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Developing Normative Data for Three Unilateral Lower Extremity Functional Tests

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Developing Normative Data for Three Unilateral Lower Extremity Functional Tests

By

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THESIS PROPOSAL

Submitted to the Department of Physical Therapy at Grand Valley State University at Allendale, Michigan in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN PHYSICAL THERAPY

1997
DEVELOPING NORMATIVE DATA FOR THREE UNILATERAL LOWER EXTREMITY FUNCTIONAL TESTS

ABSTRACT

The purpose of this research study was to gather normative data on three unilateral extremity functional tests: single-leg triple hop for distance, single-leg timed hop, and single-leg cross-over triple hop for distance. A total of ninety-six male and female subjects between the ages of 18-30 volunteered to participate in this study. The variables looked at in this study were: age, gender, height, weight, leg dominance, activity level, and order of tests performed. Data from the three functional hop tests were divided into aggregated data and non-aggregated data. The data were analyzed using SPSS® for Windows and SAS® software packages. Gender, activity level, and leg dominance influenced the results of the functional tests. This study may assist rehabilitation professionals in evaluating and documenting functional progression.
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DEFINITION OF TERMS

Closed Kinetic Chain (CKC): "Occurs when the terminal segment of the limb is fixed, such as during a squat, leg press, step up, stair climber machine" (Wilk, Escamilla, Flesig, Arrigo, & Barrentine, 1995, p.337).

Fryette's Laws:

Law I- Side bending and rotation of the thoracic, lumbar, and sacral vertebrae occur in the opposite direction when in the neutral spine position.

Law II-Side bending and rotation of the cervical spine always occur in the same direction. Side bending and rotation of the thoracic, lumbar, and sacral vertebrae occur in the same direction when the spine is in full flexion or extension.

Law III-Vertebral motion in any plane will reduce the available motion in another plane.

*It is theorized that cervical motion as described in Law 11 actually encompasses vertebrae extending from the first cervical vertebra to the third or fourth thoracic vertebra. It is also theorized that the fifth lumbar vertebra and the first sacral vertebra always move in the same direction regardless of the spinal position (Kaltenborn, 1993).

Functional Testing: "The performance of x number of trials of a functional activity or series of activities, to indirectly assess muscle strength and power, and attempt to quantify functional ability" (Bandy, 1994, p. 108).
Leg Length: The length of the leg measured from the floor to the subject's anterior superior iliac spine on the pelvis. The subject will not be wearing shoes for this measurement.

Normal population: Subjects that have not had any surgeries of the back, hip, knee, ankle, or foot; have not had any injuries of the same structures that required care by a physician within the last year; a range of motion of at least 65°-70° of the hip flexors, quadriceps, and hamstring muscle groups; a range of motion of at least 10° of the gastrocnemius, and at least 10° of the soleus muscle groups; no known knowledge of any pathologies; are not currently pregnant or have given birth within the last six months, and are currently not involved in intercollegiate sports.

Normative values: Those values collected from unilateral functional tests performed by the normal population.

Open Kinetic Chain (OKC): "Occurs when the terminal segment is free to move, such as with knee extension, knee flexion, or kicking" (Wilk et al., 1995, p.337).

Partially Kinetic Chain Exercises: "Occurs when the distal segment meets resistance but is not completely fixed or stationary, such as during use of the slide board, cross-country skiing, or swimming" (Wilk et al., 1995, p.337).

SLR: Subject lies down with low back and sacrum flat on the table and one leg flexed with foot flat on the table. Subject then raises the other leg with knee straight and foot relaxed. An angle of approximately 80° between the table and the raised leg is considered normal hamstring length (Kendall, F., Kendall, E., Provance, 1993).
**Succession of CKC -OKC Drills:** "Occurs when the distal or terminal segment repeatedly and rapidly opens and closes, such as during plyometrics, high-stepping agility drills, running, and Jumping" (Wilk et al., 1995, p.337).

**Thomas Test:** "Subject is seated at end of table with thighs halfway off table. The examiner places one hand behind subject's back and the other hand under one knee, flexing subjects thigh toward their chest and giving assistance as the subject lies down. The subject then holds thigh, pulling knee towards chest only enough to flatten the low back and sacrum on table" (Kendall et al., 1993-19931, p.333). The subject allows the unsupported thigh to drop towards the table with the knee flexed over the end of the table. If subject's posterior thigh touches the table and knee is flexed approximately 80°, hip flexors are considered normal in length (Kendall et al., 1993).
CHAPTER I

INTRODUCTION

Context and Background

Within the medical field, assessment and accountability of treatment methods as well as method effectiveness, is growing in importance. This push for quality and effectiveness of health care has even been dubbed "the third revolution in medical care" by Arnold Relman (Jette, 1993, p. 528). This "Era of Assessment and Accountability" follows the "Era of Expansion" and "Era of Cost Containment" as major shifts in how medical care has been looked upon since the end of World War II (Jette, 1993, p. 528; Jette, 1995, P. 965).

The governmental expenditures for health care have been continuously rising during the past thirty years. In 1965, the total expenditure for health care was $5.6 billion (Jette, 1995). In 1989, this increased to $620 billion encompassing 11.2% of the Gross National Product (GNP) (Jette, 1995). Although costs decreased to $150 billion in 1990 (Jette, 1995), 13% of the GNP was spent on health care concerns (Jette, 1995). The major factors contributing to these high costs include the increasing incidence of chronic disease, the increasing proportion of the elderly in the population, and the high costs of healthcare (Jette, 1990).

Physical therapy is one of the largest nonphysician groups of health professionals (Jette, 1993) that has shown marked growth as a profession in recent years. With this growth, utilization of services has increased and is projected to increase even more in the
future (Jette, 1995). As in medicine, which uses outcome assessments that look at function and quality of life as well as disease and mortality rates (Jette, 1995), physical therapy needs to address the pros and cons of different interventions to better contain cost expenditures. Governmental agencies and third-party payers have recently been addressing cost issues by carefully scrutinizing therapeutic interventions and procedures and the resulting outcomes of patient care. The Joint Commission on Accreditation of Health Care Organizations' (JCAHCO) emphasis has shifted from traditional structural measures to patient outcomes and quality assurance (Jette, 1993). The Agency for Health Care Policy and Research (AHCPR) was developed to examine the impact of health care services and procedures on patient's survival, health status, functional capacity, and quality of life (Jette, 1993). As a consequence of the changing outlook on health care, outcomes of physical therapy are being used to justify policies regulating practice as standards for reimbursement. These outcomes have started to shift from a traditional impairment basis (e.g. limits in range of motion and muscle weakness) to one that is thought to more optimally reflect functional status (Jette, 1995) (e.g. hop tests, shuttle run, no pivot shift and pivot shift, carioca, stairs running, etc.) (Barber, Noyes, Mangine, McCloskey, & Hartman, 1990; Risberg & Ekeland, 1994; Tegner, Lysholm, Lysholm, & Gillquist; 1986).

Physical therapists, as well as other rehabilitation experts, need practical functional evaluation methods that are easy to use and relatively inexpensive. A large proportion of functional performance activities used for assessment in the clinic include the use of the lower extremities. Examples of these activities include walking, squatting
and going up and down stairs. Development of reliable and valid measures of lower extremity functional status is greatly needed for documenting changes in rehabilitation, for follow-up studies, and for quality assurance (Oberg, U., Oberg, B., & Oberg, T., 1994).

The lower extremity (LE) is made up of a series of rigid links (bones) interconnected together to form a system. The lower spine, hip, knee, and ankle-foot complex work together in a kinematic chain to produce functional movements. There are two types of kinematic chain systems, open and closed. Each type affects the lower extremity functions differently. During closed kinematic chain (CKC) activities whereby, the distal end of the segment is fixed (Bunton, Pitney, Kane, Cappaert, 1993; Norkin & Levangie, 1992; Fu, Woo & Irrgang, 1992; Wilk & Andrews, 1992; Wilk, Escamilla, Fleisig, Arrigo, Barrentine, 1995), multiple joints within the system work together to provide the movement (Bunton et al., 1990; Norkin & Levangie, 1992; Wilk & Andrews, 1992). One example is rising from a squatting position, where the lower spine, hips, and knees extend while the ankles plantarflex. Ligaments and muscles interconnect the segments within the LE. Ligaments provide passive elastic moments, whereas, muscles dynamically accelerate and decelerate the limb during CKC multiplanar movements (Bunton et al., 1993). Bunton also emphasized that a wide variety of muscle actions are possible with CKC activities: isometric, concentric, and eccentric contractions. Open chain systems (OKC) function when the distal segment is free to move as with isolated knee flexion and extension, for example in sitting (Bunton et al., 1993; Norkin & Levangie, 1992; Fu et al., 1992; Wilk et al., 1995).
Many functional activities that use the lower extremities, such as those previously mentioned, include closed kinematic chain systems, exclusively or in part. Although methods of evaluating lower extremity functional performance should include CKC activities, many physical status measures that incorporate open chain movements have been used in the past. These include goniometry for ROM assessments, isokinetic testing for muscle strength, functional score questionnaires, joint laxity and limb girth measurements. Isokinetic testing, which operates as an OKC system, is a common tool for assessing functional performance due to its inherent safety, objectivity, and reproducibility. Recently, this technique's ability to objectively assess lower extremity function, and do it safely, has been questioned. (Wilk, Romaniello, Soscia, Arrigo, & Andrews, 1994). Research results have indicated that isokinetic testing may actually increase the amount of anterior shear forces occurring at the knee joint. This method uses open kinetic chain motions that do not produce as much compressive stabilizing forces as with functional testing. The increased compressive forces associated with closed kinetic chain testing appear to reduce the amount of shearing at the joint (Bunton et al., 1990; Graham, Gehlsen, & Edwards, 1993; Wilk & Andrews, 1992; Wilk et al., 1995; Wilk et al., 1994). The use of CKC testing, such as hop tests, has been shown to be potentially safer and more accurate in simulating functional movements and activities as compared to tests that use OKC motions (Bunton et al., 1993; Fu et al., 1992; Graham et al., 1993; Wilk & Andrews, 1992; Wilk et al., 1995). CKC movements may transmit more compressive versus shearing forces through the joints of the lower extremity which increases joint stability. This reduces the risk of trauma or injury to joint structures.
Functional performance also is thought to include a series of OKC and CKC actions (Wilk et al., 1995). Events such as walking and running in which a proportion of the gait cycle is spent in either OKC or CKC systems demonstrates this. Functional testing of performance should reflect the actual activity the individual will perform, in addition to functional stability and strength. Bandy emphasized that evaluation of an extremity must include functional testing to reduce the risk that future participation in activities may "cause major problems and increase the incidence of re-injury" (1994, p. 108).

**Significance, Problem, and Purpose of Study**

Andrews, Thomas, and Bohannon stated that there needed to be reference values against which a patient's performance could be compared (1996, p. 248). These authors explained that patient performance could be assessed by comparing outcome measurements to those obtained from apparently unimpaired individuals. However, there is a lack of adequate information on normative values for unilateral lower extremity functional testing of the general population. The purpose of this study was to gather normative values for three unilateral lower extremity functional tests: single-leg triple hop for distance, single-leg timed hop, and single-leg cross-over triple hop, in a normal population between the ages of 18-30. These values can then be used clinically during assessments of lower extremity functional performances.
CHAPTER 2
LITERATURE REVIEW

Kinematic/Kinetic Chains

How segments of bodies move and the forces behind those movements has been an area of interest for researchers for many years. Kinematics describes motions of segments without making references to the forces producing the motion. Movements can be described kinematically by the type of motion that is occurring, as well as location, magnitude and direction. For example, general plane motions of the knee include flexion and extension in the sagittal plane. The amount of movement about the axis of the knee can be measured in degrees. Kinetics studies the internal and external forces producing motion or maintaining the segments a body in equilibrium (Norkin & Levangie, 1992).

The concepts of kinetic and kinematic chains are most often referred to in engineering terms. Kinematic chains are a series of rigid links that are interconnected in a mechanical system. Motion occurring at one joint within the system would produce a predictable motion in other joints in the system (Bunton et al., 1993; Norkin & Levangie, 1992; Wilk and Andrews, 1992). Kinetic chains represent the linkage of muscles and ligaments that dynamically and passively accelerate and decelerate the limb during locomotion in the sagittal, frontal and transverse planes (Wilk and Andrews, 1992). Within the body, this system appears when some joints are linked together in a series in which motion at one joint produces motion at an adjacent joint (Bunton et al., 1993; Norkin & Levangie, 1992; Wilk et al., 1995). Often in the literature the definitions of kinematic and kinetic chains are used interchangeably. For the purpose of this study, the use of kinematic and kinetic chains will also be used interchangeably.
Closed Kinematic Chain

Closed kinetic chains (CKC) have been described by Steindler in 1973 (Wilk and Andrews, 1992) as having both the proximal and distal joints being fixed to an immovable framework. Other authors have differing opinions about whether proximal joint segments are free to move or are also fixed within the system (Bunton et al., 1993; Fu et al., 1992; Wilk et al., 1995). The general consensus is that closed chain systems arise through weight bearing or other activities in which the distal end of the segment is fixed.

