetic leg flexion and extension tests. The right leg was tested within 10 s and the left leg was tested within 1 min of the completion of the Wingate test. These values were compared to the initial values collected during the first testing period. The isokinetic tests were used to determine the amount of decrease in muscular strength and endurance that occurred following the fatiqued state.

The third testing session included cinematographic analysis of a maximal effort countermovement vertical jump during a non-fatigued and fatigued state. The participants performed the vertical jumps with the hands remaining on the waist at all times. The non-fatigued countermovement vertical jump was performed first and the fatigued jump was performed second. The fatigued vertical jump was conducted immediately after (within 10 s) the participant had performed the Wingate Anaerobic Power Test.

The remainder of this section is divided into the following subsections: (a) Isokinetic Testing, (b) Wingate Anaerobic Power Testing, (c) Anthropometric Measurements, (d) Anatomical Landmarks, (e) Cinematographic Procedures, and (f) Force Plate Analysis.

<u>Isokinetic Testing</u>

The procedures for isokinetic testing of the lower extremities includes a description of the participant preparation in addition to the actual testing of the participant. The tests were performed on a Cybex II isokinetic machine.

The participant preparation for testing knee extension and flexion was as follows. The subject sat in an upright position with the hips flexed to 90 degs. This investigator stabilized the hips and thighs with a pelvic strap and a thigh strap. The axis of rotation of the knee joint was aligned with the input shaft of the dynamometer. The shin pad of the lever arm was adjusted and placed in contact with the tibia just above the malleoli of the ankle. The subject was able to move the leg from 90 degs to 180 degs without any restrictions in the range of motion.

Before the testing protocol began, the participants were familiarized with the procedures and allowed to warm-up by performing five submaximal repetitions at about 50% of their maximal voluntary contractions. The isokinetic strength testing on all participants was performed on the right leg. One leg was used because of the time required to change the set-up for the testing of the other leg. During the time required to change the set-up, phosphagen (ATP and PC) stores could replete and confound the results of the fatigued condition.

The strength testing procedures included four maximal voluntary contractions at 60 deg/s. This was preceded by three submaximal repetitions performed at about 25, 50, and 75% of their maximal voluntary contraction. Immediately following the three submaximal repetitions, the participant performed four maximal contractions. Verbal encouragement was provided by the investigator to try to assure that a maximal effort was given. Peak torque for extension and flexion was determined by the greatest force produced during any of the four maximal voluntary contraction.

Following the strength testing, a test of muscular endurance on the left leg was conducted on each participant. The same preparation procedures were used for the endurance testing. The Thorstensson and Karlson protocol (1976) was used to assess muscular endurance. This test was performed at 180 deg/s for 50 maximal voluntary contractions. The Thorstensson and Karlson (1976) fatigue index was not used but the absolute torque values of the peak torque and repetitions 25 and 50 were analyzed to assess the difference between muscular endurance during a non-fatigued and fatigued condition.

Wingate Anaerobic Power Test

The Wingate Anaerobic Power Test was used as a fatiguing mechanism. The purpose of the test was to fatigue the anaerobic energy system prior to isokinetic testing and vertical jumping. Since it was used to fatigue, anaerobic power and mean anaerobic power were not measured but the fatigue index was used to assess the amount of fatigue that occurred during the test. The fatigue index was the amount of revolutions during the last 5 s of the test divided by the amount of revolutions during the first 5 s. This value was then expressed as a percentage and subtracted from 100. This is identified as the amount of decline in power output that occurs during the test. The fatigue index will provide some insight into the amount of fatigue that is occurring during the test. This is supported by Sahlin's (1992) definition of fatigue, which stated that fatigue is the inability to maintain the required or expected force leading to the reduced performance of a given task. The remainder of this section provides the procedures used when conducting the Wingate Anaerobic Power Test.

The test was performed on a Monark cycle ergometer. Prior to testing, the participant cycled at a low intensity (about one-third of the prescribed force setting) that was interspersed with 4 to 5 sprints of 4 to 6 s in duration.

The prescribed force setting was determined by the updated procedures described by Bar-Or (1987). The force setting was determined by multipling the subjects body weight in kgs by 0.090, with the force setting expressed in kgs.

The warm-up period was followed by a recovery period that lasted 5 minutes. Following the recovery period, the acceleration period began and consisted of two components. In the first component, the subject pedaled at 20 to 30 revolutions per minute (rpm's) for 10 s at a force setting that was approximately one-third the prescribed force setting. In the second component, the subject gradually increased the rpm's to their maximal effort while the resistance was increased to the prescribed force setting. This sequence occurred in less than 5 s, thus the acceleration period lasted no longer than 15 s. Immediately following the acceleration phase, the stopwatch was started and the test continued for 30 s. Verbal encouragement was provided during the entire test to motivate the participant to perform at a maximal level until the test was completed.

<u>Anthropometric Measures</u>

Anthropometric measures were taken on each subject for use in predicting joint centers, segmental masses, segmental centers of mass, and moments of inertia. The lower extremity characteristics of the participant were determined by 11 anthropometric measurements. The measurements taken of the right side of the body consisted of thigh length, midthigh circumference, calf length, calf circumference, knee diameter, foot length, malleolus height, malleolus width, and foot breadth. The total body mass (body weight) and the distance between the left and right anterior superior iliac spine (ASIS) of each subject was also determined. Three measurements were taken at each site with standard anthropometric measuring device or a cloth tape measure. Body mass was determined by a standard medical scale.

The description of each measurement is presented in Table 3 (Vaughan, Davis, & O'Connor, 1992). Figure 1 illustrates the areas of interest. All measurements were recorded to the nearest mm and then the three measurements were averaged.

Table 3

Anthropometric Measurements

Measurements	Descriptions
Body mass	Measure the mass of the subject with t-shirt, shorts, and underwear on.
ASIS breadth	With a beam caliper, measure the horizontal distance between the right and left anterior iliac spines.
Thigh length	With a sliding caliper, measure the vertical distance between the superior point of the greater trochanter of the femur and the superior margin of the lateral tibia.
Midthigh circumference	With a tape perpendicular to the long axis of the leg and at a level midway between the trochanteric and tibial landmarks, measure the circumference of the thigh.
Calf length	With a sliding caliper, measure the vertical distance between the superior margin of the lateral tibia and the lateral malleolus.
Calf circumference	With a tape perpendicular to the long axis of the lower leg, measure the maximum circumference of the calf.
Knee diameter	With a spreading caliper, measure the maximum breadth of the knee across the femoral epicondyles.
Foot length	With a beam caliper, measure the distance from the posterior margin of the heel to the tip of the longest toe.
Malleolus height	With the subject standing, use a sliding caliper to measure the vertical distance from the standing surface to the lateral malleolus.

(Table continues)

Malleolus width	With a sliding caliper, measure the maximum distance between the medial and lateral malleoli.
Foot breadth	With a beam caliper, measure the breadth across the distal ends of metatarsals one and five.

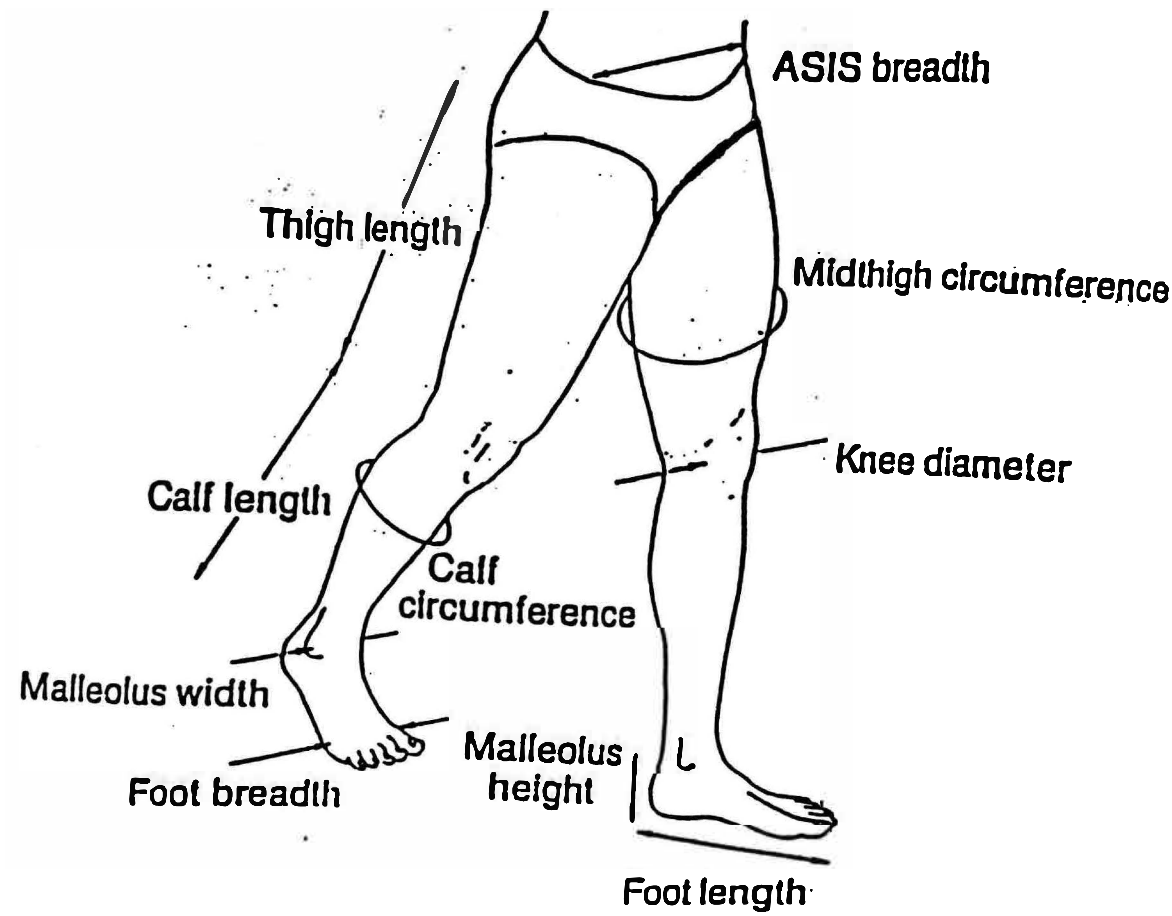

Figure 1. Anthropometric measurements. Adapted from Vaughan, Davis, & O'Connor (1992)

Anatomical Landmarks

Retro-reflective markers made from varying sizes of styrofoam spherical balls covered with retro-reflective 3M Style II tape were placed at specific anatomical landmarks as outlined by Vaughan et al. (1992) for the calculations of forces and moments at the ankle, knee, and hip. The markers were placed at the left and right anterior superior iliac spine (ASIS), sacrum, right greater trochanter, right femoral epicondyle, right tibial tubercle, right lateral malleolus, right calcaneous, and right fifth metatarsal head. All markers were attached to the landmarks with double-sided tape. The marker placement shown in Figure 2 depicts the desired site of each marker from the anterior view and Figure 3 depicts the posterior view.

