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The Relationship Among Isokinetic Knee Parameters and Three Functional Tests

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THE RELATIONSHIP AMONG ISOKINETIC KNEE PARAMETERS and THREE FUNCTIONAL TESTS

By

Kristen Brinks
Ronda DeLong
Tanya Stout

THESIS

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

Master of Science in Physical Therapy

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Abstract

The purpose of this study was to investigate the correlation between knee strength and endurance, as tested by the Biodex® isokinetic system, and the lateral step-up, cross-over hop for distance, and triple hop for distance. Subjects included 20 males and 30 females aged 21-40 years with no history of low back, hip, knee, or ankle injury that was treated by a physician. Bilateral knee flexion and extension strength, power, and endurance was measured at 60, 180 and 300 degrees/second with the hip extended and flexed 115°. Isokinetic data were normalized to body weight and correlated to hop distance which was normalized to height. The relationship between total work from the lateral step-up and isokinetic data was also determined. Paired t-tests demonstrated no difference (p<.05) in quadriceps femoris and hamstrings torque in the sitting and supine positions. Likewise, there was no difference in torque production between right and left extremities. The lateral step-up was the only functional test to demonstrate little or no correlation (r =.00-.25) with all isokinetic variables. Triple hop and cross-over hop for distance demonstrated a moderate to good (r =.50-.69) correlation to various isokinetic values, although no specific trend was noted. All other correlations between isokinetic and functional variables ranged from r =.26-.49. The results suggest that open chain isokinetic data should be used cautiously when assessing a patient's functional status.
Acknowledgements

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Chapter 1
Introduction
Background to Problem

Physical therapists, exercise scientists, athletic trainers, and other rehabilitation experts have been searching for valid and reliable methods for the assessment of human muscle performance for many years. Physical therapists need objective methods of muscle performance measurement in order to guide treatment plans and assist in diagnosis. These measurements help to document the effects of therapeutic techniques and to validate the need for interventions.

The focus in health care has, recently, shifted from an emphasis on technological advancement to accountability and assessment of treatment efficacy. The major reasons for this shift include the prominence of chronic diseases, the aging population in the United States, and an emphasis on cost containment (Jette, 1993).

Because 80 percent of health care resources in the United States are spent on chronic disease management and research (Cluff, 1981), some form of objective measurement of patient outcome is needed. Since health care is demanding functional outcomes, traditional indicators including range of motion and strength measures, may not be appropriate objective measures of function.

Thirteen percent of the gross national product is spent on health care (Jette, 1993). Insurance companies have begun to place the burden on health care providers to justify their services. Documentation of patient progress, objectively and in functional terms, in order to justify reimbursement for the treatment delivered is the motivation for the continued search for an accurate method of assessment of human muscle performance.

For many years, the data obtained from isokinetic dynamometers, like the Biodex®
system, have been used to document patient performance. Isokinetic testing is considered safe (Davies, 1984), objective and reproducible (Wilk, Johnson, Levine, 1988), but it may not be able to predict function. For example, isokinetic dynamometers do not have the capacity to simulate velocities reached during functional activity (Oman, 1994). The average speed of an isokinetic dynamometer ranges from zero to 300 degrees/second (Oman, 1994) while the velocity of the knee during a soccer kick may exceed 1200 degrees/second (Poulmedis, Ronodoyannis, Mitsou, 1988). Additionally, a majority of isokinetic testing is carried out in a non-weightbearing, open chain position, which is not functional (Oman, 1994).

Most isokinetic dynamometers are designed to test the performance of only one joint at a time. Good function of one joint is dependant on appropriate strength, coordination, and neuromuscular control of the surrounding joints (Tegner, Lysholm, Lysholm, Gillquist, 1986). Isokinetic dynamometers may not have the capacity to assess these variables. The functional tests (hop, jump, figure-eight run, etc.), while giving objective data, stress the extremity in different ways, and may give a more accurate idea of overall limb function (Tegner, Lysholm, Lysholm, Gillquist, 1986).