Open Kinematic Chain

Open kinematic chains (OKC) consist of the distal end of the segment(s) being able to freely move and not necessarily inducing movement on any other joint (Bunton et al., 1993; Norkin & Levangie, 1992; Fu et al., 1992; Wilk & Andrews, 1992).

Open and Closed Kinematic Chain

When a body part is fixed or meets resistance, there are certain patterns of muscle recruitment and proximal motions that vary based upon the desired functional activity. These recruitment patterns and joint motions also vary from open kinematic chain movements in which the distal segment is free to move. These two types of kinematic motions can also produce different forces at the joints as a result of the position the body segment is in and type and location of muscles recruited.

Many functional activities may be thought of as containing a combination of OKC and CKC motions. Wilk et al. (1995) referred to these movements as succession CKC-OKC drills. These movement patterns are often seen in activities such as basketball and
volleyball that require an individual to run, jump, and change directions. These movements greatly challenge the ability of the LE and spine to control and absorb tremendous ground reaction forces, maintain balance, and to perform the skill with a high degree of coordination. Though gait is not usually thought to be as challenging as those sports mentioned above, it too possesses successions of CKC and OKC motions. During walking, 60% of the gait cycle is in stance phase (CKC) and 40% in the swing phase (OKC). As speed increases, time spent in stance decreases to 30% and 20% and 70% and 80% in swing during running and sprinting respectively.

**Kinematic Chain of the Lower Extremity**

The joints of the lower spine, hip, knee, ankle and foot form an interdependent kinematic system. Norkin & Levangie (1992) emphasized that during CKC movements, a change in function or structure in one joint will usually cause a change in the function of another joint within the system. For example, when a person who is standing erect bends over from the waist, the muscles, passive ligamentous structures and bones of the spine and hips all contribute to the motion. Also, how particular joints are involved in OKC-CKC activities impacts the range of motion (ROM), positioning, and function of each joint.

**Joints of the Low Back (Lumbar Spine)**

Often during weight bearing or CKC activities, movements of the hip cause accompanying motions of the pelvis and compensatory motions in the spine. These movements of the vertebrae within the spine affect positions of vertebral bodies, facet joints, intervertebral joints and spaces, soft tissues nervous system structures in
relationship to vertebrae above and below. A few examples of the relationships between the hip, pelvis, and lumbar spine will be addressed in CKC patterns, but it should be noted that these motions are usually the opposite during OKC activities and both kinematic patterns are dependent upon Fryette's laws of spinal motion. During hip flexion, the pelvis initially tilts anteriorly while the lumbar spine extends. Posterior tilt of the pelvis and lumbar flexion initially occurs with hip extension. When the right hip adducts, the pelvis drops to that side and the spine bends to the left. Opposite actions of the spine and pelvis occur with right hip abduction (Norkin & Levangie, 1992).

**Hip Joint**

**Open Kinematic Chain**

The hip joint, which comprises the pelvic acetabulum and the head of the femur, primarily functions to support the head, arms and trunk in static and dynamic positions such as standing, running, and stair climbing. The hip uses OKC and CKC motions in order to correctly perform these and other functional activities. The hip primarily uses OKC movements in order to initiate and terminate rotary movements of the lower extremity about the axis of the hip joint. Any forces occurring at the hip joint result mainly through muscular activity approximating the femoral head and acetabulum. The amount and direction of these compressive and shearing forces depend upon the position of the joint and what muscles are facilitated (Norkin & Levangie, 1992).

**Closed Kinematic Chain**

The supportive functions of the hip during activities mainly represents the joint in a CKC pattern. Norkin & Levangie stated that these supportive functions that often occur
during weight bearing activities, not only influence stresses placed across the hip joint, but also results in a predominance of CKC responses, such as translatory and accessory motions at the interdependent joints within the lower extremity kinematic system (1992).

The muscles, ligaments, and tendons at the hip work to support the leg during stance phase by balancing out body weight forces, joint reaction forces, and ground reaction forces that produce joint torques and compression, shear and torsional stresses. These structures also help to maintain the orientation of the articular surfaces. Maintained joint congruency decreases the chances of joint subluxation, excessive and/or abnormal stresses on the joint capsule, and abnormal forces on the articular cartilage (Norkin & Levangie, 1992).

During bilateral stance, two-thirds of the body weight is supported by each femoral head. During one-legged stance, as much as five-sixths of the body weight is supported by one femoral head. As a result, joint reaction and compressive forces are approximately two and a half to three times the body weight. Therefore, activities consisting of CKCs, such as walking and stair climbing can produce forces up to five to seven times the body weight (Norkin & Levangie, 1992).

Knee Joint

The knee is one of the largest joints in the body and is very complex. The tibiofemoral and patellofemoral joints, which share a single capsule, make up the knee. The knee joint depends on its ligaments, menisci, capsule and musculotendinous insertions to provide the needed stability for functional activities. Although the knee is capable of withstanding large loads to provide dynamic and static support to the body, it
is vulnerable to injuries. The ligaments and menisci are placed under the most stress and are most likely to be injured (Norkin & Levangie, 1992).

As with the hip, function at the knee can be affected by limitations in other joints. If the ankle has restricted dorsiflexion, the knee would either be restricted in flexion, or compensate by becoming hypermobile and be able to flex despite the ankle limitation. Also, movements occurring distally, as with pronation and supination at the subtalar joint causes the tibia to medially or laterally rotate. This places valgus and/or varus stresses and rotational stresses at the knee (Norkin & Levangie, 1992).

Open Kinematic Chain

Whether the knee joint moves in OKC or in CKC motions determines its functional ability, the types and magnitude of forces occurring at the knee, which muscles are activated, and the overall force produced. During OKC movements, the knee primarily provides mobility for the foot in space. Although eleven muscles act on the knee joint, the ligaments primarily help to provide stability of the knee during OKC activities by preventing excessive movements including hyperextension, varus and valgus stresses, anterior-posterior (A-P displacements), and medial and lateral rotations of the tibia. These ligaments include the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial and lateral collateral ligaments (MCL and LCL) and the oblique and popliteal ligaments (Norkin & Levangie, 1992).

A study by Wilk, Escamilla, Flesig, Arrigo and Barrentine (1995) looked at what types of forces were present at the knee and the EMG activity of surrounding muscles during OKC movements of knee extension. The three types of forces studied included
compressive, anterior tibiofemoral shear and posterior tibiofemoral shear forces. Maximal compressive forces were found to be 4598 +/- 2546 Newtons (N) at 90° +/- 5° of knee flexion. No compressive forces were found at the knee joint once the influence of muscle activity was excluded. Anterior tibiofemoral shear force was found to be more apparent from 40° to 0° of knee flexion. The greatest force of 248 +/- 259 N occurred at 14° of knee flexion. These forces as well as greater anterior translation of the tibia on the femur, seemed to place the most stress upon the ACL. Posterior tibiofemoral shear forces were greatest from 100° to 40° of knee flexion. The maximum posterior shear force of 1178 +/- 594 N was at 91° +/- 9° of knee flexion.

The researchers also looked at the EMG activity of the quadriceps femoris and hamstring muscle groups. The subject sat and performed isolated knee extension exercises. It was discovered that hamstring activity was almost silent during knee extension whereas quadriceps femoris activity increased with knee extension. At 0° to 30° of knee flexion, the quadriceps to hamstring EMG peak amplitude ratio reached 5/6:1.

Torque production by the knee musculature, tendons and ligaments depends on the moment arm (MA) of the lever system and the length-tension relationship in the muscles. When the MA of the muscle decreases in length from the axis of the joint, more force is required to move the limb through the available range of motion (ROM). This condition is evident during OKC knee extension activities. As the knee approaches terminal extension without added resistance, the distance of the quadriceps tendon from the axis of the knee shortens. With extension of the knee, the patella moves deeper into
the intercondylar groove. Because the patella cannot continue to increase the quadriceps's leverage, more force needs to be generated by the quadriceps to fully extend the knee (Norkin & Levangie, 1992). This increased force may overstress the ligaments and menisci causing damage or rupture.

OKC activity (via isometric and isotonic quadriceps contraction) produces increased ACL strain from 75° flexion to maximum stress at 0° (Fu et al, 1992). Terminal extension creates a stress that is 5.5% more than with passive motion. The greatest amount of anterior tibial translation occurs between 30° - 0° knee flexion during OKC activities (Wilk and Andrews, 1992). In a study by Wilk et al. in 1995, quadriceps to hamstring activity was greater in OKC isokinetic extension exercises between 0° - 40° of knee flexion. Also in this study, the authors documented that the ACL was stressed by 248 ± 259N between 40° - 0° of knee extension during the exercise.

Closed Kinematic Chain

In activities, the knee works with the hip and ankle to support body weight in static postures and to dynamically support and transfer weight bearing forces during sitting, squatting, locomotion, and other activities. Norkin & Levangie (1992) suggested that dynamic compressive forces at the knee could increase from two to three times body weight in normal gait to at least five to six times body weight during running and stair climbing. Wilk et al. (1995) showed that with level walking, the ground reaction forces at heel strike were about two to three times body weight, and three to five times body weight during running.

Wilk et al. (1995) also looked at forces occurring at the tibial femoral joint and
EMG activity of muscles during the vertical squat and horizontal leg press. Compressive joint forces occurred with both activities. The squat produced a maximal force of 6,139 +/- 1,708 N at 91° +/- 12° of knee flexion, while the leg press produced its greatest force of 5,762 +/- 1,508 N at 89° +/- 7° of knee flexion. No noticeable anterior shear forces occurred at the joint, but posterior shear forces occurred throughout the knee's complete ROM. The greatest posterior shear forces were 1,783 +/- 634 N at 90° +/- 170 of knee flexion during the squat and 1,167 +/- 55 N at 94° +/- 120 of knee flexion with the leg press. These forces were most noticeable for both activities from 70° to 100° of knee flexion (Wilk et al, 1995).

EMG activity of the quadriceps was compared to hamstring activity during the vertical squat and horizontal leg press. It was found that quadriceps activity was highest at greater angles of knee flexion and not towards terminal knee extension. Also, with the vertical squat more co-contraction between the quadriceps femoris and hamstrings was seen at 45 to 0 degrees of knee flexion. The horizontal leg press primarily produced concentric quadriceps contractions (Wilk et al, 1995).

Graham et al. looked at EMG activity during OKC and CKC exercises. At 60° per second the quadriceps to hamstring ratios were 4.65:1 and 2.25:1 during 30° per second isokinetic speeds. The high quadriceps to hamstring ratio indicated that the quadriceps activity was placing high anterior shear forces on the tibia. During assessment of the following CKC activities: unilateral one quarter squats to 60° knee flexion, lateral step up (20.3cm step), and movements on the Fitter, Stairmaster 4000 and a slide board revealed a ratio of only 1.41:1 to 1.64:1. It was found the speed of the activities didn't
influence the ratios. Graham et al. cited limitations in this study and concluded that the CKC exercises used in their study resulted in minimal A/P shear forces at the knee joint (1993).

Wilk et al. (1995) discovered through EMG testing that positioning of LE components altered the magnitude of force about the knee and muscle activity produced. When the LE were placed in a narrower stance, an increase in PCL stress, and muscle activity and torque production of the quadriceps and gastrocnemius occurred. A wider stance increased compressive forces and muscle activity of the hamstrings and gluteus maximus.

In addition to muscles and ligaments, correct biomechanical alignment (posture) of the femur and tibia equalizes body weight forces and ground reaction forces that occur at the knee joint in order to provide additional amount of knee stability during CKC activities. Also, maintenance of correct skeletal alignment may be thought of as providing the needed compensations for decreased muscle activity during functional activities. For example, if there is decreased quadriceps muscle activity, knee extension can be maintained in standing because the body's center of gravity passes anterior to the joint axis and the ground reaction forces passively maintain the knee in extension (Bunton, et al., 1993; Norkin & Levangie, 1992; Fu et al., 1992).

Several authors have indicated that closed kinetic chain exercises have been used in knee rehabilitation in recent years instead of traditional OKC methods, e.g.: isokinetics (Bunton et al., 1993; Graham et al., 1993; Fu et al., 1992; Wilk & Andrews, 1992; Wilk et al., 1995). The premises for using CKC exercises include the following: (1) reduced
anterior/posterior stress on the ACL (2) decreased patellofemoral joint reaction forces (3) re-education of joint proprioceptors (4) better simulation and replication of functional movements and activities (Bunton et al., 1993; Fu et al., 1992; Graham et al., 1993; Wilk et al., 1995).