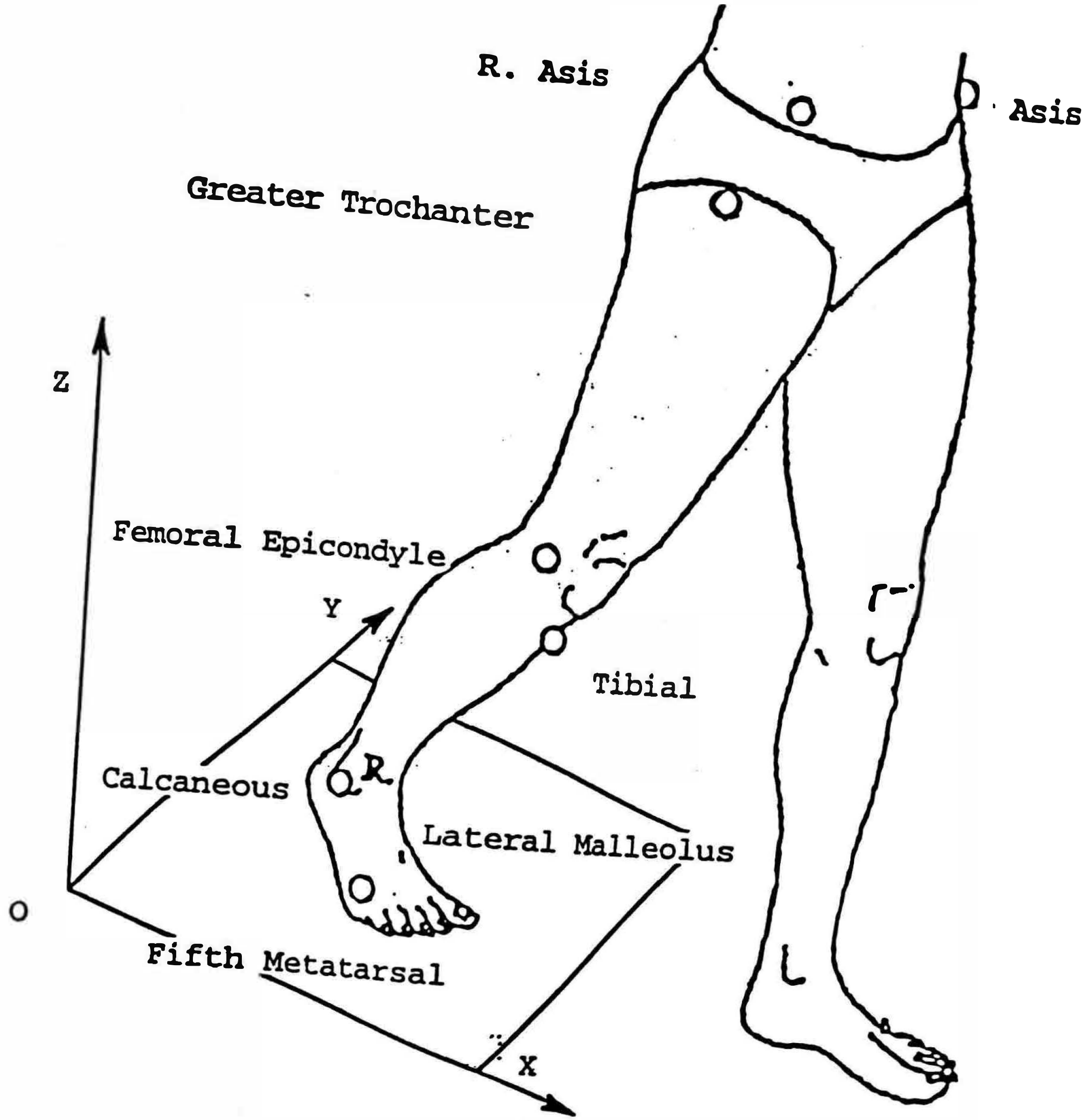

Figure 2. The marker placement from the anterior view. Adapted from Vaughan, Davis, & O'Connor (1992).

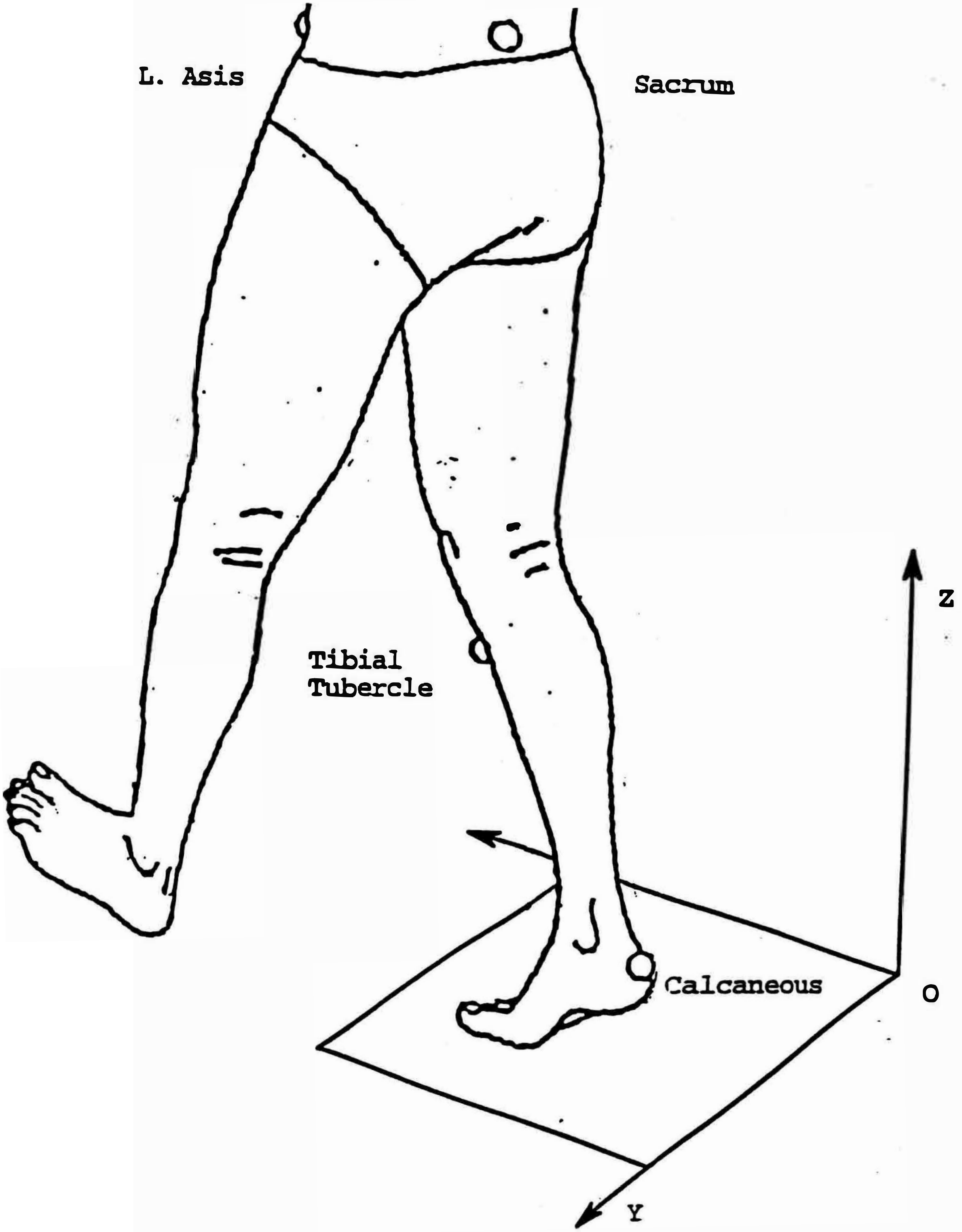

Figure 3. The marker placement from the posterior view. Adapted from Vaughan, Davis, & O'Connor (1992)

Biomechanical Equipment

The Peak5 Motion Measurement System (Peak Performance Technologies, 1993) and an Advanced Mechanical Technology, Inc.(AMTI, 1993) Model OR6-5 Biomechanical Platform were the biomechanical equipment that was used for this study. The Peak5 System consisted of a control object, four Panasonic AG-1960 VCR's for recording data, a Panasonic AG-7350 VCR for analyzing data, two Sony video monitors, an analog to digital interface unit, and multiple software components. Data were collected from these sources and then analyzed via computers.

Cinematographic Analysis

Cinematographic data were collected by the Peak5 Motion Measurement system. The video data were collected at 120 Hz. Four video cameras were used to determine segmental coordinates and displacement data. The cameras were mounted approximately 3 m above the floor at each corner of the Biomechanical Laboratory. They were placed in a 9 m by 18 m configuration (see Figure 4 for camera placement). Camera two, three, and four were genlocked to camera one to provide simultaneous filming by all four cameras. Video data were collected once on each participant during two different conditions. The first condition consisted of data collectionwhen the participant performed a countermovement

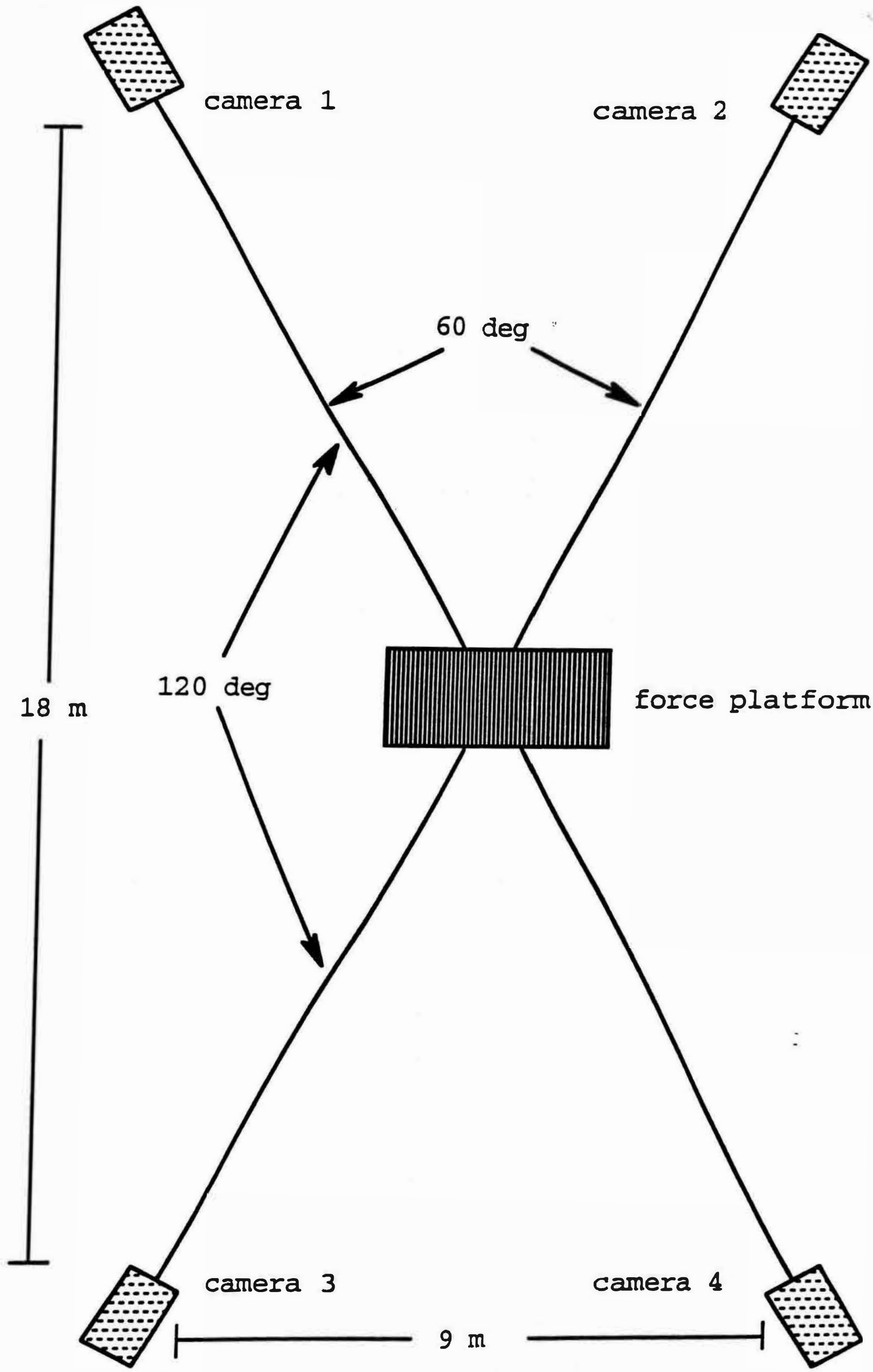

Figure 4. Camera and force plate placement illustration.

vertical jump in a non-fatigued state. The second condition consisted of data collection when the participant performed a countermovement vertical jump in a fatigued state.

Force Plate Analysis

An AMTI force platform was used to collect ground reaction forces. The force plate was mounted in the center of the four video cameras and even with the floor (see Figure 4). Force data were transmitted to the computer via an analog to digital converter. The ground reaction forces were collected at 1200 Hz and were synchronized with the video data for the determination of joint kinetics.

The participant started with both feet off the force plate. Then the participant performed a countermovement vertical jump and landed with the right foot on the force platform and left foot beside the platform. The participant was instructed to land with both feet making contact at the same time.

Description of Jump

The participant performed a countermovement vertical jump with the hands on the hip. The amount of knee bend was self-determined by the participant. Each was instructed to perform a maximal effort countermovement vertical jump with a self-determined preparatory knee bend. The take-off and landing were to be with both feet leaving the ground and contacting the ground simultaneously. The participant performed this jump twice, once in a non-fatigued condition and once in a fatigued condition. The non-fatigued jump occurred before the Wingate Anaerobic Power Test and the fatigued jump occurred within 3 to 5 s of the completion of the Wingate test.

Data Reduction and Analysis

For the purpose of this study, the area of interest was the impact experienced following the contermovement jump and descent phase. Data processing began with digitation of the control object. The control object consisted of 25 surveyed reference points and they were digitized from all camera views using the Peak5 software package. A different control object was filmed and digitized for each collection period. The Peak5 system used the Direct Linear Transformation (DLT) method to obtain 3D coordinate data from four 2D camera views. This was used to calculate the position and the displacement of the subject in the image space. The following two sections describe the data reduction and analysis of the: (A) Joint Forces and Moments and (B) Vertical Jump Height.