The purpose of this study was to investigate the correlation between knee strength and endurance data, obtained by the Biodex® isokinetic system and the data obtained from three different functional tests. We hypothesized that there would be a positive correlation between strength and endurance data, obtained isokinetically, compared to the data obtained from functional tests for strength and endurance.
Chapter 2

Literature Review

Closed vs. Open Kinetic Chain

The term "kinetic chain," as used in kinesiology, originated in 1973 from concepts used in mechanical engineering (Gowitzke & Millner, 1988). Kinetic chain is a concept based on a series of adjacent rigid segments connected by joints. A closed kinetic chain position has been defined in terms of the distal segment of an extremity being fixed. In this type of linkage system, the proximal segment moves over the fixed distal segment (Fu, Woo, & Irrgang, 1992). Activities such as squatting, walking, and pull-ups incorporate closed kinetic chain movement. When the kinetic chain is open, the distal segment of the extremity is free, and movement of the distal segment occurs with the proximal segment fixed. Open chain movement includes activities like straight leg raise exercise, for the hip, and throwing a ball, for the shoulder.

Open and closed chain movements have been frequently discussed in the literature, particularly in reference to exercise and its effects on knee biomechanics (Fu et al., 1992; Palmitier, An, Scott, & Chao, 1991; Wilk & Andrews, 1992; Yack, Collins, & Wheildon, 1993). Studies have demonstrated that open kinetic chain activity of the knee produced strain on the anterior cruciate ligament especially from seventy-five degrees of knee flexion to maximum strain at terminal knee extension (Paulos, Noyes, Grood, & Butler, 1981; Renstrom, Arms, Stanwyck, Johnson, & Pope, 1986). In closed kinetic chain exercises, the hamstring musculature contracted with the quadriceps femoris. This contraction minimized the anterior tibial displacement produced by the quadriceps femoris during knee extension, therefore causing less strain on the anterior cruciate ligament (Fu et al., 1992; Giove, Miller, & Kent, 1983).
Patellofemoral joint forces have also been shown to be different during open and closed chain knee activity. Fu et al. (1992) stated that in open chain knee extension, the patellofemoral joint reaction force increased as full extension was reached. Patellofemoral joint contact area also decreased near full extension during open chain movement, resulting in a high contact force per unit area. Fu et al. (1992) also reported that during closed kinetic chain activity, such as squatting, greater quadriceps femoris and patellar tendon tension was required to overcome the increasing flexion moment at the knee, resulting in greater patellofemoral joint force. However, this force was dispersed over a larger contact area than the force during open chain activity, resulting in less stress at the patellofemoral joint. Because closed kinetic chain exercise has been shown to cause less stress at the patellofemoral joint, it may be better tolerated than open chain exercise when treating patellofemoral dysfunction (Fu et al., 1992).

Differences between closed and open chain activities have been demonstrated relative to muscle function around the knee. During open chain knee flexion and extension in sitting the hip is stabilized by a chair. In this position, movement occurs only at the knee where the rectus femoris shortens and the hamstrings lengthen. In closed chain activity, movements at one joint often result in simultaneous movement at another joint. For example, getting up from a squatted position requires both hip and knee extension. The rectus femoris muscle shortens at the knee and lengthens over the hip, while the hamstrings shorten over the hip and lengthen across the knee. These complex two-joint muscle actions, which exhibit shortening/lengthening across two joints, are applied during functional activities; and can not be simulated with open kinetic chain knee flexion and extension (Fu et al., 1992; Palmitier et al., 1991).

Palmitier et al. (1991) noted the importance of closed kinetic chain exercise with regard to specificity of training used to restore of function after musculoskeletal injury. An application of this "specificity of training" concept suggests that since the lower extremity is used more often in a closed chain manner during function it should be
exercised in that manner. The traditional idea that gains made in strength and endurance in the open chain will carry over into closed chain function has been questioned. Also, it has been theorized that neural adaptation of muscles is different when a joint is exercised in isolation to, or in concert with, the joints proximal and distal to it. With rehabilitation based predominantly on open chain exercise, the neural protection needed during functional closed chain activity may not be developed. It has been suggested that closed chain exercise is very important to ensure optimal rehabilitation and restoration of function. (Palmitier et al., 1991)