There are two main theories on how ACL stress is reduced during CKC. The first occurs through dynamic and co-contraction activity of the hamstring muscles. The hamstring muscles contract to minimize anterior tibial displacement produced by the quadriceps. Also during weight bearing exercises, such as a squat, hamstring activity increases to stabilize hip flexor movements and consequently the knee. The second way shear forces are minimized is by CKC activities increasing the joint compression forces.

Electromyographic analyses of muscle activity at certain OKC isokinetic speeds and during certain functional activities have confirmed the CKC tend to reduce anterior-posterior shear forces across the knee joint (Wilk et al., 1995). CKC activities can also specifically affect the patellofemoral joint. Ground reaction forces during 0° to 15° of knee flexion can produce forces on the patella that equal as much as 50% of the body weight. This is due to decreased surface area of the patella making contact with the femur. The same amount of total force acting on a smaller area increases the force per unit area. Flexor and extensor muscle activity during stair climbing and running hills may increase the joint reaction forces to 3.3 times the body weight at 60° of knee flexion (Norkin & Levangie, 1992). During deep knee bends when the knee flexes to 130°, the reaction forces may be 7.8 times the body weight (Norkin & Levangie, 1992).

Bunton et al. describe the importance of re-education of joint proprioceptors during
rehabilitation to increase functional ability. Engram patterning of the central nervous system can be accomplished by using a progression of slow to quicker CKC movements. These movements should be precise and specific to the functional performance desired. Increased proprioceptive awareness improves neuromuscular coordination of acceleration reducing risks of further injury.

Ultimately, how the knee joint functions depends upon the position of the knee joint, how stresses are applied, and which structures are intact (Norkin & Levangie, 1992). Compressive forces are greatest with CKC movements, especially if the body is vertical in relation to the knee joint. Posterior shear forces are also significantly greater during CKC versus OKC activities. Anterior shear forces are greatest during OKC terminal knee extension (40°-0° of flexion) in which more anterior translation of the tibia on the femur occurs. These findings suggest that CKC movements are best to test and exercise ACL reconstructed knees due to the minimal shear forces on the ACL. Also, with respect to muscle activation, in order to facilitate hamstring activity and co-contractions of the hamstrings and quadriceps, CKC movements should be included in the exercises and testing procedures.

**Ankle and Foot Joints**

The ankle and foot are often thought of as forming a complex that functions together. It is made up of the proximal and distal tibiofibular joints, talocrural joint, subtalar joint, talocalcaneonavicular joint, transverse tarsal joint, tarsometatarsal joints, metatarsophalangeal joints and interphalangeal joints.

**Open Kinematic Chain**
This ankle-foot complex must meet demands of OKC and CKC movements. In OKC motions, the ankle-foot complex work together to clear the foot during swing phase of gait and to position the foot for initial contact. During the swing phase of gait, dorsi-flexion occurs in the talocural joint. The arthrokinematics of the subtalar joint itself is unique in OKC movements. Pronation produces calcaneal eversion and abduction and dorsiflexion of the talus. Supination involves calcaneal inversion with adduction and plantar flexion of the talus. These movements also affect movement of the transverse tarsal joint because the talus and calcaneus are part of both joints (Norkin & Levangie, 1992).

**Closed Kinematic Chain**

This complex must also meet CKC demands to allow the LE to function optimally. This complex provides a stable base of support for numerous weight bearing postures without excessive muscle activity or energy expenditure. The ankle-foot complex must also act as a rigid lever for push off during gait. The ankle-foot complex needs to meet the following mobility demands: to dampen rotation created by more proximal joints, have the flexibility to absorb body weight forces during loading response, and permit the foot to conform to altered terrain (Norkin & Levangie, 1992). Tremendous compressive forces are transmitted through the talocural joint during gait, as much as 450% of body weight (Norkin & Levangie, 1992). During weight bearing, the subtalar joint motion absorbs the lower extremity rotations that would otherwise spin the foot or injure the ankle joint. During normal gait, the calcaneus itself takes 85 to 100% of the body weight load during loading. In running, forces can increase to 250% of body
weight (Norkin & Levangie, 1992).

The arthrokinematics of subtalar pronation and supination also differ with OKC and CKC activities. In an open system, supination involves adduction and plantar flexion of the calcaneus. Functioning in a closed system, supination involves abduction and dorsiflexion of the talus. Basically, the determination of how one bone moves in conjunction with another at the site of articulation is whether the connected segments are in open or closed chain systems (Norkin & Levangie, 1992).

Joint Proprioception

Rehabilitation is based upon optimizing functional capacity. Deciding whether or not to use OKC or CKC interventions and assessment measures has been a topic of concern in recent years. According to Bunton et al. (1993), there is not a strong relationship between OKC and functional activities. CKC activities allow for accelerating and decelerating movements in sagittal, frontal and transverse planes. Due to the position of the body during activity, CKC exercises allow for more functional patterns of movement with regard to athletics, and provide for multiplanar isometric, concentric, and eccentric contractions (Bunton et al., 1993). CKC exercises can also address factors influencing function such as weight, terrain, joint hypermobility and hypomobility, ground reaction forces and limb pathologies (Bunton et al., 1993).

Simulation and Replication of Functional Activities

CKC exercises also simulate "psuedoisometric" contraction during functional activities requiring a muscle to lengthen over one joint and shorten over a second while its antagonist does the opposite. This occurs with the quadriceps femoris and hamstring
muscles as one rises from a squatting position (Fu et al., 1992).

Wilk et al. suggested that CKC movements did not completely replicate functional activities. These authors suggested that there were actually four kinematic classifications: OKC, CKC, partially kinetic chain exercise, and succession CKC-OKC drills (1995). Examples of succession CKC-OKC include plyometrics, high-stepping agility drills, running and jumping. These activities are part of many sports activities. Gait analyses can also be used to advocate this classification. During walking, 60% of the gait cycle is in stance phase and 40% in the swing phase. As speed increased, time spent in stance decreased to 30% and 20% and 70% and 80% in swing during running and sprinting respectively.

The use of CKC or Succession OKC-CKC exercises during rehabilitation are more efficient, effective, and economical. They most closely resemble functional activities as compared to OKC activities (Bunton et al., 1993). Therefore, tools to assess functional performance of the lower extremities must also show specificity to the functional activity, as well as addressing issues of efficiency, effectiveness, and safety.

**Testing Methods**

**Isokinetics**

The goal of rehabilitation professionals is to return the patient to a pre-injury level of function. One of the more commonly utilized tools in assessing muscular strength in an orthopaedic setting is isokinetic testing (Wilk et al., 1994). "Isokinetics are frequently chosen because of their inherent patient safety, objectivity, and reproducibility in testing measures" (Wilk et al., 1994, p. 60). Isokinetic testing uses isokinetic dynamometers,
machines that are designed to be set at constant angular velocities and to provide accommodating resistance throughout the full ROM, to assess muscle strength (e.g. as torque), work, power, and endurance.

There are advantages and disadvantages to using isokinetic machines to evaluate joint function. Some of the advantages include being able to produce maximal muscle tension throughout the full ROM, moving about an axis at a fixed rate and inherent safety due to the accommodating resistance. The disadvantages include the joint moving about a non-physiological axis, the production of maximal speed and muscle tension during the entire ROM, and the decreased ability to produce accelerating and decelerating movements. These disadvantages feed into abnormal proprioceptive input at the joint and decreased carry-over to functional activities. Reliability of measurements also vary based on the position the limb is tested in as well as the speed it is tested at (Schwarz, personal communication, June 18, 1996).

It is also a concern as to whether functional capacity can be evaluated effectively with isokinetics because velocities achieved during functional activities are much higher than can be produced by the dynamometers. According to Prentice (1994), velocities produced during hip and knee movements while kicking a soccer ball exceeded 400°/second and 1200°/second, respectively. The Biodex and Lido Active isokinetic machines can attain 450° and 400°/second respectively, but only as the maximal concentric speed. The Merac can attain up to 500°/second in concentric mode only. These machines approach the speeds joints can attain, but can not provide optimal speeds specific to many functional activities (Prentice, 1994).
Another area of concern about whether isokinetics adequately assesses functional performance arises because it uses OKC movements and many functional activities use CKC movements entirely or in part. Examples of these functional activities include walking and stair climbing in which the distal joints are fixed. While several authors have questioned the correlation of isokinetic testing to functional activities, others have found correlations between peak torque test results and functional test maneuvers rated using subjective knee scores such as the Noyes scale (Noyes et al., 1989), the Marshall scale, the Modified Noyes scale. Wilk et al. (1994) found positive relationships and good correlations between subjective knee scores (based on the modified Noyes scale) and knee extension peak torque values at 180° and 300°/second. Subjective knee scores of more than 85 represents an individual being able to resume jumping, hard pivoting and cutting at least three times a week. A statistical trend (fair correlation) was shown between knee extensor peak torque at 300° and 450°/second and knee scores. As a result of the study, it was also found that at 180° and 300°/second of knee extension significant antagonist muscle contraction developed. It was suggested by the authors that this may help to decelerate the limb and better control ACL stress.

Wilk et al. (1995) also cited many authors that found positive correlations between subjective knee scores and peak concentric quadriceps torque at 30° and 60°/second. Other studies were cited that suggested no correlation between isokinetic testing and athletic performance drills such as sprinting, jumping, and agility drills. Wilk et al. (1995) also cited studies that used Kin-Com dynamometers that test knee flexion and extension separately and in two different positions instead of reciprocally like the
Cybex and Biodex machines do. The authors suggested that those machines that tested more reciprocal motions showed more positive correlations with functional performances.

**Functional Testing**

For the purposes of this paper, functional testing has been defined as the performance of x number of trials of a functional activity or series of activities, to indirectly assess muscle strength and power, and attempt to quantify functional ability (Bandy, 1994). In physical therapy "there is a need for practical evaluation methods, suitable for the everyday practice, that are easy to use and that can be used with equipment that's not too expensive" (Oberg et al., 1994, p. 861).

Methods of assessment used to record changes in functional status between admission and discharge, in follow-up studies, and for quality assurance need to be valid and reliable (Oberg et al., 1994). In the past, physical assessment measures have included goniometry, force plates, and x-ray exams (Oberg et al., 1994). Other assessment tools include isokinetic testing for muscle strength (Arnold, Perrin, & Hellwig, 1993; Barber et al., 1990; Brinks, DeLong, Stout, 1995; Lephart, Perrin, Fu, Gieck, McCue, & Irgang, 1992; Magnusson, Geismar, Gleim, Nicholas, 1993; McCleary & Andersen, 1992; Perrin, 1986; Reilly, Atkinson, & Coldwells, 1991; Wilk et al., 1994); subjective functional score questionnaires (Lephart et al., 1992, Noyes, Barber, & Mooar, 1989; Noyes, Mooar, & Barber, 1991; Risberg & Ekeland, 1994); joint laxity measurements (Lephart et al., 1992; Noyes, Barber, Mangine, 1991; Risberg & Ekeland, 1994); muscular girth (Lephart et al., 1992; Reilly et al., 1991; Risberg & Ekeland, 1994); and gait assessments (Noyes et al., 1991). These methods of assessment should, but do not, reflect physical,
sociability, and quality of life (Oberg et al., 1994). "Current methods of clinical examination do not always provide an adequate assessment of these primary treatment goals: restoration of function in the shorter term and prevention of long-term pathological changes" (Andriacchi & Birac, 1993, p. 40).

Functional testing is a tool found to be useful in providing unique and important information relevant to the therapeutic treatment. The purposes of functional testing include screening to determine asymmetry in the extremities that may predispose someone to injury, objectively assessing patient progression in a rehabilitation program, indirectly assessing muscle strength, power, and aerobic fitness, attempting to quantify function in order to establish team norms, and as an assessment of the ability of the extremity to tolerate external forces (Bandy et al., 1994, p. 108). They can evaluate present and expected physical status and indicate the need for physical therapy (Oberg et al., 1994).

There are a large variety of functional tests, both single limb and double limb that can be used to assess the lower extremity. The double limb tests include: shuttle run no pivot, shuttle run pivot, figure-of-eight, stairs running, broad jump, and slope running (Barber et al., 1990; Risberg & Ekeland, 1994; Tegner et al., 1986). A study by Risberg and Ekeland (1994), indicated that double limb testing should occur early in the rehabilitation process as indicators of "daily life" function. The single limb tests include: one-legged single hop for distance, one-legged timed hop, one-legged crossover triple hop, one-legged triple hop, one-legged vertical jump, side jump test, triple jump, stairs hopple and lateral step-up (Bandy, 1994; Barber et al., 1990; Booher et al., 1993; Brinks
et al., 1995; Noyes et al., 1991; Wilks et al., 1994). These single-limb tests should be used to assess functional strength and stability in the affected leg later in the therapeutic process (Risberg & Ekeland, 1994).