Joint Forces and Moment Analysis

The starting point for automatic data capture (video digitization) was 10 frames before first contact and 6 frames after maximum knee flexion. The Peak5 software package determined appropriate parameters for marker identification. Two frames were manually digitized and then automatic data capture began. Nine anatomical landmarks were digitized in each frame. The data from the video records were smoothed using a Butterworth filter. The ground reaction data were scaled and smoothed by using a Butterworth filter. The Peak5 software package was designed to determine optimal levels for smoothing when using the Butterworth filter. The smoothed ground reaction force data were reduced to match the video data so that each body position had a corresponding applied ground reaction force during force platform contact. After matching plate contact with the corresponding increase in ground reaction force data, every tenth ground reaction data point was then match with each frame of video data. Positive vertical force platform data indicated vertical ground reaction forces acting upward on the body. Positive horizontal ground reaction forces represented an acceleration of the body forward. The point of application of the ground reaction forces on the body was calculated as the center of pressure.

The location and magnitude of the lower extremity segmental masses, segmental centers of mass, joint centers, and their moments of inertia were estimated using a mathematical model from Vaughan et al. (1992), and the individual subject's anthropometric data. Joint reaction forces and joint moments of force were calculated for the lower extremity by using an inverse dynamic analysis that combined anthropometric, film, and ground reaction force data. The positive joint moments of force represented extension at the hip and knee, and plantar flexion at the ankle joint (Figure 5).

Joint angular positions, velocities, and accelerations were calculated from the kinematic data. Zero degrees at the three joints corresponded to an erect standing position with the trunk, thigh, and shank in a straight line and the foot at a right angle to the shank. Positive values were assigned for extension at the hip and knee and plantar flexion at the ankle (Figure 5). All calculations were performed with the 3D kinetic software developed by the University of Delaware's Sports Science Center (University of Delaware, 1991). The computer program was adapted to accept the file format of the data collected by the Peak5 analysis system and the AMTI force platform. The local coordinate systems for the cinematography and force plate data were translated and rotated to match the coordinate system of Vauhn et al. (1992). All translations and rotations of the coordinate systems are located in Figures 6 and 7. Figure 6 represents the coordinates before translation and rotation and Figure 7 represents the coordinates after translation and rotation. Compression forces, anterior/posterior shear forces and flexion/extension moments of force at the ankle, knee, and hip generated during both conditions, non-fatigued and fatiqued vertical jump, were then compared.

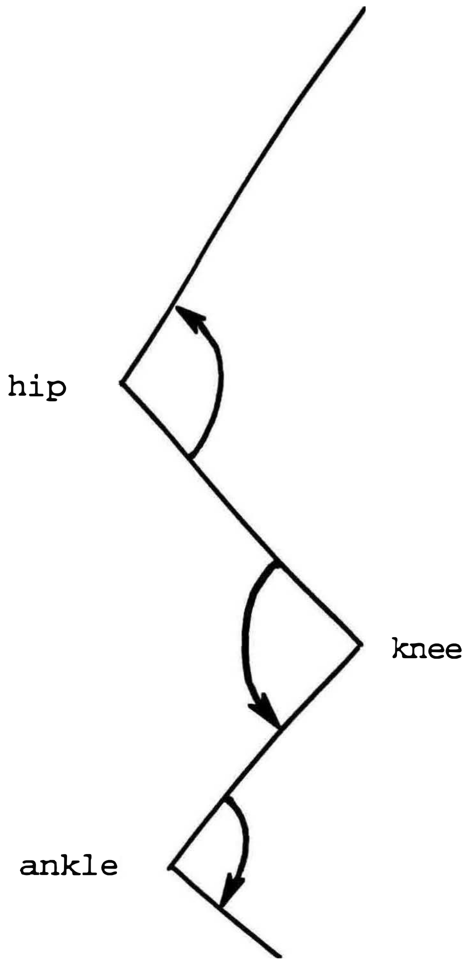

Figure 5. Joint moment of force that were extensor at the hip and knee, and plantar flexor at the ankle, were assigned the positive direction.

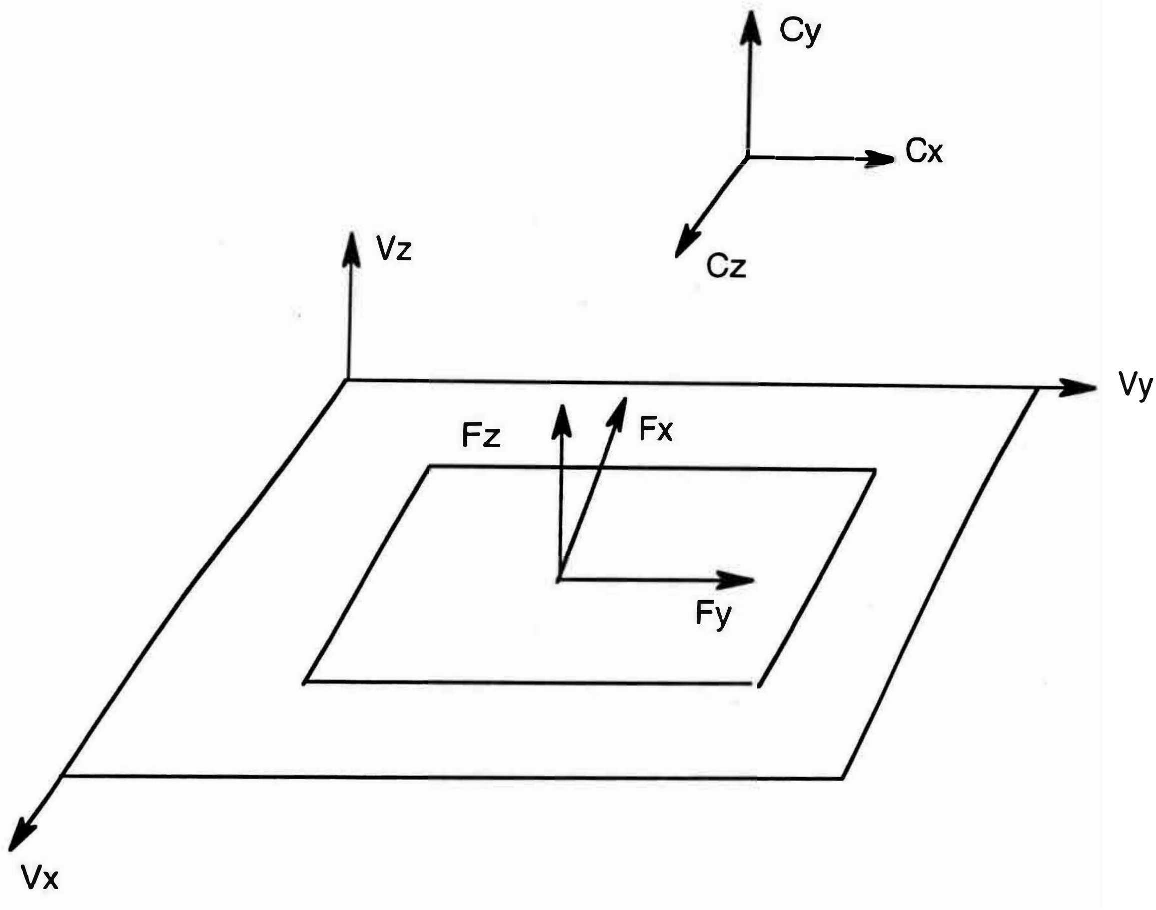

Figure 6. Coordinate systems of the force platform (Fx, Fy, Fz), cinematography (Cx, Cy, Cz), and Vaughn's model (Vx, Vy, Vz) before being realigned.

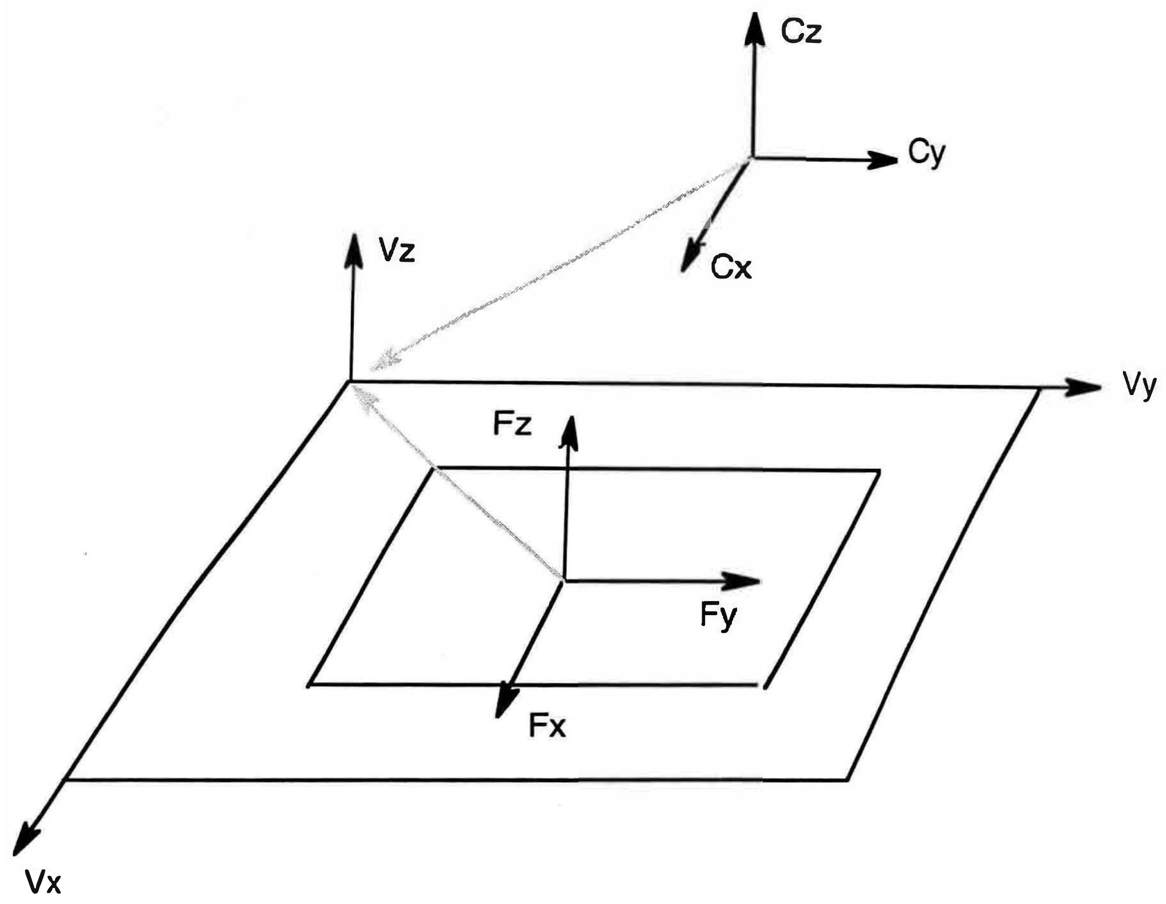

Figure 7. Coordinate systems of the force platform (Fx, Fy, Fz), cinematography (Cx, Cy. Cz), and Vaughn's model (Vx, Vy, Vz) after being realigned.

Vertical Jump Height Analysis

The greater trochanter was used as a reference point when determining the participant's jump height. A separate method of digitization was used when assessing greater trochanter displacement. The camera that viewed the right sagittal plane and anterior view of the participant was used for vertical jump displacement analysis. Digitization of the greater trochanter began when the participant was in an erect body position and continued until the beginning of the decent phase of the jump. Erect body position was defined as zero degree angles at the hip and knee joint with the shank to foot angle being 90 degs while still being in contact with the ground. The displacement data were then scaled to cm.

Statistical Analysis

BMDP software was used to analyze all of the following variables. Peak torque for knee flexion and extension at 60 deg/s, peak torque for knee flexion and extension at 180 deg/s, and the torque of the 25th and 50th repetitions at 180 deg/s in both a non-fatigued and fatigued condition were analyzed. A dependent t-test was used to analyze the differences between these variables. The alpha level was set at .01.

A multivariate Hotellings T^2 with repeated measures was used to analyze compression joint reaction forces, anterior/posterior joint reaction forces, and flexion/extension joint moments at the ankle, knee, and hip. The dependent variable consisted of a combined score made up of the compression joint reaction force, anterior/posterior joint reaction force, and flexion/extension joint moment for each joint. These dependent variables were compared during a non-fatigued (NFT) and fatigued (FT) state. The means of 20 untrained unskilled females between the age of 18 to 35 years of age were tested at an alpha level of .01.

Jump heights during a non-fatigued and fatigued condition were analyzed. A dependent t-test was used to analyze the differences between these two variables. The alpha level was set at .01.

CHAPTER IV

PRESENTATION OF THE FINDNGS

The purpose of this study was to compare the differences between selected mechanical parameters in vertical jumping in both a non-fatigued and fatigued state. More specifically, the purpose of the study was to investigate the changes in anterior/posterior shear forces, compression forces and flexion/extension moments at the ankle, knee, and hip during the impact phase of a vertical jump in both a non-fatigued and fatigued state.