Isokinetics

Although most functional activities are classified as closed chain movements, the most common method for assessing muscle function has been an open chain isokinetic test. The concept of isokinetics was created by James Perrine and was introduced into the literature in 1967 by Hislop and Perrine and Thistle, Hislop, Moffroid, and Lowman (Perrin, 1993; Davies, 1984). An isokinetic machine is designed to be set to operate at a fixed speed and to provide accommodating resistance throughout the full range of motion. The speed of isokinetic exercise is expressed in degrees of movement per second around an axis of rotation. The accommodating resistance in isokinetic exercise responds to muscle length-tension changes, moment arm changes, fatigue, and pain by eliminating resistance whenever the subject moves slower than the pre-selected speed of the machine (Biodex® manual, 1990). The accommodating resistance offered by isokinetics is different from the fixed or variable resistance provided during isotonic exercise. Free weight exercises are examples of fixed isotonic resistance where maximum muscle force occurs at only one point in the range of motion. Exercises performed on Eagle and Universal weight machines are examples of variable resistance where maximum muscle force occurs at multiple points throughout the range of motion.
The Biodex® is one of the many isokinetic devices on the market. The test-retest reliability and face validity of the Biodex® isokinetic dynamometer has been well established in the research. Peak torque, mean peak torque, average power, single repetition work, total work, percent of peak torque to body weight, and agonist to antagonist ratio (see Appendix A for operational definitions) have all been proven reliable at speeds varying from 60 to 450 degrees per second (Fering, Ellenbecker, & Dersheid, 1990; Klopfer & Greij, 1988; Wilk, Johnson, & Levine, 1988).

Many studies have been performed to evaluate the validity and reliability of isokinetic testing protocols (Perrin, 1993; Johnson & Siegel, 1978; Davies, 1984). Patient positioning and stabilization, gravity correction, warm-up repetitions, and consistent rest periods are factors that have been considered important.

**Positioning and Stabilization**

Consistency in positioning and stabilization of the patient for isokinetic testing has been assessed to show that test results are indicative of muscle performance and not changes in body position. It has been shown that unwanted movements of the hip and trunk during testing allowed muscles to develop different length-tension relationships that affected torque production (Johnson, 1981). Studies have shown that test scores can vary as much as 25% without the use of proper stabilization (Garrick, 1980). High errors are significant since bilateral comparisons that show a deficit of 10% or less in the involved extremity as compared to the unininvolved extremity have been used as criteria for the return to activities (Gleim, Nichols, & Webb, 1978; Harter, Ostering, & Standifer, 1990; Nunn & Mayhew, 1988; Wyatt & Edwards, 1981). Davies (1984) suggested that proper stabilization was necessary to prevent substitution of stronger muscles for weaker muscles.

Biodex Corp., Shirley, NY
Gravity Correction

Correction for gravity has also been included in the knee isokinetic assessments in order to more accurately obtain measurements of muscle torque (Perrin, 1993; Winters, Wells, and Orr, 1981). In the early 1980's several researchers showed that quadriceps femoris strength was underestimated by 4-43% and hamstrings strength overestimated by 15-510% based on the effect of gravity alone (Nelson & Duncan, 1983; Winters et al., 1981). Perrin (1993) suggested using an identical gravity correction factor for each side when making bilateral comparisons.

Warm-up and Rest Intervals

Test protocols with warm-up sessions consisting of submaximal and maximal repetitions at each test speed have been recommended in order to ensure reproducible results (Perrin, 1993; Davies, 1984). Studies on maximal actions of the knee extensors in sedentary subjects that were unfamiliar with isokinetic testing demonstrated that the first trial of a six trial session was significantly different from the other trials (Mawdsley & Knapik, 1982). The authors suggested that at least one maximal repetition should occur before recording the measures (Mawdsley & Knapik, 1982). Johnson and Siegal (1978) concluded that three submaximal and three maximal warm-up repetitions must be included prior to testing for peak torque measures to be reliable and stable. Perrin (1986) also found that a warm-up session consisting of three submaximal and three maximal repetitions prior to testing for total work, average power, and peak torque gave reliable measures. Warm-ups have been shown not to limit peak torque measurements (Mawdsley & Croft, 1982). An analysis of subjects with past experience in exercise and/or testing on an isokinetic dynamometer showed that maximum isokinetic strength test results did not differ significantly in either the presence or absence of three warm-up submaximal muscle actions (Mawdsley & Croft, 1982). However, some subjects in the group with no warm-up experienced discomfort during testing while no subject in the warm-up group reported
discomfort. Therefore, submaximal muscle actions have been used as a safety precaution with no effect on peak torque measurements (Mawdsley & Croft, 1982).