Many functional activities, such as walking, running, and jumping, include CKC or a succession of CKC-OKC movements (Wilk et al., 1995). These kinematic and kinetic chain movements are included in single-limb hop tests. Single-limb hop tests, therefore, may more accurately simulate functional activities by replicating forces across joint structures (Wilk et al., 1995) and providing the needed proprioceptive information in order to time and coordinate neuromuscular actions (Bunton et al., 1993). According to Noyes et al. (1991), hop tests are valuable as a general screening assessment in the clinical setting. These authors stated that hop tests were economical because they did not involve expensive equipment, they were efficient, and allowed one to use the opposite leg for a control (1991). Three single-limb tests were chosen for this study: the one-legged single hop for distance, the one legged timed hop, and the one-legged cross-over hop. These tests were chosen based upon the findings mentioned above and previous research by Barber et al. (1990), Noyes et al (1991), Booher et al (1993), Bandy (1994), and Wilk et al (1994) that indicated these tests were reliable and correlated with performance during functional activities.

Determining the reliability of tests used to evaluate a patient is very important to ensure accuracy of assessments (Bandy, 1994). Due to the lack of data on the reliability of lower extremity hop tests, Booher et al. (1993) and Bandy et al. (1994) looked at the test-retest reliability of several functional tests. Booher et al. (1993) looked at the:
single-leg hop for distance, single-leg timed hop, and 30m single-leg agility hop. The results of the study indicated that correlation values of .77 to .94 were acceptable and proven reliable (Booher et al., 1993). In their study, the subjects had one practice trial and two test trials. These authors found that with this many trials the results appeared acceptable and differences were small. Booher et al. (1993) also noticed, however, that scores were improving which indicated that the measures were not stable. These authors suggested that in future studies, researchers should use a greater number of trials to see if the measures stabilized (Booher et al., 1993). A study performed by Bandy (1994), addressed the reliability of five functional tests: one-legged vertical hop, one-legged horizontal hop, timed one-legged vertical hop, one-legged triple hop, and one-legged cross-over hop. This author indicated that correlations ranging from .85 to .94 appeared appropriate to meet the standard necessary for clinical evaluation and obtaining objective measurement of a patient's progress during a rehabilitation program" (Bandy, 1994, p. 111).

There are two lower extremity functional tests that have been proven unreliable and invalid. Although Bandy (1994) found the one-legged vertical jump to be reliable, a more recent study by Barber et al. (1994) found this test to be unreliable. In this test, the participant jumps off of a particular limb, touches the wall, and lands on the same limb. The distance that the participant jumped is then measured and recorded. The vertical jump test was proven not reliable due to the fact that a large number of normal subjects scored outside the normal limb symmetry range, which was 85% (Barber et al., 1994). The authors concluded that this test could not be recommended for use in detecting lower
limb function (Barber et al., 1994). The second test proven unreliable was the shuttle run test. This test consists of a 6m course marked off with cones on each end. The time it takes for the patient to complete two laps is recorded (Barber et al., 1994). The researchers concluded that validity and reliability have been difficult to determine due to the fact that subjects could compensate by running at half speed and guarding both legs during the cutting and turning movements (Barber et al., 1994).

A study conducted by Noyes et al. (1991), indicated that the single-leg hop for distance and the single-leg timed hop could be used to assess abnormal limb symmetry or lower extremity functional limitation. These tests, however, could not be used to confirm which of the many variables involved in lower extremity function were deficient. The authors also concluded that although these tests have a low sensitivity rate, the high specificity and low false-positive rates allow them to be used as confirmation tools. The authors suggested "that these tests be used in conjunction with other clinical assessment tools to provide confirmation of the extent of lower limb function limitations" (Noyes, 1991, p. 518). A study by Barber et al. (1990), also indicated that the single-leg timed hop and the single-leg cross-over hop to be the most sensitive and best indicators of function. These authors advised clinicians "to use two one legged hop tests as a screening procedure to determine lower-limb function" (1990, p. 211). A study performed by Wilk et al. (1994), had results that were similar to those of Barber (1990) and Noyes et al. (1991). In Wilk's study "A relationship and positive correlation existed between knee extension torque at 180°/sec and the timed hop, hop for distance, and triple cross-over hop" (1994, p. 66). Wilk suggested "that clinicians performing functional hop
tests should include the single-leg hop for time and the single-leg cross-over triple hop and possibly the single-leg hop for distance" (1994, p. 67).

**Functional Testing versus Isokinetic Testing**

Isokinetic testing operates as an OKC system and has been reliable and commonly used to determine muscular force and strength throughout a joint's ROM and at specific joint angles (Arnold et al., 1993; McCleary & Anderson, 1992; Perrin, 1986). Recent research on isokinetic testing has indicated that potentially damaging forces on knee joint structures may be produced (Bunton et al., 1993; Graham et al., 1993; Wilk & Andrews, 1992; Wilk et al., 1995; Wilk et al., 1994). The use of isokinetics has also been questioned as to whether it provides "the specificity of training that is necessary to ensure restoration of function" (Fu et al., 1992). Reasons behind this specificity training assumption include that patients are restrained when doing isokinetic testing (Arnold et al., 1993; McCleary et al., 1992; Magnusson et al., 1993); testing does not duplicate the same proprioceptive joint inputs (Bunton et al., 1993); testing does not duplicate the same forces across joints (Bunton et al., 1993; Fu et al., 1992; Wilk et al., 1995); and testing does not produce a "psuedoisometric" contraction of opposing muscles to help stabilize joint structures (Fu et al., 1992).

Functional testing is able to operate as CKC or a succession of CKC-OKC systems (Wilk et al., 1995) and can simulate multi-planar movements inherent in a lot of functional activities (Bunton et al., 1993). Functional activities that contain CKC systems, in part or exclusively, produce movements at all joints within the system.
Functional testing allows for these multi-planar movements whereas isokinetic testing, with the patient restrained, is unable to do this. Functional testing may also reduce shear forces on knee joint structures, help in the re-education of joint proprioceptors, and may better simulate and replicate functional movements and activities (Bunton et al., 1993; Fu et al., 1992; Graham et al., 1993; Wilk et al., 1995). Specificity of training to the activities the patient needs to perform has become very important. It only makes sense that specificity in evaluating functional performance should be as or more important to ensure the patient will be able to optimally function in the desired activity and to screen for any potential risk factors.

Normative Values

Andrews, Thomas, and Bohannon stated that there needed to be reference values against which a patient's performance can be compared (1996, p. 248). These authors explained that patient performance could be assessed by comparing outcome measurements to those obtained from apparently unimpaired individuals. The problem is that there is a lack of adequate information on normative values for unilateral lower extremity functional testing of the general population. The purpose of this study was to gather normative values for three unilateral lower extremity functional tests: single-leg triple hop for distance, single-leg timed hop, and single-leg cross-over triple hop for distance, in a normal population between the ages of 18-30. These values can then be used clinically during assessments of lower extremity functional performances.
CHAPTER 3

METHODS AND MATERIALS

Subjects

A total of ninety-six male and female subjects ages 18-30 years old were the participants in this study. Participants were from a nonprobability sample. The participants were volunteers from local geographical areas of western Michigan including Grand Valley State University and Lakeshore Athletic Club.

The age range for the subjects was primarily chosen on the basis of convenience, although other factors were taken into consideration. There would be decreased hormonal influences in the female subjects if under the age of 45. Ninety percent of postmenopausal American women have osteoporosis or decreased bone density (Lewis, 1996). Decreased bone density increases the risk for bone fractures if placed under enough stress. Also bone mass generally decreases in both sexes after the age of 40 due to more osteoclastic activity versus osteoblastic activity. The body has an imbalance between calcium in the bones and the serum. Altered protein metabolism due to decreased levels of androgens and estrogen that occurs over 40 years contributes to this imbalance and the risk of osteoporosis (Brashear & Raney, 1986). The age of when skeletal maturity occurs was also taken into consideration. Generally, girls reach maturity at 15 years of age while boys reach it at the age of 17. Bones have finished forming and therefore should not be influenced by the forces produced by the unilateral hop tests (Brashear & Raney, 1986).
Each participant signed the informed consent (Appendix A) and filled out a pretest questionnaire (Appendix B) that included items regarding medical history, present activity level, age, weight, height and gender. Leg dominance was determined by having the subjects kick a ball placed squarely in front of them. The subjects were then put through a flexibility screen (Appendix D) to assess muscle tightness and ROM in the hip flexors, quadriceps, hamstring, gastrocnemius, and soleus muscle groups. The Thomas Test, Straight Leg Raise Test (SLR), and other flexibility measurements were utilized during the screening procedure.

The criteria that excluded the subject from this study included the following: 1.) Any previous surgeries of the back, hip, knee, ankle or foot; 2.) Injuries requiring care by a physician within the last year of the back, hip, knee, ankle or foot; 3.) Less than 80° of knee flexion evaluated using the Thomas Test position; 4.) A SLR of less than 65°; 5.) Less than 10° of dorsiflexion with the knee extended; 6.) Less than 10° of dorsiflexion with knee bent to 90°; 7.) If currently participating in intercollegiate sports; 8.) Any pathology affecting muscle, bone or nervous system. For example, multiple sclerosis, Parkinson’s disease, CVA, cancer, rheumatic diseases; 9.) Current pregnancy; and 10.) Given birth within the last six months. If the subjects met the criteria, they proceeded to participate in the warm-up and testing procedures. Twelve subjects that participated in this study did not follow flexibility and warm-up protocols. This occurred at the end of subject data collection under the pretense of acquiring more subjects under limited time constraints. In order to ensure that the name of the subject and information gained through his or her participation was kept strictly confidential, each subject was assigned
an identification number.

**Materials**

Three single-limb tests were chosen for this study: one-legged triple hop for distance, the one legged timed hop, and the one-legged cross-over triple hop for distance. The names of these tests were changed in this study to single-leg triple hop for distance, single-leg timed hop, and single-leg cross-over triple hop to more accurately describe them.

The single-leg triple hop for distance and the single-leg cross-over triple hop for distance are tests to determine the total distance a subject can hop three times on one leg either in a straight line or by alternately crossing over a piece of tape. During the single-leg cross-over triple hop test, a subject jumped the length and alternately crossed over a strip of tape six meters long and 15 centimeters wide. These distances were measured with a standard tape measure and recorded in centimeters (cm). Measurements began where the subjects’ toes touched a starting line to the back of the heel where the foot lands firmly on the ground on the third hop. The single-leg timed hop is a test to determine the length of time it takes a subject to cover a distance of 10 feet using a series of hops in a straight line. The time was measured using a stop-watch and recorded in seconds (sec). Timing began when the subjects' toes crossed a starting line and ended when the back of their heel crossed a piece of tape indicating the end of the 10 feet.

**Methods**
Volunteers were randomly placed into one of two groups. The first group consisted of subjects using their dominant leg first to perform the tests. The second group consisted of subjects using their non-dominant leg first to perform the tests. The order was randomly assigned by having the subject pick one of two labeled pieces of paper from a hat. Leg dominance was determined when the subject filled out the questionnaire, as was explained earlier, and recorded on the prescreen questionnaire and the data collection sheets (Appendix H).

Each subject went through a warm-up session prior to testing. This warm-up session included five minutes of low resistance cycling on a stationary bike at a rate of 20 revolutions per minute (RPM) followed by 30 second self-stretches to the hip flexor, quadriceps, hamstring, gastrocnemius and soleus muscles of each leg. Based on the researchers' personal experience, a rate of 20 RPM was chosen because it was easily attained and could be maintained without excessive perceived exertion for five minutes.

Two to five minutes after the warm-up session was completed, the subject was taken to the testing station. Each subject performed three unilateral lower extremity functional tests on each leg. The tests included the single-leg triple hop for distance, the single-leg timed hop, and the single-leg cross-over triple hop for distance. The order the tests were performed was randomized by the subject picking labeled pieces of paper from a hat. There were three strips of paper in the hat. Each piece of paper contained the name of one test. The order the tests were to be performed were recorded on each subject's data collection sheet. Before each test was performed, two practice trials were allowed to familiarize the subject with the test. All data from the three unilateral lower extremity
functional tests were measured and determined by the methods previously described in the materials section.

The researchers involved in this study instructed the subjects on how to perform the tests via the functional testing instructions protocol in Appendix G. Each instruction and data collection procedure was not performed by the same researcher during each data collection session. To address concerns of reliability, each researcher performed all data collection procedures on the first ten subjects. An interrater reliability statistical analysis was performed to determine the reliability for measurements of distance and time between each of the three researchers.