Twenty adult female volunteers performed a vertical jump in both a non-fatigued and fatigued state. Each participant performed a non-fatigued and fatigued vertical jump with a self-selected countermovement that produced their maximum jump height. The arms were placed on the hips to eliminate technique differences among the participants. The Wingate Anaerobic Power Test was used as the fatiguing method. Approximately one week before the non-fatigued and fatigued vertical jumps were performed, each subject's isokinetic leg strength was tested during a non-fatigued and fatigued state with the Wingate Anaerobic Power Test being used as the fatiguing instrument. These data were used to quantify and support the fact that anaerobic muscle fatigue was occurring. The joint reaction forces and moments were determined from a kinetic model utilizing cinematography, anthropometric, and force platform data. The findings in this chapter are organized under the following headings: (a) Description of the Subjects, (b) Analysis of Isokinetic Data, (c) Analysis of Biomechanical Data, and (d) Examination of the Hypotheses.

Description of the Participants

The participants consisted of 20 females, aged 18 to 35 years. The participants were classified as physically healthy based on their responses to the Health History Questionnaire and their responses to the Physical Activity Readiness questionnaire. Each participant had to be free from any previous joint injuries and abnormalities to the lower extremities and no history of cardiovascular disease. The participants were also classified according to their physical activity level. Physical activity level was assessed by the Health History Questionnaire (Appendix A). Each participant was untrained. This was defined as individuals who engaged in physical acitivity on the average of one day per week or less.

The description of the participants is presented in two sections: (a) Demographic Profile of the Participants and (b) Anthropometric Profile of the Participants. Table 4 represents the demographic data for the participants and Table 5 represents the anthropometric data for the participants.

Demographic Profile of the Participants

The mean age of the participants was 26.6 ± 2.6 years. The average height of the participants was 169.2 ± 6.5 cm. The average weight of the participants was 61.4 ± 9.2 kgs.

Table 4

Demographic Profile

Variable	Range (min.-max.)	*M*	*SD*
Age (yrs)	15.0 (20 - 35)	26.6	2.6
Height (cm)	30.5 (152.5 - 182.9)	169.2	6.5
Weight (kg)	38.6 (44.6 - 83.2)	61.4	9.2

Anthropometric Profile of the Participants

The anthropometric profile of the subjects was obtained from anthropometric measurements taken during the first testing session. Ten anthropometric measurements were taken on each subject in order to predict joint centers, segmental masses, centers of mass, and moments of inertia. Individual anthropometric measurements are located in Appendix C. Table 5 provides a summary of the anthropometric data. According to the anthropometric data collected, the group of female volunteers are homogeneous.

The average measurements of right lower extremity circumferences were 48.4 cm ± 4.7 for the mid-thigh and 33.7 cm ± 3.4 for the calf. The average measurements of right lower extremity diameters were 10.1 cm ± 1.3 for the knee and 6.2 cm ± 0.4 for the malleolus. The average measurements of right lower extremity lengths were 43.9 cm ± 3.3 for the thigh, 40.5 cm ± 3.6 for the calf,23.7 cm ± 0.7 for the foot, and 5.4 cm + 1.1 for malleolus height. The average measurements of foot breadth and ASIS breadth were 8.6 cm ± 0.3 and 25.4 cm + 2.1, respectively.

Table 5

Anthropometric Profile

Variable	Range (min-max)	M
Mid-thigh Circumference	16.0 (39.0 - 55.0)	48.4
Calf Circumference	13.9 (26.0 - 39.9)	33.7
Knee Diameter	5.9 (6.2 - 12.1)	10.1
ASIS Breadth	9.3 (21.7 - 31.0)	25.4
Malleolus Diameter	1.6 (5.4 - 7.0)	6.2
Foot Breadth	1.0 (8.2 - 9.2)	8.6
Thigh Length	12.9 (38.3 - 51.2)	43.9
Calf Length	11.9 (34.2 - 46.1)	40.5
Foot Length	3.4 (22.0 - 25.4)	23.7
Malleolus Height	4.2 (3.6 - 7.8)	5.4

Note. All measurements are in cm.

Analysis of Isokinetic Data

Isokinetic knee extension and flexion strength were tested for the purpose of quantifying the amount of fatigue that occurred following the Wingate Anaerobic Power Test. Knee extension and flexion were tested during a non-fatigued and fatigued state for both, 60 deg/s and 180 deg/s. The variables analyzed were peak torque during knee extension and flexion at 60 and 180 deg/s, knee extension and flexion torque during the 25th and 50th repetitions at 180 deg/s.

Comparisons between the non-fatigued and fatigued conditions are presented in Table 6. A dependent t-test was used to analyze the differences between these two variables. All variables were tested for differences at a .01 alpha level. Variable means, standard deviations, percentage change, and alpha levels are presented in Table 6. All percentage change calculations represent the percentage of decrease in torque production during isokinetic knee extension and flexion following the Wingate Anaerobic Power Test. All raw isokinetic data are located in Appendix D.

Table 6

Isokinetic Knee Extension and Flexion Comparisons During a Non-fatigued and Fatigued State

Variable	M ft/lbs	SD	% change	t	p
60 deg/s, peak torque					
extension					
NFT	53.00	15.3	14.6	4.03	.0007
FT	45.29	11.6			
flexion					
NFT	39.14	9.3	9.1	2.93	.0082
FT	35.57	7.7			
180 deg/s, peak torque					
extension					
NFT	37.14	7.2	14.2	3.90	.0009
FT	31.85	6.3			
flexion					
NFT	28.14	9.5	8.9	3.60	.0018
FT	25.71	6.5			
180 deg/s, 25th rep					
extension					
NFT	21.86	6.9	29.2	7.65	<.0001
FT	13.29	3.9			
flexion					
NFT	19.57	5.6	20.5	5.10	<.0001
FT	15.57	4.1			
180 deg/s, 50th rep					
extension					
NFT	10.14	4.3	11.3	1.63	.1188
FT	9.00	2.8			
flexion					
NFT	14.00	3.6	8.2	1.28	.2137
FT	12.86	4.3			
Average percentage change			14.5		

Note. Non-fatigued (NFT), Fatigued (FT)
$p < .01$.

The first and third hypotheses stated that no significant differences were in peak knee extensor strength during a non-fatigued and fatigued state. This was determined by measuring the peak torque produced by the extensor muscles during isokinetic leg extension at 60 and 180 deg/s in a non-fatigued and fatigued condition. Significant (p <.01) differences were determined for extension at 60 and 180 deg/s. At 60 deg/s and 180 deg/s, the non-fatigued group produced a 14.6% and 14.2% greater force than the fatigued group, respectively.

The second and fourth hypotheses stated that no significant differences were in knee flexor strength during a non-fatigued and fatigued state. This was tested by measuring the peak torque produced by the flexor muscles during isokinetic leg flexion at 60 and 180 deg/s in a non-fatigued and fatigued condition. Significant (p <.01) differences were determined for flexion at 60 and 180 deg/s. At 60 deg/s and 180 deg/s, the non-fatigued group produced a 4.1% and 8.7% greater force than the fatigued group, respectively.

The fifth and seventh hypotheses stated that no significant differences were in knee extensor muscular endurance during a non-fatigued and fatigued condition. This was tested by observing extensor torque during the 25th and 50th repetitions at 180 deg/s. Significant (p <.01) differences were determined for extensor muscular endurance during the 25th repetition but significant differences did not occur during the 50th repetition. During the 25th and 50th repetitions at 180 deg/s, the non-fatigued group produced a 29.2% and 11.3% greater force than the fatigued group, respectively.

The sixth and eighth hypotheses stated that no significant differences were in knee flexor muscular endurance during a non-fatigued and fatigued condition. This was tested by observing flexor torque during the 25th and 50th repetitions at 180 deg/s. Significant ($\underline{p}$ <.01) differences were determined for extensor muscular endurance during the 25th repetition but signficant differences did not occur during the 50th repetition. During the 25th and 50th repetitions at 180 deg/s, the non-fatigued group produced a 20.5% and 8.2% greater force than the fatigued group, respectively. Figures 6 through 9 illustrate the torque values and patterns of decrease in the torque values during a non-fatigued and fatigued condition at 60 deg/s and 180 deg/s.

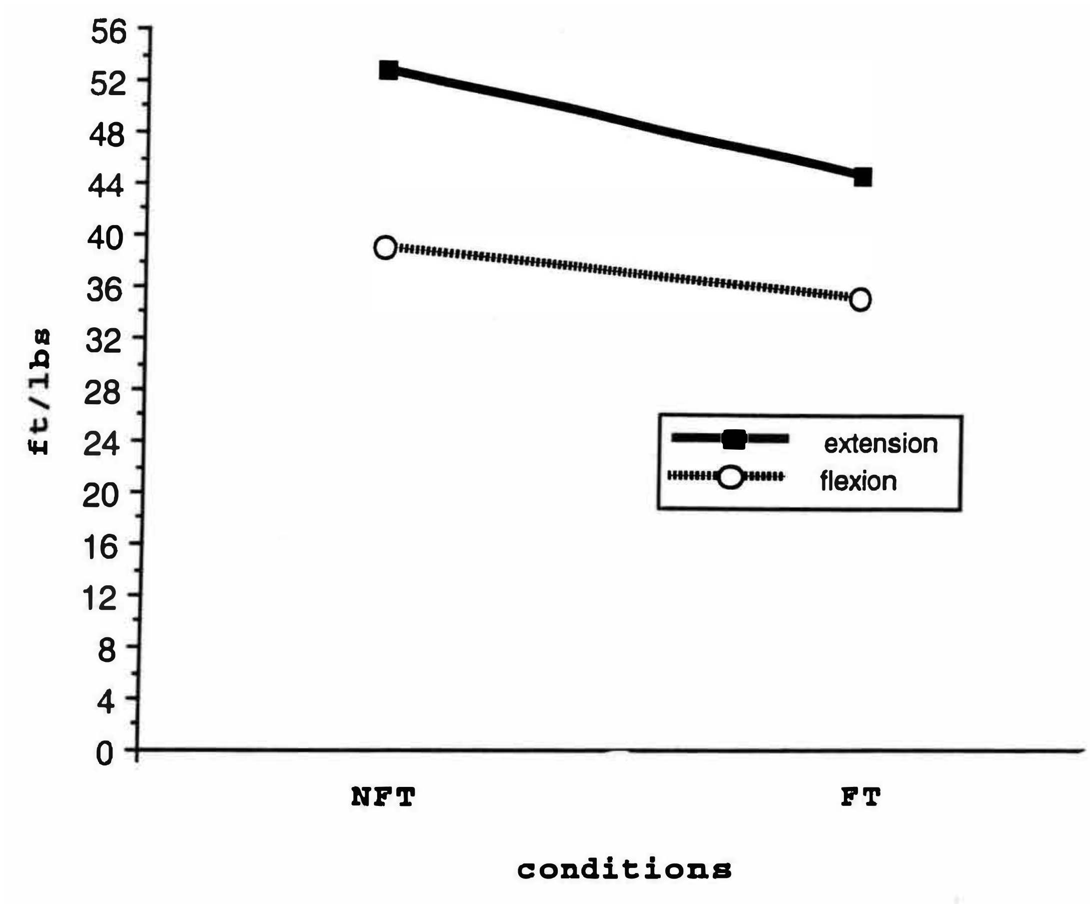

Figure 8. Isokinetic Knee Extension and Flexion Peak Torque (ft/lbs) at 60 deg/s during non-fatigued (NFT) and fatigued (FT) conditions.

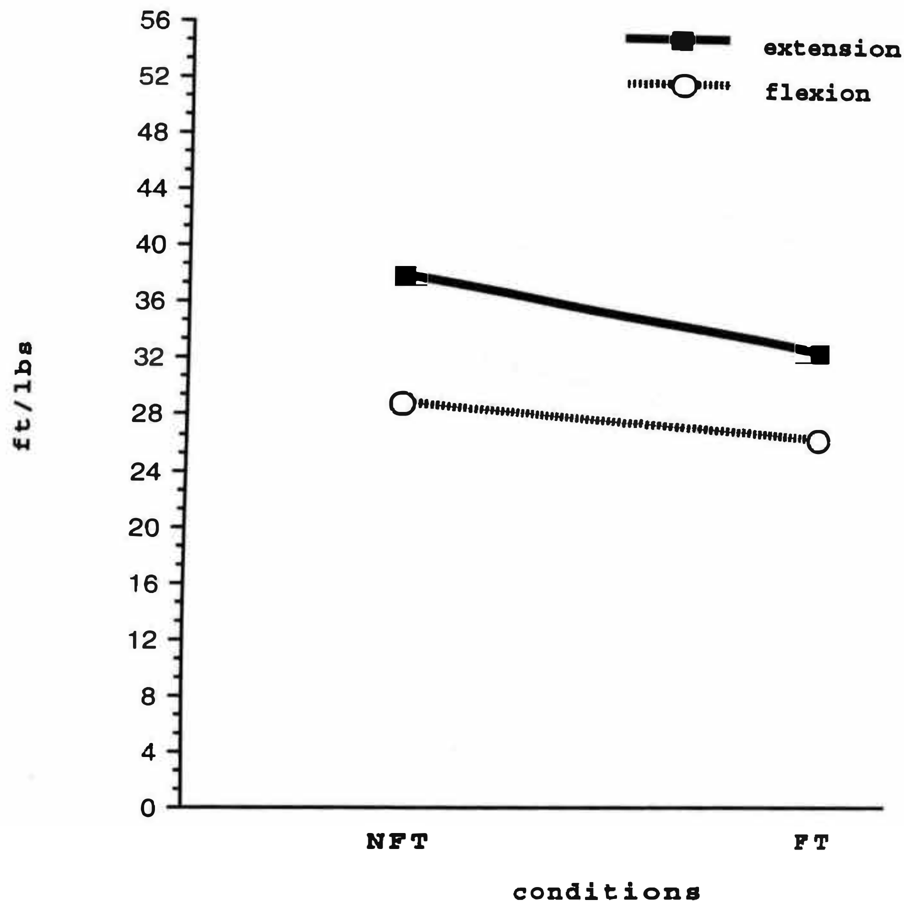

Figure 9. Isokinetic Knee Extension and Flexion Peak Torque (ft/lbs) at 180 deg/s during non-fatigued (NFT) and fatigued (FT) conditions.