Test protocols have also provided consistent rest intervals between each series of test repetitions and velocities (Perrin, 1993). Rest intervals have been shown to result in measurements that are 5% higher and more reliable than when no rest is provided between trials (Stratford, Bruulsema, Maxwell, Black, & Harding, 1990). Perrin (1993) suggested a 30 second to one minute rest following endurance testing consisting of 25-30 repetitions.

**Isokinetic Testing**

One advantage of isokinetic testing has been the ability to test muscle group strength at a variety of joint angular velocities. Biodex® (1990) has recommended test speeds of 60, 180, and 240 degrees per second for general knee patients and 300, 360, and 420 degrees per second for athletes with knee injuries. Davies (1984) recommended test speeds of 60, 180, and 300 degrees per second to evaluate knee flexor and extensor strength and 240 or 300 degrees per second to evaluate muscular endurance. Testing at speeds below 60 degrees per second have not been recommended because of excessive compression and shear forces to the knee joint and its lack of functional significance (Wyatt & Edwards, 1981). Testing at 300 degrees per second has been recommended because that speed has been shown to approximate the knee angular velocity during natural speed walking (Davies, 1984). Wyatt & Edwards (1981) also suggested including slow, medium, and fast speeds during knee testing. When using multiple test speeds, it has been recommended that subjects experience slower speeds prior to faster speeds in order to obtain more reliable results (Wilhite, Cohen, & Wilhite, 1992).

The number of test repetitions has also been shown to affect test reliability. Some authors have concluded that several repetitions were required to reach maximum torque (Baltzopoulous & Brodie, 1989; Wyatt & Edwards, 1981). Perrin (1993) suggested three to four repetitions at each testing speed to get a reliable measure of maximum torque.
Davies (1984) recommended five test repetitions at each speed. Another study suggested four to six repetitions for more reliable measures (Wessel, Gray, Loungo, and Isherwood, 1989).

There has been a lack of consistency in the testing positions used in isokinetic research making comparisons between studies difficult (Anderson et al., 1991). The classic position for testing knee flexor and extensor muscle performance was a seated position (hip flexed approximately 115 degrees) with the body stabilized by straps around the thigh, waist, and trunk and the arms folded across the chest (Perrin, 1993; Biodex® manual, 1990). A study investigating the effects of stabilizing the trunk by allowing subjects to grasp the table or pelvic strap during knee testing was conducted by Kramer (1990). He found no difference in knee torque production between subjects grasping the test table or the pelvic strap. Other studies have described knee testing with hip flexion angles of 80 degrees (Afzali, Kuwabara, Zachazewski, Browne, & Robinson, 1992; Lacerte, deLateur, Alquist, & Questad, 1992; Peterson et al., 1990; Wilhite et al., 1992), 120 degrees (Durand, Malobin, Richards, & Bravo, 1991), and zero degrees (Anderson et al., 1991). A study by Wilk and Andrews (1993) used a hip flexion angle of 115 degrees since that appeared to be optimal for quadriceps femoris torque generation (Currier, 1977).

The one consistent characteristic found in the literature was related to the position of the axis of rotation of the dynamometer relative to the anatomical axis of the knee during flexion and extension. Most researchers aligned the dynamometer axis with an imaginary horizontal line through the femoral condyles (Durand et al., 1991; Lord, Aitkens, McCrory, & Bernauer, 1992; Wessel et al., 1989).

Muscular endurance testing in isokinetics is often used in an attempt to assess knee function. Endurance has been defined as the ability of a muscle to contract repeatedly over a prolonged period of time (Kisner & Colby, 1990). Davies (1984) outlined two testing procedures for determining endurance. One was a 50% decrement test and the
other a pre-determined repetition bout test. A 50% decrement test is performed at either 180 or 240 degrees per second and is completed when the subject can no longer produce at least 50% of the initial force for two to five consecutive repetitions. The measurement obtained in this test is the total number of repetitions completed. Some have shown that the 50% decrement test is not meaningful (Montgomery, Douglass, & Deuster, 1989).