The explanations on how the single-leg triple hop for distance, single-leg timed hop, and single-leg cross-over triple hop for distance were described to the subjects and performed are listed in Appendix G. The subjects performed three trials in each of the three tests. The best of the three scores was taken to determine aggregated data results and each score from the trials was used to analyze the non-aggregated data. If the subject lost his or her balance, the trial was counted as a zero and not included in analyses.

Data Analysis

Data from the three functional hop tests were divided into aggregated and non-aggregated data and analyzed separately. Aggregated data used the best results from each hop test per individual for analysis. Non-aggregated data represented repeated measures, or results from each trial from all hop tests per individual for analysis. The data were analyzed using SPSS® for Windows and SAS® software packages.

SPSS® software was used to summarize the demographic information. Age,
height, weight, and activity levels were determined for both males and females. Descriptive statistics and multiple regression analyses were done using the aggregated data. The descriptive statistics determined the mean, standard deviation, and total number of results of outcomes within each individual's group of trials and over all trials of data collection. Multiple regression analyses were used to test for and describe significant relationships between predictors and outcomes. Potential predictors were gender, age, weight, height, activity level, leg dominance, and order of hop test performed. Outcomes were the single-leg triple hop for distance, single-leg timed hop, and single-leg cross-over triple hop for distance tests. Scatterplots, tests for significance (p-values), and goodness-of-fit tests ($R^2$) were used to determine relationships between predictors and outcomes.

Relationships were determined to be significant with $p < 0.05$. Practical significance of the proportion of the variation in the outcome was explained by the predictors during regression analyses. If ($R^2$) was close to 1.00 a good-fit resulted, but $R^2$ closer to 0.00 reflected a poor fit. A good-fit reflected that, that predictor primarily determined outcomes of the test.

Non-aggregated data were analyzed using descriptive statistics and linear regressions with Type I Generalized Estimating Equations (GEE's). Descriptive statistics were as for aggregated data. GEE's were used for regression analyses for correlated data. Correlated data reflected that trials between individuals were considered as independent, but repeated trials per individual were not. Parameter estimates and tests for significance ($p < 0.05$) were calculated with GEE's for the three functional tests.

GEE's used repeated measures from each trial per individual which provided extra
data that made the analysis more sensitive, for example, able to detect smaller relationships between predictors and outcomes. The extra data reflected an effective sample size that was used to determine working correlations between these variables. Working correlations close to 1.00 or -1.00 indicated that trials per individual showed highly correlated values. Each trial could be considered almost identical to the other and therefore would not provide extra information necessary to detect small relationships between the data. Values closer to 0.00 reflect that results per individual could be considered as if from separate individuals. Values closer to zero; therefore, reflect significant differences between data to determine small relationships.

Pearson's Correlation Coefficient Test was used to determine interrater reliability of the researchers in performing the data collection for the three functional hop tests. Coefficients below 0.50 represented poor reliability, values 0.50-0.75 represented moderate reliability, and values greater than 0.75 indicated good reliability.
CHAPTER 4

Results

Normative data from three unilateral lower extremity functional tests were collected from 51 males and 45 females ranging in age from 18 to 30 years. See Table 4.1 for full demographic information.

Table 4.1: DEMOGRAPHIC SUMMARY

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male (n=51)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yrs.)</td>
<td>24.12</td>
<td>2.71</td>
<td>18-30</td>
</tr>
<tr>
<td>Height (cm.)</td>
<td>180.30</td>
<td>6.62</td>
<td>165.1-190.5</td>
</tr>
<tr>
<td>Weight (kg.)</td>
<td>83.72</td>
<td>11.60</td>
<td>63.63-121.43</td>
</tr>
<tr>
<td>Activity Level</td>
<td>78.82</td>
<td>8.98</td>
<td>55-95</td>
</tr>
<tr>
<td><strong>Female (n=45)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yrs.)</td>
<td>23.40</td>
<td>2.36</td>
<td>18-28</td>
</tr>
<tr>
<td>Height (cm.)</td>
<td>168.24</td>
<td>6.25</td>
<td>160-170.8</td>
</tr>
<tr>
<td>Weight (kg.)</td>
<td>64.93</td>
<td>9.61</td>
<td>52.22-82.54</td>
</tr>
<tr>
<td>Activity Level</td>
<td>80.44</td>
<td>10.43</td>
<td>65-95</td>
</tr>
</tbody>
</table>

Although twelve subjects did not participate in the flexibility and warm-up protocols, they were included in the statistical analysis. Tables 4.2 through 4.4 show descriptive statistics results using non-aggregated data from the single-leg triple hop for distance, single-leg timed hop, and single-leg cross-over triple hop for distance. These tables include results based upon gender, leg dominance, and order of functional test performed. Means, standard deviations, as well as total number of results (n) with values
≥ 1 are included. Although each subject performed each hop test three times, not every jump was counted due to subject violating the established jumping protocol i.e.: losing balance, therefore, the values of (n) are different for each category. Use of the non-dominant lower extremity usually resulted in the subject observationally jumping farther distances than when using the dominant lower extremity. During the timed hop tests, use of the non-dominant lower extremity usually resulted in observationally quicker times to completion by approximately 0.02 seconds.

Tables 4.5 through 4.7 summarize the descriptive statistics of the three functional hop tests mentioned above using aggregated data. Aggregated data is data that uses the longest jump and the fastest time from each test trial. The table includes results based upon gender, leg dominance, and order of functional test performed. Means, standard deviations, and total number of results are included. Again, results indicated that the males tended to jump farther in distance than the females. Use of the non-dominant lower extremity resulted in the subject jumping farther than when using the dominant lower extremity during the single-leg cross-over triple hop for distance. Use of the dominant lower extremity during the single-leg triple hop for distance resulted in farther distances than use of the non-dominant extremity, however. During the single-leg timed hop, use of the dominant lower extremity resulted in faster time to completion of the test.
Table 4.2: Summary of Descriptive Statistics of the S3H Test Using Non-aggregated Data.

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Values</th>
<th>S3H(cm) mean</th>
<th>S3H(cm) std. dev.</th>
<th>S3H n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td>428.36</td>
<td>92.77</td>
<td>417</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>490.17</td>
<td>67.61</td>
<td>226</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>355.23</td>
<td>59.22</td>
<td>191</td>
</tr>
<tr>
<td>Dominance</td>
<td>Dominant</td>
<td>425.62</td>
<td>91.35</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>Non-Dominant</td>
<td>431.02</td>
<td>94.25</td>
<td>212</td>
</tr>
<tr>
<td>S3H Order</td>
<td>First</td>
<td>432.89</td>
<td>103.88</td>
<td>184</td>
</tr>
<tr>
<td></td>
<td>Second</td>
<td>407.53</td>
<td>92.70</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td>Third</td>
<td>441.33</td>
<td>68.93</td>
<td>119</td>
</tr>
</tbody>
</table>

STH= Single-leg Triple Hop for Distance

Table 4.3: Summary of Descriptive Statistics of the STH Test Using Non-aggregated Data.

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Values</th>
<th>STH(sec) mean</th>
<th>STH(sec) std. dev.</th>
<th>STH n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td>1.36</td>
<td>.28</td>
<td>629</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>1.31</td>
<td>.27</td>
<td>353</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>1.43</td>
<td>.28</td>
<td>276</td>
</tr>
<tr>
<td>Dominance</td>
<td>Dominant</td>
<td>1.34</td>
<td>.27</td>
<td>313</td>
</tr>
<tr>
<td></td>
<td>Non-Dominant</td>
<td>1.38</td>
<td>.29</td>
<td>316</td>
</tr>
<tr>
<td>STH Order</td>
<td>First</td>
<td>1.39</td>
<td>.30</td>
<td>204</td>
</tr>
<tr>
<td></td>
<td>Second</td>
<td>1.37</td>
<td>.22</td>
<td>219</td>
</tr>
<tr>
<td></td>
<td>Third</td>
<td>1.34</td>
<td>.31</td>
<td>206</td>
</tr>
</tbody>
</table>

STH= Single-leg Timed Hop
Table 4.4: Summary of Descriptive Statistics of the SC3 Test Using Non-aggregated Data.

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Values</th>
<th>S3H (cm) mean</th>
<th>S3H (cm) std. dev.</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td>428.36</td>
<td>92.77</td>
<td>417</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>490.17</td>
<td>67.61</td>
<td>226</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>355.23</td>
<td>59.22</td>
<td>191</td>
</tr>
<tr>
<td>Dominance</td>
<td>Dominant</td>
<td>425.62</td>
<td>91.35</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>Non-Dominant</td>
<td>431.02</td>
<td>94.25</td>
<td>212</td>
</tr>
<tr>
<td>SC3 Order</td>
<td>First</td>
<td>432.89</td>
<td>103.88</td>
<td>184</td>
</tr>
<tr>
<td></td>
<td>Second</td>
<td>407.53</td>
<td>92.70</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td>Third</td>
<td>441.33</td>
<td>68.93</td>
<td>119</td>
</tr>
</tbody>
</table>

SC3 = Single-leg Cross-over Triple Hop for Distance

Table 4.5: Summary of Descriptive Statistics of the S3H Test Using the Aggregated Data.

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Values</th>
<th>S3H (cm) mean</th>
<th>S3H (cm) std. dev.</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td>451.57</td>
<td>93.35</td>
<td>96</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>502.11</td>
<td>68.99</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>394.28</td>
<td>84.20</td>
<td>45</td>
</tr>
<tr>
<td>Leg Dominance</td>
<td>Dominant</td>
<td>450.06</td>
<td>92.87</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Non-Dominant</td>
<td>463.22</td>
<td>100.89</td>
<td>11</td>
</tr>
<tr>
<td>S3H Order</td>
<td>First</td>
<td>457.02</td>
<td>104.58</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>Second</td>
<td>426.46</td>
<td>97.00</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Third</td>
<td>468.47</td>
<td>68.45</td>
<td>29</td>
</tr>
</tbody>
</table>

S3H = Single-leg Triple Hop for Distance
Table 4.6: Summary of Descriptive Statistics of the STH Test Using the Aggregated Data.

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Values</th>
<th>STH(sec)</th>
<th>STH(see)</th>
<th>STH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>mean</td>
<td>std. dev.</td>
<td>N</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1.55</td>
<td>.28</td>
<td>96</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>1.50</td>
<td>.25</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>1.61</td>
<td>.130</td>
<td>45</td>
</tr>
<tr>
<td>Leg Dominance</td>
<td>Dominant</td>
<td>1.55</td>
<td>.27</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Non-Dominant</td>
<td>1.57</td>
<td>.32</td>
<td>11</td>
</tr>
<tr>
<td>STH Order</td>
<td>First</td>
<td>1.57</td>
<td>.32</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Second</td>
<td>1.53</td>
<td>.23</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Third</td>
<td>1.56</td>
<td>.28</td>
<td>35</td>
</tr>
</tbody>
</table>

STH= Single-leg Timed Hop

Table 4.7: Summary of Descriptive Statistics of the SC3 Test Using the Aggregated Data.

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Values</th>
<th>SC3(cm)</th>
<th>SC3(cm)</th>
<th>SC3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>mean</td>
<td>std. dev.</td>
<td>n</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>398.17</td>
<td>103.64</td>
<td>96</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>459.07</td>
<td>78.19</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>329.14</td>
<td>84.08</td>
<td>45</td>
</tr>
<tr>
<td>Leg Dominance</td>
<td>Dominant</td>
<td>400.55</td>
<td>99.48</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Non-Dominant</td>
<td>379.77</td>
<td>135.96</td>
<td>11</td>
</tr>
<tr>
<td>SC3 Order</td>
<td>First</td>
<td>344.90</td>
<td>94.56</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Second</td>
<td>403.61</td>
<td>99.56</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>Third</td>
<td>417.31</td>
<td>105.78</td>
<td>39</td>
</tr>
</tbody>
</table>

SC3= Single-leg Cross-over Triple Hop for Distance
Tables 4.8 through 4.12 (see Appendix I) include scatterplot distributions which show the pairwise relationships between independent (predictor) and dependent (outcome) variables using aggregated data. In all the scatterplots, the three functional tests were the dependent variables. In Tables 4.8 through 4.12 the independent variables were as follows: age, weight, height, activity number, and leg dominance, respectively. These tables suggest that there was not a significant relationship between the independent and dependent variables. These findings were derived from the fact that there was a random pattern in the plots rather than a definitive linear relationship. Also these plots represent relationships between one predictor and one outcome at a time. Other predictors could therefore influence the visual pattern and not represent a significant relationship between the predictor and outcome analyzed.