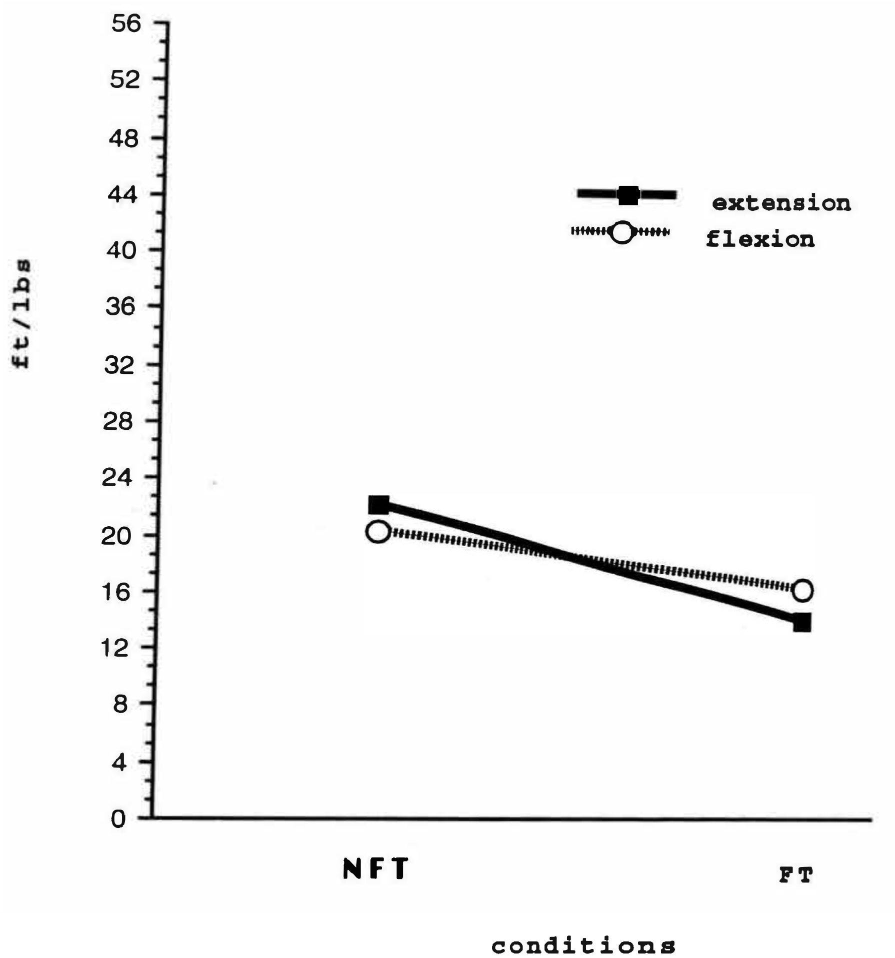

Figure 10. Isokinetic Knee Extension and Flexion Torque (ft/lbs) for the 25th Repetition at 180 deg/s during non-fatigued (NFT) and fatigued (FT) conditions.

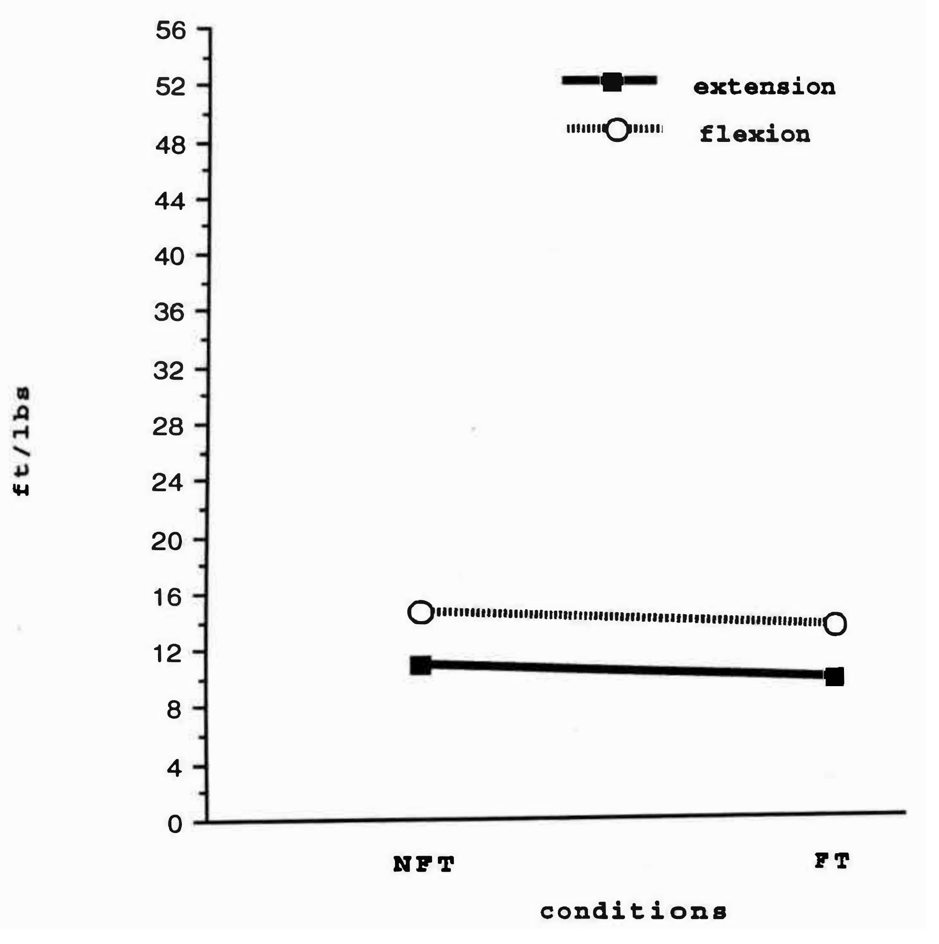

Figure 11. Isokinetic Knee Extension and Flexion Torque (ft/lbs) for the 50th Repetition at 180 deg/s during non-fatigued (NFT) and fatigued (FT) conditions

Wingate Anaerobic Power data

The Wingate Anaerobic Power Test was used to fatigue the participants' anaerobically. Each participant performed this method before the Cybek isokinetic testing of knee flexion and extension (Wingate-1) and before the countermovement vertical jump (Wingate-2). A fatigue index was used to quantify the amount of fatigue that occurred during the Wingate test. This was determined by examining the peak amount of revolutions that occurred during a 5-s period (Pkgm/5s) and comparing it with the low amount of revolutions that occurred during a 5-s period (Lkgm/5s). This was then expressed as a percentage of decline in power output. The Lkgm/5s was divided by the Pkgm/5s and then was expressed as a percentage. The average decline in power output for Wingate-1 and Wingate-2 was 71.1% and 71.5%, respectively (see Table 7).

Table 7

Descriptive Data for Wingate Test Power Output.

Variable	M	SD
Wingate-1		
Pkgm/5s	471.96	59.6
Lkgm/5s	136.45	26.5
Fatigue Index (%)	71.1	8.1
Wingate-2		
Pkgm/5s	478.11	52.5
Lkgm/5s	136.27	25.2
Fatigue Index (%)	71.5	7.3

Note. Pkgm = peak kilogram meters
Lkgm = low kilogram meters

Correlational research was used to provide additional evidence that anaerobic fatigue was present following the Wingate Anaerobic Power test (Table 8). The differences between non-fatigued and fatigued isokinetic knee extension at 60 deg/s was compared with the Wingate fatigue index. There was a moderate correlation (r = .73) between the two variables. There was also a high correlation (r = .80) between isokinetic knee extension at 60 deg/s and decreases in vertical jump heights. In addition, there was a high correlation (r = .82) between decreases in vertical jump height and decreases in power output during the Wingate Anaerobic Power test.

Table 8

Correlational Relationships Between Isokinetic Strength, Fatigue Index, and Vertical Jump Height Difference.

Variables	r	r^2
Isokinetic Strength/Fatigue Index	.73	.53
Isokinetic Strength/Vertical Jump	.80	.64
Vertical Jump/Fatique Index	.82	.67

Analysis of Biomechanical Data

The biomechanical data were analyzed for the purpose of quantifying the amount of change that occurred during the impact phase of a vertical jump. The variables examined were anterior/posterior shear forces, compression forces and flexion/extension moments at the ankle, knee, and hip during a non-fatigued and fatigued condition. Vertical jump height was also examined during a non-fatigued and fatigued condition.

A multivariate Hotellings T^2 with repeated measures was used to analyze compression joint reaction forces, anterior/posterior joint reaction forces, and flexion/extension joint moments at the ankle, knee, and hip. The dependent variable consisted of a combined score made up of the compression joint reaction force, anterior/posterior joint reaction force, and flexion/extension joint moment for each joint. These dependent variables were compared during a non-fatigued (NFAT) and fatigued (FAT) state.

The dependent variables of the ankle, knee, and hip for 20 untrained unskilled females between the age of 18 to 35 years of age were tested at an alpha level of .01. The means and standard deviations of the compression joint reaction forces, anterior/posterior joint reaction forces, and the flexion/extension joint moment for the ankle, knee, and hip are located in Table 9, Table 10, and Table 11, respectively. Vertical jump heights were analyzed and the summary of the data is located in Table 11. A dependent _t_-test was used to analyze the differences between these two variables.

Table 9

Descriptive Data of the Ankle.

Variables	M	SD
Compression force (N)		
NFT	513.6	121.5
FT	533.0	130.1
Shear force (N)		
NFT	261.0	95.5
FT	287.4	88.2
Joint moment (Nm)		
NFT	363.8	124.5
FT	355.2	117.8

Note. Non-fatigued (NFT), Fatigued (FT)

Table 10

Descriptive Data of the Knee.

Variables	M	SD
Compression force (N)		
NFT	480.2	210.8
FT	517.6	256.9
Shear force (N)		
NFT	262.6	87.5
FT	275.8	136.1
Joint moment (Nm)		
NFT	324.9	84.8
FT	306.0	74.6

Note. Non-fatigued (NFT), Fatigued (FT)

Table 11

Descriptive Data of the Hip.

Variables	M	SD
Compression force (N)		
NFT	345.4	87.0
FT	274.5	69.4
Shear force (N)		
NFT	86.2	51.8
FT	67.3	36.1
Joint moment (Nm)		
NFT	323.5	80.1
FT	282.5	83.5

Note. Non-fatigued (NFT), Fatigued (FT)

The ninth hypothesis stated that there would be no differences in the compression joint reaction forces, posterior/anterior joint reaction shear forces, and flexion/extension moment at the ankle between non-fatigued and fatigued subjects performing vertical jumps. No significant differences occurred between the two conditions (see Table 12).

The tenth hypothesis stated that there would be no differences in the compression joint reaction forces, posterior/anterior joint reaction shear forces, and flexion/extension moment at the knee between non-fatigued and fatigued subjects performing vertical jumps. No significant differences occurred between the two conditions (see Table 12).

The eleventh hypothesis stated that there would be no differences in the compression joint reaction forces, posterior/anterior joint reaction shear forces, and flexion/extension moment at the hip between non-fatigued and fatigued subjects performing vertical jumps. No significant differences occurred between the two conditions (see Table 12).

Table 12

Summary of Biomechanical Statistical Results.

Variable	T^2	F	p
Ankle	1.3624	0.4302	.7326
Knee	1.3345	0.4214	.7387
Hip	9.0204	2.8484	.0510

Note. Significance was $p < .01$.

After examining the compression joint reaction forces, anterior/posterior joint reaction forces, and the flexion/extension joint moment for the ankle, knee, and hip, it was determined that jump heights during a non-fatigued and fatigued condition may have played a major role in determining why differences did not occur between the biomechanical variables at the ankle, knee, and hip. Vertical jump height during a non-fatigued and fatigued condition were then analyzed. A dependent *t*-test was used to determine significant differences between the two conditions (see Table 13). Significant differences did exist between the two conditions ($p < .0001$). It was determined that the non-fatigued jumps were 6.65 cm higher than the fatigued jumps.

Table 13

Summary of Vertical Jump Height Statistical Results.

Variable	M (low-high)	SD	t	p
Jump height				
NFT (cm)	23.94 (19.8 - 30.8)	3.4	7.21	<.0001
FT (cm)	17.29 (11.1 - 22.3)	2.6		

Note. Significance was set at $p < .01$.

Summary of Isokinetic Data Hypotheses

The following hypotheses were tested at the .01 level of significance:

1. There is no difference in peak knee extensor strength during a non-fatigued and fatigued condition at 60 deg/s.

REJECTED

2. There is no difference in peak knee flexor strength during a non-fatigued and fatigued condition at 60 deg/s.

REJECTED

3. There is no difference in peak knee extensor strength during a non-fatigued and fatigued condition at 180 deg/s.

REJECTED

4. There is no difference in peak knee flexor strength during a non-fatigued and fatigued condition at 180 deg/s.

REJECTED

5. There is no difference in knee extensor muscular endurance (25th repetition) during a non-fatigued and fatigued condition at 180 deg/s.

REJECTED

6. There is no difference in knee flexor muscular endurance (25th repetition) during a non-fatigued and fatigued condition at 180 deg/s.

REJECTED

7. There is no difference in knee extensor muscular endurance (50th repetition) during a non-fatigued and fatigued condition at 180 deg/s.

FAILED TO REJECT

8. There is no difference in knee flexor muscular endurance (50th repetition) during a non-fatigued and fatigued condition at 180 deg/s.

FAILED TO REJECT

Summary of Biomechanical Hypotheses

The following hypotheses were tested at the .01 level of significance:

1. There is no difference in the compression joint reaction force, posterior/anterior shear joint reaction force, and flexion/extension moment at the ankle between non-fatigued and fatigued subjects performing vertical jumps.

FAILED TO REJECT

2. There is no difference in the compression joint reaction force, posterior/anterior shear joint reaction force, and flexion/extension moment at the knee between non-fatigued and fatigued subjects performing vertical jumps.

FAILED TO REJECT

3. There is no difference in the compression joint reaction force, posterior/anterior shear joint reaction force, and flexion/extension moment at the hip between non-fatigued and fatigued subjects performing vertical jumps.

FAILED TO REJECT

Summary

All data were classified as physiological data and biomechanical data. The physiological data were used to quantify the amount of anaerobic fatigue that occurred following the Wingate Anaerobic Power Test. Isokinetic knee flexion and extension was tested immediately following the Wingate Anaerobic Power Test. It was determined that significant differences occurred between a non-fatigued and fatigued condition. These differences occurred when testing peak torque production at 60 and 180 deg/s. Significant differences also occurred when testing at 180 deg/s during the 25th repetition. Significant differences did not occur during the 50th repetition when testing at 180 deg/s. All non-fatigued participants produced a greater amount of torque than the fatigued subjects.

The Wingate Anaerobic Power test was performed at two different times during this study. Peak anaerobic power output for 5-s during the Wingate Anaerobic Power Test was compared to least anaerobic power output for 5-s. There was a 71% decline in anaerobic power output during the Wingate test that proceeded the fatigued condition of the isokinetic testing. There was also a 75% decline in anerobic power output during the Wingate test that proceeded the fatigued condition of the vertical jump. This provides further support that anaerobic fatigue did occur during and immediately following the Wingate Anaerobic Power Test.

The biomechanical data were used to describe lower extremity responses to impacts associated with non-fatigued and fatigued vertical jumps. No significant differences occurred between the compression joint reaction force, posterior/anterior shear joint reaction force, and flexion/extension moment at the ankle, knee, and hip during a non-fatigued and fatigued condition. Significant differences did occur in vertical jump height between the non-fatigued and fatigued conditions. The non-fatigued group jumped 23.94 cm and the fatigued group jumped 17.29 cm.

CHAPTER V

DISCUSSION

This investigation was conducted for the purpose of determining if anaerobic fatigue would contribute to changes in lower extremity joint compression and shear forces and joint flexion/extension moments during the impact of a countermovement vertical jump. Isokinetic knee extension and flexion testing was conducted for the purpose of quantifying the amount of anaerobic fatigue that occurred following the fatiguing instrument.

The participants consisted of 20 unskilled untrained college age females, 18 to 35 years with no history of orthopaedic problems to the ankle, knee, or hip joints. Each individual participated in three testing sessions. The first session was used to obtain health history information, anthropometric measures, and to familiarize the participant with the cycle ergometer, vertical jumping, and testing protocol. Muscular strength and muscular endurance were assessed by lower extremity extension and flexion isokinetic testing during the first session.

During the second session, the Wingate Anaerobic Power Test was performed. This was immediately followed by lower extremity extension and flexion isokinetic testing. The right leg was for muscular strength and was tested within

10 s of the completion of the Wingate test. The left leg was tested for muscular endurance and was tested within 1 min of the completion of the Wingate test. These data were used to substantiate the amount of fatigue that occurred to each participant following the Wingate test.

Vertical jumping during a non-fatigued state and fatigued state was conducted during the third session. The non-fatigued vertical jump was conducted first with the fatigued jump occuring second. Each jump was conducted with the hands on the hips. Each participant performed a self-selected countermovement before each jump. The fatigued jump was preceeded by a Wingate anaerobic test with the jump being performed immediately following the Wingate Test. During the third session, the movement patterns of the vertical jump were analyzed by the Peak5 video analysis system, and the ground reaction forces were determined by an AMTI force platform. Anterior/posterior and compression joint forces at the ankle, knee, and hip were calculated from anthropometric, video, and force data. Flexion/extension moments at the ankle, knee, and hip were calculated using the same method.

Comparison of the joint forces and joint moments that occurred during the landing phase of the vertical jump in both a non-fatigued and fatigued state followed. A multivariate T^2 with repeated-measures was used to analyze the impact forces at the ankle, knee, and hip. After examining the compression joint reaction forces, anterior/posterior joint reaction forces, and the flexion/extension joint moment for the ankle, knee, and hip, it was determined that jump heights during a non-fatigued and fatigued condition may have played a major role in determining why differences did not occur between the biomechanical variables at the ankle, knee, and hip. Vertical jump height during a non-fatigued and fatigued condition were then analyzed by using a paired _t_-test.

Comparison of torque production that occurred during lower extremity isokinetic testing in both a non-fatigued and fatigued state was also analyzed by a paired _t_-test. Each of the hypothesis was tested at the .01 level of significance.

Descriptive statistics (means, standard deviations, and ranges) were calculated for the anthropometric measurements and demographic data of the participants. The average age of the participants was 26.6 (SD = 2.6) years, average weight of 61.4 (SD = 9.2) kg, and average height of 169.2 (SD = 6.5) cm. All subjects led an inactive lifestyle, had no history of lower extremity injuries or orthopaedic problems, and did not participate in high school or intercollegiate athletics that had a vertical jumping component. The anthropometric measurements were used for joint forces and moment calculations.

All data were classified as physiological data and biomechanical data. The physiological data were used to quantify the amount of anaerobic fatigue that occurred following the Wingate Anaerobic Power Test. Isokinetic knee flexion and extension was tested immediately following the Wingate Anaerobic Power Test. It was determined that significant differences occurred between a non-fatigued and fatigued condition. These differences occurred when testing peak torque production at 60 and 180 deg/s. Significant differences also occurred when testing at 180 deg/s during the 25th repetition. Significant differences did not occur during the 50th repetition when testing at 180 deg/s. All non-fatigued participants produced a greater amount of torque than the fatigued participants.

Peak anaerobic power output for 5 s during the Wingate Anaerobic Power Test was compared to least anaerobic power output for 5 s. There was a 71.1% decline in anaerobic power output during the test. This provides further support that anaerobic fatigue did occur during and immediately following the Wingate Anaerobic Power Test.

The biomechanical data were used to describe lower extremity responses to impacts associated with non-fatigued and fatigued vertical jumps. No significant differences occurred between the compression joint reaction force, posterior/anterior shear joint reaction force, and flexion/extension moment at the ankle, knee, and hip during a non-fatigued and fatigued condition. Significant differences did occur in vertical jump height between the non-fatigued and fatigued conditions. The non-fatigued group jumped 23.94 cm and the fatigued group jumped 17.29 cm.

Discussion

Significant differences were found for six of the eight isokinetic knee extension and flexion tests during a non-fatigued and fatigued condition. Significant differences were also found between the vertical jump heights during a non-fatigued and fatigued condition. No significant differences were found between the ankle, knee, and hip joint reaction forces and joint moments during non-fatigued and fatigued conditions. The following is a brief discussion that should provide a better understanding of the findings. This discussion will be divided into the following two sections: (a) Physiological Discussion and (b) Biomechanical Discussion.

Physiological Discussion

The physiological data collected were used to support and quantify the amount of anaerobic fatigue that occurred following the Wingate Anerobic Power Test. As noted earlier in Chapter 4, all isokinetic knee flexion and extension patterns exhibited a reduction in torque output following the Wingate Anaerobic Power Test. Significant differences ($p < .01$) occurred in six of the eight variables tested. The two exceptions were the differences between data collected in fatigued and non-fatigued state for isokinetic knee flexion and again knee extension during the 50th repetition at 180 deg/s. Although the differences were not significant, the reduction in torque output for extension and flexion were 11.3% and 8.2%, respectively.

Isokinetic knee flexion and extension peak torgue at 60 deg/s, peak torgue at 180 deg/s, and torgue for the 50th repetition at 180 deg/s exhibited similiar (parallel) patterns of torque reduction following the fatigued condition. The quadricep muscle group (knee extension) was able to produce a greater amount of force than the hamstring muscle group (knee flexion). This was expected because investigators have suggested that hamstring strength should be 50 to 75% of quadricep strength (Glick, 1980; Knapik, Bauman, Jones, & Vaughan, 1989).

Isokinetic knee extension and flexion torque for the 25th repetition at 180 deg/s had significant decreases in torque production but the patterns were not similiar to the other variables and testing conditions. The quadricep muscle group during a non-fatigued condition produced a greater amount of force than the hamstring muscle group; however, during the fatigued condition, the hamstrings produced a greater amount of force than the quadriceps (Figure 10, p.78). This could be a result of differences in muscle fiber composition between the quadricep and hamstring muscle groups. The quadricep muscle group may contain a larger number of fast glycolytic muscle fibers and/or the hamstring muscle group may contain a larger number of slow oxidative and/or fast oxidative-glycolytic muscle fibers. This would make the quadricep muscle group fast to fatigue and the hamstring muscle group slow to fatigue (Thorstensson & Karlsson, 1976). This may suggest that the hamstring muscle group would be able to resist fatigue for a longer period of time. The determination of the fiber types of the quadricep and hamstring muscle groups are beyond the scope of this research study.

A second explanation may be that the predominant muscle group working during cycle ergometry is the quadricep muscle group. Knee extension was the major movement pattern during the downstroke phase of the pedal revolution of the cycle ergometer. The quadricep muscle group was the primary mover during knee extension. Knee flexion occurred during the upstroke phase of cycle ergometry, but this was considered a passive movement with little contraction of the hamstrings occurring. Many investigators conducting electomyographical studies of hamstring activity during cycle ergometry have agreed that hamstring work during submaximal cycle ergometry is minimal (Ericson, Nisell, Arborelrus, & Ekholm, 1985; Houtz & Fischer, 1959; McLeod & Blackburn, 1980). These investigators stated that there was a minimal electromyographical signal present during the upstroke phase of the entire cycle. All subjects used toe-clips and were not instructed to pull up during the upstroke phase of the entire pedal cycle. All of the studies mentioned above used submaximal protocols. This may not represent the muscle activity that is occurring during maximal or supramaximal cycle ergometry. This researcher was unable to find electromyographical evidence that would support or dispute the submaximal electromyographical studies. The quadricep muscle group may fatigue at a faster rate than the hamstring muscle group because it is performing a greater amount of work (Ericson, Nisell, Arborelrus, & Ekholm, 1985; Houtz & Fischer, 1959; McLeod & Blackburn, 1980).