Table 4.13 (see Appendix J) shows a scatterplot with the dependent variable being the functional tests and the independent variable reflecting gender. This table shows a significant relationship between gender and the three functional hop tests. This was the only independent variable to show what appeared to be a significant relationship.

Table 4.14 reflects non-aggregated variable results from generating generalized estimating equations (GEE 1) for predicting the actual distances and time of the three functional tests. Using values from the intercept and gender variables, distances for the single-leg triple hop and single-leg cross-over triple hop tests could be determined. Values from the intercept, gender, and dominant or non-dominant leg variables could be used to determine time for the single-leg timed hop tests.
The last 12 subjects in this study did not participate in the flexibility screen nor warm-up protocol. A binary predictor variable was used to determine significant variations in results between those last 12 subjects who did not follow the above protocols to those that did. Values from the last 12 subjects had predicted times in the single-leg timed hop test to be faster by 0.15 seconds compared to those that did participate in these protocols.

Table 4.14: Variables for Generalized Estimated Equations (GEE 1) for Predicting Actual Distances and Time

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Predictors</th>
<th>Parameter Estimates</th>
<th>p-Values</th>
<th>Working Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3H</td>
<td>Intercept</td>
<td>489.49 (cm)</td>
<td>&lt;0.0001</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>-132.38 (cm)</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>STH</td>
<td>Intercept</td>
<td>1.30 (sec)</td>
<td>&lt;0.0001</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>0.13 (sec)</td>
<td>0.0047</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dominant/Non-Dominant</td>
<td>0.04 (sec)</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>SC3</td>
<td>Intercept</td>
<td>440.65 (cm)</td>
<td>&lt;0.0001</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>-153.28 (cm)</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
</tbody>
</table>

S3H= Single-leg Triple Hop for Distance
STH= Single-leg Timed Hop
SC3= Single-leg Cross-over Triple Hop for Distance

Table 4.15 reflects aggregated variables from regressions for generating equations to predict maximal distance values for the single-leg triple hop and single-leg cross-over triple hop functional tests. No significant predictors were found to predict minimal times for the single-leg timed hop. The results indicated gender and activity level to be significant predictors in determining the outcome of the single-leg triple hop functional test (p<.0001 and p<.0102, respectively). For the single-leg cross-over triple hop functional test only gender was a significant predictor of outcome at p<.0001. Using an equation including gender and activity level values, it could be predicted what an individual could
jump in the single-leg triple hop for distance test. Using gender values, maximal
distances for the single-leg cross-over hop test could be predicted. Goodness-of-fit was
$R^2 = .38$ for the single-leg triple hop and $R^2 = .40$ for the single-leg cross-over triple hop
functional test which indicated a poor fit. This meant the regression only explained 38%
and 40% of the variability in the single-leg triple hop and single-leg crossover triple hop
for distance tests, respectively. These results suggested that other important factors were
involved. Also, age, height, weight, and leg order were examined, but were not found to
be statistically significant predictors for outcome.

Table 4.16 shows p-values and working correlations for the prediction variables
used to predict distances and time values for the three functional tests. The p-values of
<0.05 were chosen to reflect significant results. The working correlation represents
correlations between each test trial for all data collected. The values closer to 0.00 reflect
smaller relationships indicating more significant correlations between the variables.

Table 4.15: Variables for Multiple Regression Analysis Equations for
Predicting Maximal Distances and Minimal Time

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Predictors</th>
<th>Parameter Estimates</th>
<th>p-Values</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3H</td>
<td>Constant</td>
<td>338.79 (cm)</td>
<td></td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>-111.19 (cm)</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Activity Level</td>
<td>2.07 (cm)</td>
<td>&lt;0.0102</td>
<td></td>
</tr>
<tr>
<td>STH</td>
<td>No significant Predictors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC3</td>
<td>Constant</td>
<td>459.07 (cm)</td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>-129.93 (cm)</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
</tbody>
</table>

S3H= Single-leg Triple Hop for Distance
STH= Single-leg Timed Hop
SC3= Single-leg Crossover Triple Hop
Table 4.16: p-Values and Working Correlations for Predictor Variables Used to Develop the GEE1 Equations for Actual Distances and Time

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Predictor</th>
<th>p-Value</th>
<th>Working Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3H</td>
<td>Intercept</td>
<td>&lt;.0001</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>STH</td>
<td>Intercept</td>
<td>&lt;.0001</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>&lt;.0047</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leg Dominance</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>SC3</td>
<td>Intercept</td>
<td>&lt;.0001</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

S3H = Single-leg Triple Hop for Distance
STH = Single-leg Timed Hop
SC3 = Single-leg Cross-over Triple Hop for Distance

Table 4.17 shows intertester test reliability for the single-leg triple hop for distance, single-leg timed hop, and single-leg cross-over triple hop for distance.

Reliability is shown for leg dominance for each of the three functional hop tests.

Table 4.17: Intertester Test Reliability for the Three Functional Hop Tests

<table>
<thead>
<tr>
<th>Functional Test</th>
<th>Leg Dominance</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3H</td>
<td>Dominant</td>
<td>.99</td>
</tr>
<tr>
<td></td>
<td>Non-Dominant</td>
<td>.99</td>
</tr>
<tr>
<td>STH</td>
<td>Dominant</td>
<td>.69</td>
</tr>
<tr>
<td></td>
<td>Non-Dominant</td>
<td>.92</td>
</tr>
<tr>
<td>SC3</td>
<td>Dominant</td>
<td>.99</td>
</tr>
<tr>
<td></td>
<td>Non-Dominant</td>
<td>.99</td>
</tr>
</tbody>
</table>

S3H = Single-leg triple Hop for Distance
STH = Single-leg Timed Hop
SC3 = Single-leg Cross-over Triple Hop for Distance
CHAPTER 5

DISCUSSION AND CONCLUSIONS

Based on the descriptive statistics, males jumped farther than the females in both the single-leg triple hop and single-leg cross-over triple hop for distance tests. Males also had faster times than the females in the single-leg timed hop tests. In looking at leg dominance using the non-aggregated data, use of the non-dominant lower extremity reflected observationally farther distances than the dominant lower extremity during the single-leg triple hop for distance tests. All the above values, however, were not statistically significant. Differences in results were seen during analysis of leg dominance use during the single-leg cross-over triple hop for distance and the single-leg timed hop. Aggregated results, however, indicated that use of the dominant lower extremity resulted in observationally farther distances and faster times than use of the non-dominant extremity. These values, again, were not found to be statistically significant.

From our observations, the third test trial usually produced the greatest distance for the single-leg triple hop and single-leg cross-over triple hop for distance using both the non-aggregated and aggregated data. The fastest times were also seen on the third test trial of the single-leg timed hop when using non-aggregated data. The results mentioned above were not found to be statistically significant. These results could be due to the learning effect, which allowed the subject to become more familiar and confident with the
test as the trials progressed. Taking the values from the variables in using non-aggregated data, equations could be developed to predict the actual distances and times for the three functional hop tests. These equations are as follows:

(1) Single-leg triple hop for distance\(= 489.49 \text{ cm} + (-132.38 \text{ cm})(\text{gender})\).
(2) Single-leg timed hop\(= 1.30 \text{ sec} + (0.13 \text{ sec})(\text{gender}) + (0.04 \text{ sec})(\text{dom/nondom leg}) + (-.15)(\text{protocol/nonprotocol})\).
(3) Single-leg cross-over triple hop for distance\(= 440.65 \text{ cm} + (-153.28 \text{ cm}) \times \text{(gender)}\)

*Gender= 0 for males and 1 for females. Dominant= 0 and non-dominant= 1. Protocol= 0 and nonprotocol=1.

The following table represents approximate distances and times using the non-aggregated equations:

**Single-leg Triple Hop for Distance**

<table>
<thead>
<tr>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>489.49 cm</td>
<td>357.11 cm</td>
</tr>
</tbody>
</table>

**Single-leg Timed Hop**

<table>
<thead>
<tr>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol: 1.30 sec (Dominant Leg)</td>
<td>Protocol: 1.43 sec (Dominant Leg)</td>
</tr>
<tr>
<td>1.34 sec (Non-dominant Leg)</td>
<td>1.47 sec (Non-Dominant Leg)</td>
</tr>
<tr>
<td>Non-Protocol: 1.15 sec (Dominant Leg)</td>
<td>Protocol: 1.28 sec (Dominant Leg)</td>
</tr>
<tr>
<td>1.19 sec (Non-Dominant Leg)</td>
<td>1.32 sec (Non-Dominant Leg)</td>
</tr>
</tbody>
</table>

**Single-leg Cross-over Triple Hop for Distance**

<table>
<thead>
<tr>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>440.65 cm</td>
<td>287.37 cm</td>
</tr>
</tbody>
</table>
Taking the values from the variables in table 4.15, equations could be developed to predict the maximal distances for the single-leg triple hop for distance and single-leg cross-over triple hop for distance tests. These equations are as follows:

(1) Single-leg triple hop for distance = (338.79 cm) + (-111.19 cm)(gender) + (2.07 cm)(activity level)
(2) Single-leg timed hop = No equation due to no significant predictors found.
(3) Single-leg cross-over triple hop for distance = (459.07 cm) + (-129.93 cm)(gender).

*Gender = 0 for males and 1 for females. Activity level = 55-100)

These tables below reflect the maximal distance values using the aggregated equations:

**Single-leg Triple Hop for Distance**

<table>
<thead>
<tr>
<th>Activity Level</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>545.79 cm</td>
<td>434.60 cm</td>
</tr>
<tr>
<td>95</td>
<td>535.44 cm</td>
<td>424.25 cm</td>
</tr>
<tr>
<td>90</td>
<td>525.09 cm</td>
<td>413.90 cm</td>
</tr>
<tr>
<td>85</td>
<td>514.74 cm</td>
<td>403.55 cm</td>
</tr>
<tr>
<td>80</td>
<td>504.39 cm</td>
<td>393.20 cm</td>
</tr>
<tr>
<td>75</td>
<td>494.04 cm</td>
<td>382.85 cm</td>
</tr>
<tr>
<td>65</td>
<td>473.34 cm</td>
<td>362.15 cm</td>
</tr>
<tr>
<td>60</td>
<td>462.99 cm</td>
<td>351.80 cm</td>
</tr>
<tr>
<td>55</td>
<td>452.64 cm</td>
<td>341.45 cm</td>
</tr>
<tr>
<td>40</td>
<td>421.59 cm</td>
<td>310.40 cm</td>
</tr>
<tr>
<td>20</td>
<td>380.19 cm</td>
<td>269.00 cm</td>
</tr>
<tr>
<td>0</td>
<td>338.79 cm</td>
<td>227.60 cm</td>
</tr>
</tbody>
</table>

**Single-leg Cross-over Triple Hop for Distance**

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>459.07 cm</td>
<td>329.77 cm</td>
<td></td>
</tr>
</tbody>
</table>

In the single-leg triple hop and single-leg cross-over triple hop for distance tests, gender was the only significant variable in predicting actual distances (p<0.0001). In the
single-leg timed hop test, gender and use of dominant or non-dominant leg were significant variables in predicting actual times for the protocol and nonprotocol groups (p=0.0047 and p<0.0001, respectively).

GEE's used repeated measures from each trial per individual which provided extra data that made the analysis more sensitive to detect smaller relationships between predictors and outcomes. Values closer to 0.00 reflect that results per individual could be considered as though they were taken from separate individuals. Values closer to zero, therefore, reflect significant differences between data to determine small relationships. In the single-leg triple hop for distance, the working correlation was 0.86, which meant that each test trial could be considered almost identical to the other and therefore would not provide extra information necessary to detect small relationships between the data. For the single-leg timed hop and single-leg cross-over triple hop for distance tests, the working correlation was 0.67. These values were closer to zero, which indicated that it could be possible to detect significant differences between potential predictors and the STH and SC3 tests to show small relationships.

Gender and activity level were determined to be the significant variables in determining maximal distances for the single-leg triple hop test (p<0.0001 and p<0.0102, respectively). Gender was the only predictor for the single-leg cross-over triple hop for distance test (p<0.0001). It makes sense that males would jump farther distances than females. Those with increased activity levels may also be more aerobically and anaerobically fit leading to increased distances.

Correlation coefficients to determine interrater reliability for data collection
revealed values of 0.99 for the single-leg triple hop and single-leg cross-over triple hop for distance tests for all three authors. Values for data collection during the single-leg timed hop differed for dominant and non-dominant LE and between the two authors responsible for this data collection. During collection of dominant LE data, the correlation coefficient between the two authors was 0.69. A correlation coefficient of 0.92 was found between the two authors when collecting data during use of the non-dominant lower extremity.