The average percentage change in torque output during lower extremity isokinetic testing between the non-fatigued and fatigued conditions was 14.2% (Table 6, p.73). The amount of fatigue varied from a 9.1% to a 29.2% decrease in strength following the Wingate Anaerobic Power Test. The limitations of the testing procedures may have underestimated the torque output differential. These differences may have been greater because of the inability to assess isokinetic knee flexion and extension torque values immediately following the Wingate Anaerobic Power Test. An elapsed time of 10 s passed before the right leg was tested for muscular strength and less than one minute passed before the left leg was tested for muscular endurance. The reason for this was that time was required to position and strap the participant into the isokinetic machine. As a result of this elapsed time, intramuscular anaerobic energy stores may have been replenished, making greater torque production a possibility in a relatively short amount of time (Sargeant & Dolan, 1987). The phosphagen and anaerobic glycolysis systems can replenish anaerobic energy stores almost immediately following a short intense bout of exercise (Sargeant & Dolan, 1987).

It is generally believed that phosphagen energy stores can be overloaded by repeated maximum bouts of heavy muscular activites lasting 5 to 10 s (Margaria, Cerretelli, & Mangilli, 1964). Such short periods of maximal exercise concomitantly result in the formation of small amounts of lactate (Tesch, 1980). Thus subsequent exercise bouts can begin after a 30 s rest period. As duration of all-out effort extends beyond 10 s, more energy is derived from glycolysis and less from phosphates, thus increasing lactate build up. This in turn, will increase the recovery time that is required for extended bouts of anaerobic activities (McArdle et al., 1991).

Ankle and hip isokinetic measurements were not taken. For this reason, evidence was not provided to support the premise that the surrounding musculature of the hip and ankle were fatigued by the Wingate Anaerobic Power Test. Hip flexion and extension, and ankle dorsiflexion and plantar flexion occurs during the Wingate Anaerobic Power Test. This allowed the investigator to assume that anaerobic fatigue was occuring in the muscles that promote and assist in these movements. The magnitude of the fatigue was unable to be determined because of the limitations of the testing apparatus and research protocol.

A fatigue index was developed to help quantify the amount of fatigue that occurred during the Wingate Anaerobic Power test. The Wingate test was administered two times, with one time begin before the lower extremity isokinetic tests and one time before the countermovement vertical jump. Decremants in power output did occur during both of the Wingate tests. There was a 71.1% and 71.5% decrease, respectively, in power output during the 30-s tests. These values appear to be within normal limits when compared to the results of other research studies. Hill and Smith (1992) reported decreases in power output values as low as 40% during the Wingate test and Jacobs et al. (1982) found decreases in power output as high as 67%. These two values are lower than this investigators data because they used workload values of .075 kg/kgBW. This study used the latest recommendations of a workload of .090kg/kgBW (Bar-Or, 1987) which would explain the higher values that were produced during the test.

For the purpose of this study, fatigue had been defined as the inability to maintain the required or expected force leading to the reduced performance of a given task (Sahlin, 1992). Based on this definition, we can support the idea that anaerobic fatigue did occur because there was a 71.1%

and 71.5% decrease, respectively, in power output during the 30-s testing period. In conjuction with the decrease in power output, there was a subsequent decrease in force production during the lower extremity isokinetic testing.

Correlational research was used to provide additional evidence that anaerobic fatigue was present following the Wingate Anaerobic Power test. The differences between non-fatigued and fatigued isokinetic knee extension at 60 deg/s was compared with the Wingate fatigue index. There was a moderate correlation (r = .73) between the two variables. This was used to determine if large decrements in isokinetic knee extension before and after the Wingate Anaerobic Power test was associated with large decreases in power output during the Wingate test. There was also a high correlation (r = .80) between isokinetic knee extension at 60 deg/s and decreases in vertical jump heights. This was used to substantiate that there was a concomitant decrease in vertical jump height when there was a decrease in isokinetic torque output. In addition, there was a high correlation (r = .82) between decreases in vertical jump height and decreases in power output during the Wingate Anaerobic Power test. This further supports the premise that anaerobic fatigue did occur and that there was a concomitant decrease in vertical jump height as a result of this fatique.

The muscles of the lower extremities were unable to produce the same amount of force during fatigued vertical jumping that was produced during non-fatigued vertical jumping. This was evidenced by a decrease in vertical jump height during the fatigued condition. The moderate to high correlation values between decreases in vertical jump height, decreases in power output during the Wingate Anaerobic Power test, and decreases in isokinectic knee extension at 60 deg/s further supports this premise.

The definition of fatigue provided by Sahlin (1992) is applicable to dynamic movements, such as, knee flexion and extension during isokinetic testing and cyclical movements used during cycle ergometry. Sahlin's (1992) definition of fatigue may not be applicable to static contributions of the muscles when providing stability for the lower extremity joints. The data in this study support the fact that fatigue did occur because there was a reduction of force output during the isokinetic testing and there was also a decrease in force production and subsequent power reduction that occurred during the Wingate Anaerobic Power Test. This data were unable to give definitive support to the question of whether enough fatigue occurred to deminish the static stabilizing contraction capabilities of the surrounding musculature of the ankle, knee, and hip.

Many sports contain a vertical jumping component. If fatigue occurs during the participation in one of these sports, then strength decrements may also occur. The lower extremity muscles provide dynamic stability for the ankle, knee, and hip and if the lower extremity muscles are fatigued then they may be unable to provide that function. This may effect the compression joint reaction forces, anterior/posterior shear forces, and flexion/extension moments of the lower extremity joints during the landing phase of a vertical jump.

<u>Biomechanical Discussion</u>

The biomechanical data were used to determine if differences existed in compression joint reaction forces, anterior/posterior shear joint reaction forces, and flexion/extension moments of force at the ankle, knee, and hip during a non-fatigued and fatigued condition. The data were collected before and immediately following the Wingate Anaerobic Power Test. Compression forces, anterior/posterior shear forces, and flexion/extension moments for the ankle, knee, and hip were then compared. No significant differences occurred between the two conditions. Although there were no significant differences, the description of the force absorption patterns does warrant further discussion.

The compression forces of the ankle and knee were slightly greater during the fatigued condition and the compression forces of the hip were greater during the non-fatigued condition (Tables 8 to 10). The greatest magnitude of compression forces were registered at the ankle, followed by the knee and then the hip. This pattern occurred in both the non-fatigued and fatigued conditions.

The shear forces of the ankle, knee, and hip demonstrated similiar patterns as the compression forces. The ankle and knee shear forces were slightly greater during the fatigued condition and the shear forces of the hip were greater during the non-fatigued condition (Tables 8 to 10). Similiar amounts of shear forces occurred at the ankle and knee with a big reduction in shear forces occurring at the hip.

Flexion/extension joint moments of force for the ankle, knee, and hip were slightly greater during the non-fatigued condition. All moments of force were similiar with the largest moments occurring at the ankle.

The expected outcome would have been that the joint forces and joint moments would increase when the surrounding musculature was placed in anaerobic fatigue. The reason being that the muscles would be unable to absorb the forces that were generated during the landing phase of the vertical jump if they were fatigued anaerobically. If this occurred during one impact, then the passive supportive tissues would be acutely stressed; if this occurred during multiple impacts, then the passive supportive structures would be chronically stressed. The acute and chronic stresses of the impacts may lead to inflamation and ruptures of the passive supportive structures of the lower extremity joints.

There may be two explanations why the compression forces, anterior/posterior shear forces, and flexion/extension moments did not increase during the fatigued condition. The first explanation is that the surrounding musculature of each joint may not have been fatigued adequately. The muscles may have been able to produce enough static tension to absorb the forces of the body landing from the vertical jump. Isokinetic knee flexion and extension did demonstrate an average decrease in torque production of 14.2% following the Wingate Anaerobic Power test. Even though there was a reduction in torque production, the Wingate Anaerobic Power test may have not fatigued the muscles of the lower extremities sufficiently. Another factor may have been the time that it took for the subject to dismount the cycle ergometer and walk to the force platform and jump. The approximate time was about 5 to 10 s. This may have been enough time for anaerobic energy stores to replenish.

The second and more likely explanation may be that there was a reduction in jump height during the fatigued condition. This decrease in jump height would cause a reduction in ground reaction forces. The participant is falling from a shorter distance causing the ground reaction forces to decrease during the fatigued condition. This would in turn produce a reduction in joint reaction forces. Vertical jump height during a non-fatigued and fatigued condition was analyzed and significant differences did occur between the two conditions (Table 11). The participants produced a greater jump height when they were non-fatigued. The non-fatigued jumps averaged 6.6 cm greater in jump height than the fatigued jumps.

Conclusion

In conclusion, anaerobic fatigue was evident because of a reduction in peak knee flexor and extensor strength when isokinetically tested at speeds of 60 and 180 deg/s. There was also a reduction in knee flexor and extensor strength during the 25 repetition of isokinetic knee testing at a speed of 180 deg/s. All isokinetic testing was performed before and after a Wingate Anaerobic Power Test. There was also a concomittant decrease in power output that occurred during the Wingate Anaerobic Power Test.

It was concluded that there was no differences in the compression joint forces, posterior/anterior shear joint reaction forces, and flexion/extension moments at the ankle, knee, and hip between non-fatigued and fatigued participants while performing vertical jumps. It was also concluded that there was a significant decrease in vertical jump height between the non-fatigued and fatigued participants.

Based on analysis of each research hypothesis and within the scope and limitations of this study, it may be concluded that anaerobic fatigue induced with the Wingate Anaerobic Power Test does not significantly influence kinetic variables of the ankle, knee, and hip during the landing phase of vertical jumping. It can also be concluded that anaerobic fatigue produces significant reductions in vertical jump heights. This reduction in vertical jump height may have been the major factor that contributed to no significant differences between the kinetic variables.

Recommendations for Future Research

Based on the results of the present study, the following recommendations for future studies are made.

1. This study should be replicated with another anaerobic fatiguing protocol being implemented. The protocol should be a running protocol and/or a protocol that mimics a real-life situation. Another protocol may include a combination of running, shuffle steps, and vertical jumps. This protocol comes closer to mimicking certain movements associated with sports activities.

2. This study should be replicated with the use of an aerobic fatiguing protocol. Many athletic events contain a large component of aerobic activity as well as anaerobic activity. Each of these components should be analyzed to determine if they will effect joint reaction forces.

3. This study should be replicated with the jump height being standardized. The next researcher may want to use drop jumps from a platform. Significant differences in ankle, knee, and hip forces and moments may occur if the jump heights were standarized during both a non-fatigued and fatigued condition.

4. This study should be replicated with participants that are experienced vertical jumpers, such as basketball and/or volleyball players.

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APPENDICES

APPENDIX A

Human Consent Form

Health History Questionaire

Physical Activities Readiness Questionaire (PAR-Q)

TEXAS WOMAN'S UNIVERSITY
HUMAN CONSENT FORM

Anaerobic Fatigue and Its Effect on Kinamatic and Kinetic Variables Associated With Vertical Jumping

You are being asked to participate in a study that measures different properties associated with vertical jumping. You will be asked to perform one vertical jump during a non-fatigued state and one vertical jump in a fatigued state. If you agree to participate, you will be asked to attend three 30-45 minute testing sessions. Participation is voluntary and you have the right at any time during the study to discontinue that participation.

The first session will be used to collect medical history information, anthropometric measurements, and to familiarize you with the procedures and equipment. Anthropometric measurements consist of girth, circumference, width, and height measurements of your lower extremities. Anthropometric measurements are used to estimate your leg mass and the center of your joints. The second session will be used to test leg strength before and after a bicycle ergometer test. Approximately one week later, the third session will occur. This session will be used to perform a maximal vertical jump during both a non-fatigued and fatigued state. The maximal vertical jump consists of a countermovement before the actual airborne phase. The jump will be performed with your hands on the hips. The countermovement is self-selected, this means that you will bend your knees enough to elicit a maximal vertical jump. The non-fatigued vertical jump will be conducted first with the fatigued jump occuring second. The vertical jump will be filmed by four video cameras to obtain the appropriate data.

The bicycle test is used to induce fatigue. The bicycle test will last for 30 seconds. You will be asked to pedal at a maximal rate for the entire 30 s. The resistance will be determined by multiplying .090 kg by your body weight in kg. A test of leg strength will be given before and after the bicycle test to determine the amount of fatigue that has occurred. The strength testing is a simple knee flexion/extension test performed on an isokinetic strength testing machine. Knee extension will consist of the leg moving from a bent knee position of 90 degrees to a straight leg position of 180 degrees. Knee flexion will consist of the leg moving from a straight leg position of 180 degrees to a bent knee position of 90 degrees. You will be tested while you are in a seated position. Your leg will be strapped to the machine at the ankle and at the mid-thigh. You will be asked to perform 5 maximal knee extension/flexion movements with the right leg at a slow speed of 60 degrees/second and 50 maximal knee extension/flexion movements with the the left leg at a faster speed of 180 degrees/second.

This consent form describes the risks associated with the study. To safeguard your privacy, records will contain only subject numbers and all data will be kept in a locked file. The data will be destroyed after four years. Please feel free to ask any questions that you have at any time.