These correlation coefficients reflect that data collection among the three authors were very comparable and reliable for the single-leg triple hop and single-leg cross-over triple hop for distance tests. Values for the coefficients were lower for the single-leg timed hop test due to the fact that data contained smaller numbers than the distance tests. More emphasis was placed on tenths or hundredths of a number. Therefore, even small differences between data values reflected great changes. Due to this fact, even the lower correlation coefficients found with the single-leg timed hop tests show good reliability between the two authors. Also, correlation coefficients were lower because the amount of human reaction time of the authors at the beginning and end of each jump and subtle mechanical defects of the stopwatch could not be controlled.

**Clinical Significance**

Clinicians could use the functional hop tests performed in this study because they have been proven valid and reliable (Bandy et al., 1994; Barber et al., 1990; Booher et al., 1993; Noyes et al., 1991; Wilkes et al., 1994). These tests also contain a combination of OKC and CKC motions to better simulate many functional activities. Based on the
results of this study, depending on the person's gender and activity level, a person within the ages of 18-30 should be able to jump similar distances or times as determined using the estimated equations regardless of his/her height, weight, and order of tests performed.

Clinicians could use the equations developed in this study to predict distances and times that a person between the ages of 18-30 could perform with these functional hop tests. The equations developed using the non-aggregated data would most likely represent true distances and times that the patients would be able to perform. The only variables needed to complete these equations would be the knowledge of a person's gender and if the dominant or non-dominant LE was used. It is important to remember, however, these tests reflect values of normal subjects between the ages of 18-30, and clinicians might see a difference in values with injured persons.

**Implication for Future Research**

Further research on gaining normative data for the single-leg triple hop for distance, single-leg timed hop, and single-leg cross-over triple hop for distance tests is still needed because this was the first study to look at gaining normative values for these three tests. The authors recommend using these three functional hop tests with a larger sample size and age range. With a larger sample size, additional small, significant relationships between potential predictors and outcomes would be more easily detected. Also, including subjects from a multi-cultural background, varied activity levels, and age ranges would make the results from this study more generalizable to the public at large.

Research using these functional hop tests with injured subjects is also needed as these test are assumed to reflect their functional progression with therapy. Future re-
search should also include more sensitive methods to reflect the subject’s activity level and leg dominance. This knowledge may then have more implications when comparing outcomes of the three tests. More reproducible and reliable set-up methods to more accurately assess the results of the three functional hop tests needs to be included in future research. Also, if there is a proven method to measure leg length, this would be a valuable asset to include in the next research paper. Although height was not found to be a predictor for outcomes, leg length differences may be.

Future research should also look at comparing subjects who go through a warm-up session and those that do not with these three functional hop tests. These authors suggest this idea as a significant difference was noted between those that had the warm-up and those who did not in the STH test. Also, future researchers should look at whether the number of test trials is significant with these three tests. It was unknown to these authors whether or not the results and equations would have been altered if subjects were allowed unlimited number of trials in order to have three trials meet requirements to be used for analysis. Some subjects in this study were not able to complete acceptable jumps on one to three of the three allowed test trials and this may have impacted the results.

Limitations

There were several limitations to this study. The authors did not obtain 150 subjects secondary to lack of subjects willingness to participate and time constraints. The total number of subjects that participated in the study was 96. By obtaining a larger sample, the authors may have seen more significant relationships between the independent
variables and dependent variables due to the increased data available for analysis. Also, the last 12 subjects of this study did not participate in the flexibility and warm-up protocols due to the drive to get more subjects within the given time constraints. A binary predictor variable determined that there was a significant difference between values from these 12 subjects and those who did participate in the above protocol for only the single-leg timed hop test using the non-aggregated data. These authors realize the implications of their actions and advise future research to explicitly follow all protocols throughout the entire research study.

The population used for this study was not a random sample but rather a sample of convenience. The majority of the participants were college students and rated themselves as active or athletic on the activity rating scale. A random sample may have shown more significance relationships between the potential predictors and the outcomes.

The pre-screen questionnaire was administered to eliminate subjects that had seen a physician within the last year for injuries associated with the low back or one or both of the lower extremities. The authors could not account for subjects that had lower extremity injuries, but were not treated by a physician. In this case, a subject may have had a decrease in proprioception and/or strength of the lower extremity which could have adversely affected the outcome of the hop tests.

The activity rating scale the authors used to categorize the subjects as to their activity was not sensitive enough and was too subjective. The subjects were asked to choose from the activities listed that best met what they participated in. The most
common problem that occurred with this was that the subjects had a difficult time choosing their sport or work activity from the activities listed on the scale. For example, many subjects participated in a form of weight training, but this was not one of the activities listed on the activity rating scale. An activity rating scale that was more reliable and valid would have been more valuable to identify a person’s activity level and thus a better prediction of the subjects performance on the hop tests.

The measuring tape set-up used to measure the distances jumped was not as accurate as the authors would have liked. Each time a group of subjects were tested the experimental test design had to be reconstructed. This included measuring and marking off ten feet to perform the timed test, laying down the 15 centimeter strip which is used for the cross-over triple hop, and laying down three sets of tape measures in order to reach the required 18 meter distance to record the distances jumped. An error could have occurred while laying down the three measuring tapes each time as well as the strip used to jump over if they were not laid down exactly the same each time. A better solution would have been to use a strip that had distances pre-measured that could have been rolled out or unfolded each time to ensure reliability and validity.

Measurement methods for measuring the outcome of the single-leg timed hop were also found to be a limitation of this study. Errors in measuring could have occurred at both the initiation and end of the jumping sequence. Errors included the vantage point of the testers when determining when the toe crossed the starting line and when the heel crossed the finish line. An author standing behind or in front of the starting line or finish line may not be as accurate when measuring the times as someone standing on the
respective lines. An error of one-tenth does not seem to be that significant, but in this
times measured to the one-hundredths were used and that one-tenth becomes very
significant. The best method for recording the outcomes of the single-leg timed hop may
be using lasers at both the start and finish lines. This method would be more accurate and
eliminate the inherent errors that may occur using manual method, such as stop watches
as the authors used.

Conclusion

The purpose of this study was to gather normative values for three unilateral
lower extremity functional tests: single-leg triple hop for distance, single-leg timed hop,
and single-leg cross-over triple hop for distance, in a normal population between the ages
of 18-30. The results indicated that individuals between the ages of 18-30 will have
similar results regardless of height, weight, and the order of the tests performed.
Knowledge of a person’s gender, activity level, dominant/non-dominant leg could be
used in regression equations developed in this study to predict distances and times for the
three functional hop tests.
REFERENCES


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APPENDIX A

Title of Study
Developing Normative Data For Three Unilateral Lower Extremity Functional Tests

Investigators
The investigators of this study are Grand Valley State University Masters of Physical Therapy students Brian Fulton, Kathleen Hegyan and Troy Wieling. This research study is being carried out under the advisement of Jolene Bennett, M.A., P.T., OCS, A.T.C., Gordon Alderink, M.S., P.T. and Timothy Lesnick, M.Sc. This study will be performed at Grand Valley State University, surrounding local western Michigan colleges, and Lakeshore Athletic Club in Holland, Michigan. This study will include a total of 150 male and female subjects.

Purpose of Study
The purpose of this study is to gather normative values for three unilateral lower extremity functional tests: single-leg triple hop for distance, single-leg timed hop and single-leg cross-over triple hop, in a normal population. The results gained in this study will help rehabilitation experts and physicians more accurately assess lower extremity functional performance.

Study Procedures
If you agree to participate in this study, you will be asked to complete a pre-test questionnaire that includes items regarding medical history, present activity level, age, weight, height and gender. You will be screened to assess muscle tightness and range of motion in the hip flexors, quadriceps, hamstrings, gastrocnemius and soleus muscle groups. Criteria that excludes you from this study include the following: 1.) Any previous surgeries of the back, hip, knee, ankle or foot; 2.) Injuries requiring care by a physician within the last year of the back, hip, knee, ankle or foot; 3.) Less than 80° of knee flexion evaluated using the Thomas Test position; 4.) A SLR Test of less than 65°. 5.) Less than 10° of dorsiflexion with the knee extended; 6.) Less than 10° of dorsiflexion with the knee bent to 90°; 7.) If currently participating in intercollegiate sports; 8.) Any pathology involving muscles, bones, nervous system. For example, multiple sclerosis, parkinsons disease, cancer, CVA, or rheumatic diseases; 9.) Current pregnancy; and 10.) Given birth within the last six months.

Volunteers will randomly be placed into one of two groups. The first group consists of subjects using their dominant leg first to perform the tests. The second group consists of subjects using their nondominant leg first to perform the tests. The order will be assigned by having the subject pick a labelled strip of paper from a hat. Each subject will perform three unilateral functional tests on each leg: single-leg triple hop for distance, single-leg timed hop and single-leg cross-over triple hop for distance. The order the tests will be performed in will be randomized by the subject picking labelled strips of paper from a hat. The best score out of the three attempts on each leg will be used for data analysis.
A warm-up session prior to the tests will include five minutes of low resistance cycling on a stationary bike followed by 30 second self-stretches to the hip flexor, quadriceps, hamstring, gastrocnemius and soleus muscles of each leg. Two practice attempts followed by three test repetitions will be performed for each of the three functional tests.

**Duration**
Each research session will take one hour to complete.

**Benefits**
The warm-up session and performance of these unilateral functional tests are a one time event and no increase in strength or functional ability should be anticipated by agreeing to participate in this study.

**Risks**
It is not anticipated that this study will lead to any physical injury and every attempt will be made to insure the safety of the subjects. This includes implementing the following precautions:

1. Pregnant women should not participate in this study.
2. You may experience soreness after the tests, but this is a normal response after physical activity.
3. The environment will be free of any hazards that may cause a fall.

**Privacy**
The information gained during this study will be kept strictly confidential. You will be assigned an identification number for privacy. Your name will never be used throughout the study. If this study is published in a scientific journal, no names will be used.

**Voluntary Participation**
Participation in this study is strictly voluntary and you may withdraw from the study at any time.

**Contacts/Questions**
If you have any questions about the procedures involved in this research study or would like a summary of the results, feel free to contact the researchers listed below.

**NAME**  Brian Fulton, Kathleen Hegyan, or Troy Wieling
**ADDRESS**  1 Campus Dr.
GVSU Physical Therapy Department
Allendale, MI  49401
**TELEPHONE#**  (616) 895-3356

If you have any questions concerning your rights as a subject in this study, feel free to contact the person listed below:
NAME                Professor Paul Huizenga  
               Chair of Human Subjects Review Committee  
ADDRESS                1 Campus Dr.  
                                   GVSU  
                                   Allendale, MI 49401  
TELEPHONE#        (616) 895-2472  

Informed Consent  
"As a subject, I acknowledge that I have read and understand the above information. In my judgment, there was sufficient access to information, including risks and testing procedures, to make an informed decision."

DATE_________________ SUBJECT'S NAME__________________________  
(SIGNATURE)  

______________________________________________  
(PRINT)  

DATE_________________ WITNESS' NAME__________________________  
(SIGNATURE)  

______________________________________________  
(PRINT)
APPENDIX B
PRESCREEN QUESTIONNAIRE

Identification #:_____

I. GENERAL INFORMATION:

AGE: _______ WEIGHT:_______
SEX: _______ HEIGHT:_______

II. MEDICAL HISTORY:
Please circle "Y" for yes and "N" for no for all areas that apply.

- Have you had any of the following injuries that required treatment by a physician within the past year? (First Column)
- Have you ever had any of the following conditions that required treatment by a physician? (Second Column)

<table>
<thead>
<tr>
<th>Injury</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back injury</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Hip injury</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Knee injury</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Ankle injury</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Foot injury</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Cardiac condition</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Pulmonary condition</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Neurovascular condition</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Neuromuscular condition</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Rheumatic condition</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>

Have you ever had any surgeries on the following?

<table>
<thead>
<tr>
<th>Surgery</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back surgery</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Hip surgery</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Knee surgery</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Ankle surgery</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Foot surgery</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>

Do you have any other medical conditions that you feel will limit your ability to participate in this study?
Y/ N (If "Y", please explain.)________________________________________________________

Are you currently taking any medication? Y/ N
If "Y", please list all (Over the counter and Prescription):
Are you pregnant?  Y/ N
Have you given birth within the last six months?  Y/ N

III. CURRENT ACTIVITY LEVEL:

Are you currently participating in intercollegiate sports?  Y/ N

What point value would you rate your current activity level based upon the Sports Activity Rating Scale categories?  _______  (See Appendix C)

IV. LEG DOMINANCE:

Leg dominance:  RIGHT  LEFT
The dominant leg will be circled.
A ball will be set in front of you. The researcher will say, "kick the ball to me."
APPENDIX C

SPORTS ACTIVITY RATING SCALE
(Letter of permission by Noyes has been attained)
Please choose your level of activity by using the numbers located in the Points column.