Risks

There is a slight chance for musculoskeletal injury in the form of sprains and strains during the bicycle test and the isokinetic test. You may also experience some discomfort in the form of delayed muscle soreness. This should disappear in 48 to 72 hours following the tests. Sufficient warm-up and supervision will help alleviate the chances of this occurring. Possible cardiac or cardiovascular event (heart attack) may occur during the maximal bicycle test. To reduce the risk: all subjects will be 18-35 years of age, non-smokers, and screened via medical history questionaire for cardiovascular risk factors and any other metabolic abnormalities (eg. diabetes) that would preclude you from the study. In addition, a 12 lead electrocardiograph (ECG) will continously monitor your heart rate during the warm-up period, the bicycle test, and the cool-down period. Blood pressure screening will also take place prior to your participation in the study.

I understand that no medical service or compensation is provided to the subject by the University as a result of injury from participation in this research.

You will be told about the results of the study when the data analysis is completed. You are able to ask questions at any time during the study. If you have any questions, you may contact me at home any time.

An offer to answer all of my questions regarding the study has been made and I have been given a copy of the dated and signed consent form. A discription of the possible discomforts and risks have been discussed with me. I understand that I may terminate my participation in the study at any time.

If you have any concerns about the way this research has been conducted, contact the Texas Woman's University Office of Research and Grants Administration at 817-898-3375.

Video Recording Consent

I, the undersigned, do hereby consent to the recording of my image for research purposes by Russell E. Robinson, acting on this date under the authority of the Texas Woman's University.

(Please check one of the following)

_____I understand that the material recorded may be made available for educational and informational purposes; and I hereby consent to such use.

_____I do not consent to the use of material recorded today for future educational and informational purposes.

Listed below are phone numbers that are available to you if any questions arise regarding this study.

Russell E. Robinson, M.S.	817-431-2823 (H) 817-898-2575 (W) 2073 Quarter Horse Lane Keller, TX 76248
Jerry Wilkerson, PhD.	817-898-2598

I hereby authorize Russell E. Robinson and Jerry Wilkerson to perform the above procedures. I also authorize, with the supervision of Russell E. Robinson, other qualified personnel in the form of graduate students in biomechanics that may assist in the data collection procedures.

__________________________ ________________
Subject's signature Date

__________________________ ________________
Witness signature Date

Self-Administered Pre-exercise Medical History Form

Name ______________________________ Date ____________________

Past History (have you ever had?)

	Yes	No	Explain:
Rneumatic fever	( )	( )	____________
Heart murmur	( )	( )	____________
High blood pressure	( )	( )	____________
Any heart trouble	( )	( )	____________
Disease of arteries	( )	( )	____________
Varicose veins	( )	( )	____________
Lung disease	( )	( )	____________
Injuries to back	( )	( )	____________
Injuries to ankle, knee or hip	( )	( )	____________
Epilepsy	( )	( )	____________

Operations (explain): ______________________________________

____

____

Present Symptons (have you recently had?)

	Yes	No	Explain:
Chest pain	( )	( )	____________
Chest pain when exercising or under emotional stress	( )	( )	____________
Shortness of breath	( )	( )	____________
Asthma	( )	( )	____________
Irregular or rapid heart beat	( )	( )	____________
Cough on exertion	( )	( )	____________
Fainting or dizziness	( )	( )	____________
Weakness or numbness of an arm or leg	( )	( )	____________
Balance problem while walking or standing	( )	( )	____________
Coughing of blood	( )	( )	____________
Back pain	( )	( )	____________
Swollen, stiff, or painful joints	( )	( )	____________
Do you regularly awaken at night to urinate?	( )	( )	____________
Allergies to drugs	( )	( )	____________
Are you currently pregnant?	( )	( )	____________

Others ____

Family History (Have any of your relatives had?)

	Yes	No	Explain:
Heart attack	( )	( )	________
High blood pressure	( )	( )	________
High cholesterol	( )	( )	________
Diabetes	( )	( )	________
Congenital heart disease	( )	( )	________
Heart operations	( )	( )	________
Cancer	( )	( )	________

Other: ____

____

Medications

	Yes	No	Explain:
Are you presently taking any medications?	( )	( )	________
Have you taken any medication during the past?	( )	( )	________

Risk Factors

1. Smoking	Yes	No	
Do you smoke?	( )	( )	________
Cigarettes	( )	( )	How many?_ How many years?_______
Cigars	( )	( )	How many?___ How many years?_____
Pipes	( )	( )	How many?_ How many years?_______

How old were you when you started?__________

If you have stopped, when did you?________ Why? ______________

2. Diet

What is your current weight?________ One year ago__________

Are you currently dieting? __________ Why and what type of diet?____

3. Exercise

Do you engage in recreational sports or physical activity?______

What?____

How often?____

How fast do you think you walk each day in addition to the above? ______________________________

Is your occupation: Sedentary ( ) Moderately active( )
Active ( ) Heavy work ( )

Do you have discomfort, shortness of breath, or pain with moderate exercise? ______
Explain: ______________________________
Were you a high school or college athlete? __________
Explain: ______________________________

4. Exercise Test
Have you ever had an exercise stress test? ___yes ___no
If yes, when? ______________________
Any problems? ______________________________

Blood Pressure History

Date____________ ______/______
Date____________ ______/______
Date____________ ______/______
Date____________ ______/______

Date of Birth____________ Age____________

Address____

____

____

Phone______________________________

Person to contact in case of emergency ______________________

Phone______________________________

Personal Physician____________________________

Phone______________________________

PHYSICAL ACTIVITY READINESS QUESTIONAIRE (PAR-Q)

Purpose: For most people, physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable.

Directions: Please read each question below. Answer each question with a "yes" or "no". If the answer is yes to any question, please explain fully the extent of the problem.

_____yes______no 1. Has your doctor said you have heart trouble?

_____yes______no 2 Do you frequently suffer from pains in your chest?

_____yes______no 3. Do you often feel faint or have spells of severe dizziness?

_____yes______no 4. Has a doctor ever said your blood pressure was too high?

_____yes______no 5. Has a doctor ever told you have a bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise?

_____yes______no 6. Is there a good physical reason not mentioned her why you should not follow an activity program even if you wanted to?

PHYSICAL ACTIVITY READINESS QUESTIONAIRE (PAR-Q)

Continued:

_____yes_____no   7. Are you over age 65 and not accustomed to vigorous exercise?

_____yes_____no   8. Are you or do you think that you are pregnant?

APPENDIX B

Anthropometric Sheet and Data

ANTHROPOMETRIC MEASUREMENTS

Subject: ______________________________ Age: _____ Date: __________

Mean

_____ 1. Mid-thigh Circumference ____________ ____________ ____________

_____ 2. Calf Circumference ____________ ____________ ____________

_____ 3. Knee diameter ____________ ____________ ____________

_____ 4. ASIS Breadth ____________ ____________ ____________

_____ 5. Malleolus Diameter ____________ ____________ ____________

_____ 6. Foot Breadth ____________ ____________ ____________

_____ 7. Thigh Length ____________ ____________ ____________

_____ 8. Calf Length ____________ ____________ ____________

_____ 9. Foot Length ____________ ____________ ____________

_____ 10. Malleolus Height ____________ ____________ ____________

_____ 11. Body Mass ____________ ____________ ____________

Anthropometric Data

Anthropometric Abbreviations: MC = Midthigh Circumference

CC = Calf Circumference

KD = Knee Diameter

AB = ASIS Breadth

MD = Malleolus Diameter

FB = Foot Breadth

TL = Thigh Length

CL = Calf Length

FL = Foot Length

MH = Malleolus Height

Part.	MC	CC	KD	AB	MD	FB	TL	CL	FL	MH
1	54.0	39.0	11.2	25.3	6.2	8.7	44.0	45.8	23.9	3.8
2	51.0	35.0	09.5	23.0	6.5	8.8	43.5	43.5	23.6	4.5
3	49.0	36.5	10.9	25.4	6.1	9.0	39.5.	41.2	23.1	4.6
4	51.0	36.2	10.8	23.7	5.8	8.4	42.2	43.5	23.5	3.6
5	48.0	33.0	09.5	23.0	5.7	8.5	41.3	38.4	23.8	7.8
6	50.0	34.5	12.1	26.9	5.4	8.4	42.2	46.1	24.0	5.4
7	52.5	39.9	11.4	26.2	6.5	9.2	42.9	40.9	23.2	4.4
8	50.0	32.0	06.2	21.7	6.2	8.3	42.8	36.7	22.7	6.6
9	55.0	34.5	11.1	24.3	6.6	8.2	41.5	34.2	23.6	6.0
10	55.0	33.0	09.7	24.7	5.8	9.0	42.2	35.2	24.4	7.7
11	52.6	35.0	10.5	24.8	6.2	8.2	43.6	37.5	23.5	5.6
12	42.5	28.5	08.8	24.0	5.8	8.6	38.3	35.7	22.0	4.8
13	51.0	38.0	12.0	31.0	6.8	8.2	51.2	40.9	25.4	6.6
14	48.3	33.6	10.1	25.3	6.1	8.5	43.9	40.5	23.6	5.4
15	41.0	26.0	09.5	23.5	5.7	8.2	44.5	38.2	23.7	5.7
16	48.4	33.7	10.1	25.4	6.2	8.6	43.9	40.5	23.7	5.4
17	44.0	31.5	10.3	25.5	6.2	8.7	49.5	43.4	24.2	5.2
18	39.0	28.0	09.5	28.0	7.0	9.1	46.0	38.6	24.5	5.6
19	43.5	31.5	09.8	26.0	5.8	8.4	50.7	39.5	23.0	5.5
20	42.0	34.0	09.8	28.2	6.2	8.5	43.3	44.2	23.7	5.1
21	48.0	35.0	09.7	27.2	6.4	8.7	45.6	45.9	24.2	4.6

APPENDIX C

Isokinetic Data

Isokinetic Data

Isokinetic Abbreviations:

60PT EX = 60 deg/s, Peak Torque, extension

60PT FL = 60 deg/s, Peak Torque, flexion

180PT EX = 180 deg/s, Peak Torque, extension

180PT FL = 180 deg/s, Peak Torque, flexion

180-25 EX = 180 deg/s, 25th rep, extension

180-25 FL = 180 deg/s, 25th rep, flexion

180-50 EX = 180 deg/s, 50th rep, extension

180-50 FL = 180 deg/s, 50th rep, flexion

Isokinetic Data

Participants	60PT EX NFAT	60PT EX FAT	60PT FL NFAT	60PT FL FAT
1	78	57	57	48
2	51	48	36	42
3	57	33	36	27
4	51	45	39	36
5	45	51	36	42
6	57	45	45	39
7	48	45	33	30
8	54	33	45	30
9	69	63	45	42
10	96	78	54	51
11	66	54	48	42
12	36	36	27	27
13	48	51	45	30
14	36	42	30	30
15	51	39	30	30
16	45	42	48	39
17	57	48	42	39
18	30	30	24	24
19	39	30	27	27
20	39	36	30	30
21	60	45	45	42

<u>Isokinetic Data</u>

Participants	180PT EX NFAT	180PT EX FAT	180PT FL NFAT	180PT FL FAT
1	60	48	39	36
2	30	30	24	24
3	36	27	27	18
4	36	36	24	21
5	36	30	33	33
6	45	36	36	30
7	33	33	27	24
8	30	33	30	24
9	33	33	27	24
10	51	42	45	36
11	54	39	39	36
12	30	21	21	18
13	36	36	18	18
14	27	21	18	18
15	30	30	27	27
16	36	27	30	30
17	42	36	30	27
18	24	27	18	21
19	30	27	21	18
20	33	30	27	27
21	48	27	33	30

Isokinetic Data

Participant	180-25 EX NFAT	180-25 EX FAT	180-25 FL NFAT	180-25 FL FAT
1	36	18	24	18
2	30	15	18	12
3	12	03	18	09
4	24	15	18	18
5	18	18	24	18
6	18	12	18	15
7	18	09	18	12
8	18	15	18	18
9	24	18	18	15
10	36	18	36	24
11	27	12	27	15
12	18	09	18	15
13	27	15	15	12
14	15	09	12	12
15	21	15	21	18
16	24	15	21	18
17	21	15	21	18
18	12	12	09	06
19	15	12	15	15
20	18	09	18	18
21	27	15	24	21

Isokinetic Data

Participants	180-50 EX NFAT	180-50 EX FAT	180-50 FL NFAT	180-50 FL FAT
1	15	12	15	12
2	18	09	18	09
3	03	03	09	09
4	09	09	15	12
5	09	12	15	18
6	06	09	15	15
7	06	06	18	15
8	12	09	15	15
9	15	12	09	15
10	15	15	18	18
11	06	09	12	15
12	12	06	12	09
13	12	09	06	06
14	06	06	12	06
15	12	12	18	18
16	18	12	18	18
17	09	09	18	12
18	09	06	12	06
19	06	09	15	09
20	06	06	09	15
21	09	09	15	18