<table>
<thead>
<tr>
<th>Points</th>
<th>Sports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level I</td>
<td>Jumping, hard pivoting, cutting (basketball, volleyball, football, soccer, gymnastics)</td>
</tr>
<tr>
<td>100</td>
<td>Running, twisting, turning (racquet sports, baseball, hockey, skiing, wrestling)</td>
</tr>
<tr>
<td>95</td>
<td>No running, twisting, jumping (running, cycling, swimming)</td>
</tr>
<tr>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Level II</td>
<td>Jumping, hard pivoting, cutting (basketball, volleyball, football, soccer, gymnastics)</td>
</tr>
<tr>
<td>85</td>
<td>Running, twisting, turning (racquet sports, baseball, hockey, skiing, wrestling)</td>
</tr>
<tr>
<td>80</td>
<td>No running, twisting, jumping (running, cycling, swimming)</td>
</tr>
<tr>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Level III</td>
<td>Jumping, hard pivoting, cutting (basketball, volleyball, football, soccer, gymnastics)</td>
</tr>
<tr>
<td>65</td>
<td>Running, twisting, turning (racquet sports, baseball, hockey, skiing, wrestling)</td>
</tr>
<tr>
<td>60</td>
<td>No running, twisting, jumping (running, cycling, swimming)</td>
</tr>
<tr>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Level IV</td>
<td>ADL with no problems</td>
</tr>
<tr>
<td>No sports possible</td>
<td>40</td>
</tr>
<tr>
<td>20</td>
<td>ADL with moderate problems</td>
</tr>
<tr>
<td>0</td>
<td>ADL with severe problems</td>
</tr>
</tbody>
</table>
APPENDIX D

PRETEST FLEXIBILITY SCREEN

Identification #:__________
EXAMINER:__________
Date:__________

GENERAL INFORMATION:

AGE: _______  HEIGHT: _______ cm.

LEG LENGTH:   WEIGHT: _______ lbs.
   RIGHT (R): _______ cm.
   LEFT (L): _______ cm.

FLEXIBILITY TESTING:

HIP/KNEE/ANKLE

Thomas Test (Hip Flexor and Quadriceps muscles):
   R LEG-- Subject can attain Thomas Test Position: Y N
   Thomas Test Position with knee flexed: <80° ≥80°
   L LEG--Subject can attain Thomas Test Position: Y N
   Thomas Test Position with knee flexed: <80° ≥80°

Straight Leg Raise (Hamstrings): R LEG-- <65° ≥65°
   L LEG-- <65° ≥65°

Gastrocnemius/Soleus:
   R LEG-- Dorsiflexion with knee extended: <10° ≥10°
       Dorsiflexion with knee flexed to 90°: <10° ≥10°
   L LEG-- Dorsiflexion with knee extended: <10° ≥10°
       Dorsiflexion with knee flexed to 90°: <10° ≥10°
APPENDIX E

SUBJECT EXCLUSION CRITERIA

1. Any previous surgeries of the back, hip, knee, ankle or foot.
2. Injuries requiring care by a physician within the last year of the back, hip, knee, ankle or foot.
3. Less than 80° of knee flexion evaluated using the Thomas Test position.
4. A Straight Leg Raise Test of less than 65°.
5. Less than 10° of dorsiflexion with the knee extended.
6. Less than 10° of dorsiflexion with the knee flexed to 90°.
7. If currently participating in intercollegiate sports.
8. Any pathology involving muscle, bone, nervous system. For example, multiple sclerosis, parkinson's, cancer, CVA, or rheumatic diseases.
10. Given birth within the last six months.
Warm-up Standard Protocol:

The purposes of stretching and riding the stationary bike during the warm-up session includes increasing the general flexibility of your lower extremities, and to prevent or minimize the risk of musculotendinous injuries that may be related to performing the three types of unilateral hop tests included in this study.

The warm-up session will start with five minutes of low resistance cycling on a stationary bike at a rate of 20 revolutions per minute.

After you are done cycling, you will participate in self-stretching activities. The researcher will first read the following steps involved in stretching the muscle group, demonstrate the steps, and the read the steps again. The subjects will then perform self-stretches to the hip flexors, hamstrings, quadriceps, gastrocnemius, and soleus muscle groups. Any questions the subjects have during this session will be answered by the researcher. These stretches were taken from *Therapeutic Exercise: Foundations and Techniques* by Kisner and Colby.

STRETCHES:
HIP FLEXOR STRETCH:
To stretch the muscles in the front portion of your hip, assume a fencer's squatlike posture.

1. Bring one leg behind you and keep your toes pointing forwards.
2. Bring your other leg out in front of your body and bend your knee while keeping your front foot flat on the floor.
3. Shift your weight onto the front leg.
4. A stretching sensation should be felt in the front part of your hip of the back leg.
5. Hold this position while you slowly count to 30.
6. Slowly shift your weight off the front leg and come up to an erect standing posture.
7. Switch legs and repeat the steps one time.
QUADRICEPS STRETCH:
To stretch your front thigh muscles, sit on the floor.
1. Bring one leg straight out in front of you.
2. Bend your other knee, and grab your ankle with your hand.
3. Bring the foot of the bent leg towards your bottom until you start to feel a stretching sensation.
4. Release your ankle and lean towards the opposite side and rest your weight on your elbow.
5. Hold this position while you slowly count to 30.
6. Slowly sit up and straighten your bent leg.
7. Switch legs and repeat the steps one time.

HAMSTRINGS STRETCH:
To stretch the muscles in the back of the thigh, sit in one of the chairs that are provided for you.
1. Bring one leg up and rest it on the chair that is in front of you.
2. Keep your other foot flat on the floor.
3. Lean your trunk towards the leg on the chair while keeping your back straight until you start to feel a stretching sensation in the back of that thigh.
4. Hold that position while you slowly count to 30.
5. Slowly sit up straight. If a stretch is still felt, you can take your leg off the chair and put your foot on the floor.
6. Switch legs and repeat the steps one time.

GASTROCNEMIUS STRETCH:
To stretch the big calf muscles, stand with arms outstretched at shoulder level so your hands are flat against a wall. Place your feet shoulder width apart.
1. Keep your knees straight and heels on the floor.
2. Lean towards the wall, allowing your elbows to bend.
3. Stop moving forward when you start to feel a stretching sensation in the calf muscles.
4. Hold this position while you slowly count to 30.
5. Slowly return to standing upright.
6. Repeat steps one through five one time.
SOLEUS STRETCH:
To stretch the smaller calf muscles, again stand with your arms outstretched at shoulder level with hands flat against a wall. Place your feet shoulder width apart.
1. Bend your knees slightly, but keep your heels flat on the floor.
2. Lean towards the wall, allowing your elbows to bend.
3. Stop moving forward when you start to feel a stretching sensation in the calf muscles.
4. Hold this position while you slowly count to 30.
5. Slowly return to standing upright.
6. Repeat steps one through five one time.
Single-Leg Triple Hop for Distance

The purpose of this test is to determine the total distance hopped on a single leg in three consecutive hops. You will be given two practice trials to familiarize yourself with the test and then you will complete three test trials. The best one of the three trials will be recorded.

You must land firmly on the leg you are hopping on. If the opposite leg or any arm touches the ground during the single-leg triple hop test, that trial will not be counted. You must return to the start line for another trial.

1. Stand on the leg to be tested with your toes at the line.
2. When instructed to do so, hop as far as you can three times in a straight line.
3. Remain of the leg that is being tested until instructed to put the your opposite leg on the ground.
4. Return back to the starting position for the next trail
5. You may now take three hops when you are ready.

Remember: Your opposite leg or any arm may not touch the floor during you jumps or that trial will not count and you will not have the chance to repeat that trial. Also, you must land firmly on the leg you are hopping on with no extra hop for balance or the trial will not count.
Single-Leg Timed Hop

The purpose of this test is to determine the time a distance of 10 feet can be covered using a series of hops. You will be given two practice trials to familiarize yourself with the test and then you will complete three test trials. The best one of the three trials will be recorded.

If the opposite leg or any arm touches the ground during the single-leg timed hop test, that trial will not be counted. You must return to the start line for another trial.

1. Stand on the leg to be tested with the toes at the line.
2. When instructed to do so, hop as fast as you can in a straight line. Your goal is reach the end of the tape that marks 10 feet as fast as you can.
3. Remain on the leg being tested until instructed to put you opposite leg on the ground.
4. Return to the starting position for the next trial
5. You may now take your hops when you are ready.

Remember: Your opposite leg or any arm may not touch the floor during any of your jumps over the 10ft. or that trial will not count and you will not have the chance to repeat that trial. Also, you must land firmly on the leg you are hopping on with no extra hop for balance or the trial will not count.
Single-Leg Cross-Over Triple Hop for Distance

The purpose of this test is to determine the total distance hopped crossing over a 15cm wide strip for each of three consecutive hops. You will be given two practice trials to familiarize yourself with the test and then you will complete three test trials. The best one of the three trials will be recorded.

If the opposite leg or any arm touches the ground during the single-leg cross-over triple hop test, that trial will not be counted. You must return to the start line for another trial. You will be required to complete three test trials.

1. Stand on the leg to be tested with the toes at the line.
2. Do a series of three hops crossing over the center line with each hop.
   Hop as far as you can each time and your foot may not touch the center line or that trial will not be counted.
3. Remain on the leg being tested until instructed to put your opposite leg on the ground
4. Return back to the start position for the next trial.
5. You may now take three hops when you are ready.

Remember: Your opposite leg or any arm may not touch the floor during your jumps or that trial will not count and you will not have the chance to repeat that trial. Also, you must land firmly on the leg you are hopping on with no extra hop for balance or the trial will not count.
APPENDIX H
Data Collection Sheet

Identification #:_______
Date:_______
Age:_______
Sex:_______

Circle "R" for right and "L" for left:

DOMINANT LEG: R  L
LEG ORDER:  R  L
TEST ORDER: (number 1 to 3)

Single-Leg Triple Hop for Distance: ______
Single-Leg Timed Hop: ______
Single-Leg Cross-Over Triple Hop for Distance: ______

SINGLE-LEG TRIPLE HOP FOR DISTANCE
Data will be collected in centimeters (cm).
Dominant leg is represented by DOM and the nondominant leg is represented by NON.

<table>
<thead>
<tr>
<th></th>
<th>DOM</th>
<th>NON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1:</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Trial 2:</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>Trial 3:</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>BEST SCORE:</td>
<td>______</td>
<td>______</td>
</tr>
</tbody>
</table>
SINGLE-LEG TIMED HOP
Data will be collected in seconds (s).
DOM and NON will be used as for the first test results.

<table>
<thead>
<tr>
<th></th>
<th>DOM</th>
<th>NON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 3:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEST SCORE:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SINGLE-LEG CROSS-OVER TRIPLE HOP FOR DISTANCE
Data will be collected in centimeters (cm).
DOM and NON will be used as in the previous test results.

<table>
<thead>
<tr>
<th></th>
<th>DOM</th>
<th>NON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 3:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEST SCORE:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix I

Scatter Plots (Table 4.8-4.12)

Table 4.8 Dependent Variable= Functional Hop Tests; Independent Variable= Age

<table>
<thead>
<tr>
<th>S3H dist</th>
<th>STH time</th>
<th>SC3 dist</th>
<th>AGE_1</th>
</tr>
</thead>
</table>
| ![S3H dist Scatter Plot](image1)
| ![STH time Scatter Plot](image2)
| ![SC3 dist Scatter Plot](image3)
| ![AGE_1 Scatter Plot](image4) |
Table 4.9 Dependent Variable= Functional Hop Tests; Independent Variable= Weight

<table>
<thead>
<tr>
<th>S3H dist</th>
<th>STH time</th>
<th>SC3 dist</th>
<th>WT_1</th>
</tr>
</thead>
</table>

[Image of scatter plots for each variable]
Table 4.10 Dependent Variable= Functional Hop Tests; Independent Variable= Height

<table>
<thead>
<tr>
<th></th>
<th>S3H dist</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STH time</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SC3 dist</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HT_1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4.11 Dependent Variable = Functional Hop Tests; Independent Variable = Activity Number

<table>
<thead>
<tr>
<th>S3H dist</th>
<th>STH time</th>
<th>SC3 dist</th>
<th>activity #</th>
</tr>
</thead>
</table>

[Diagram of scatter plots showing relationships between variables]
Table 4.12 Dependent Variable= Functional Hop Tests; Independent Variable= Leg Dominance
Appendix J

Scatter Plot (Table 4.13)

Table 4.13 Dependent Variable = Functional Hop Tests; Independent Variable = Gender