The pre-determined repetition bout test requires 30 repetitions from average subjects, 40 repetitions from high performance athletes, and 20 repetitions from cardiovascularly compromised subjects (Davies, 1984). Thirty repetitions have been recommended for the pre-determined bout test since most subjects fatigued to greater than 50% of maximum torque within 30 repetitions (Davies, 1984). Total work, as determined by summing the area under the torque curve has allowed researchers to assess endurance using the pre-determined bout test.

One of the most common parameters used to evaluate muscle performance is peak torque (Davies, 1984). Determination of peak torque has been affected by the "overshoot phenomenon" (Harter et al., 1990). Isokinetic resistance requires that the extremity accelerate to a pre-determined test velocity. The corresponding deceleration of the extremity and the lever arm of the dynamometer can cause a sudden peak or spike in the isokinetic torque curve. This spike is termed the "overshoot phenomenon". Because of this spike, average torque has been shown to be a better indicator of muscle performance than peak torque (Perrin, 1993).

Total work is another variable that has been used to evaluate muscle performance (Davies, 1984; Harter et al., 1990; Perrin, 1983; Wilk & Andrews, 1991). Total work has been calculated by summing the areas under the torque curves. Work has been suggested to be a better indicator of dynamic muscle activity than peak torque because it is a measure of force production throughout the whole range of motion as opposed to one point in the range (Feiring et al., 1990). When making work measurements between
extremities, researchers have recommended that the range of motion limits be consistent, since work is a function of range of motion (Davies, 1984; Perrin, 1993).

Average power can also be used to evaluate muscle performance. Average power is the sum of total work accumulated during the test repetition divided by the total contraction time (Perrin, Lephart, & Weltman, 1989). Davies (1984) found that there are greater average power deficits at slower test speeds as compared to faster speeds.

Functional Testing

Within the last ten years many authors have investigated lower extremity closed kinetic chain assessment using functional tests. Tegner, Lysholm, and Gillquist (1986) used the one-leg hop, running in a figure-of-eight, running up and down a spiral staircase, and running up and down a slope to monitor the rehabilitation of anterior cruciate ligament injuries. Barber, Noyes, Mangine, McCloskey, and Hartman (1990) utilized five functional tests—hop for distance, vertical jump, hop for time, shuttle run no pivot, and shuttle run with pivot to determine lower extremity functional limitations for persons with anterior cruciate ligament deficient knees. Noyes, Barber, and Mangine (1991) used the one legged hop for distance, timed hop, triple hop for distance, and the cross-over hop for distance to evaluate the lower extremity.

Because there was no reliability data on single leg hop tests, Booher et al. (1993) worked to establish test-retest reliability of the hop for distance, six meter hop for time, and thirty meter agility hop. The authors found that all three hop tests were found to be reliable. Risberg and Ekeland (1994) looked at the vertical jump, figure-of-eight, stair-running, triple jump, stairs hopple, and side jump tests in order to categorize the tests according to their functional demands. Overall, very few functional tests have been shown to be valid and/or reliable (Barber et al., 1990).

The one-legged vertical jump test is performed by having a subject jump using one limb, touching the wall and landing on the same limb. The corresponding height of the jump is then measured. The vertical jump failed reliability tests secondary to the large
percentage of normal subjects who fell outside the normal limb symmetry range which was 85%. The symmetry range was defined as a comparison of right to left or involved to uninvolved (Barber et al., 1990). The vertical jump test was also shown to have a significant difference in jump height when comparing men and women (Risberg & Ekeland, 1994) and has not been recommended as a functional test (Barber et al., 1990).

The shuttle run is performed on a six meter course with cones at each end. The time the subject takes to complete two laps is recorded. Validity and reliability has been difficult to establish because subjects were able to compensate by running at one-half speed and guarding both legs during turning and cutting movements (Barber et al., 1990).

The one-legged hop test is performed by having the subject stand and complete either three straight hops, three cross-over hops, one hop for distance, or a hop for time. The distance hopped or the number of hops completed in a specified amount of time (for the hop for time) is recorded. One-legged hop tests have been recommended because comparisons can be made using the contralateral limb as a control (Barber et al., 1990; Noyes et al., 1991).

A study investigating one-legged hop tests, including the hop for distance, hop for time, cross-over hop for distance, and the triple hop for distance showed that any one of these tests could be used to assess lower limb function (Noyes et al., 1991). Barber et al. (1990) also advocated the use of the hop for time and hop for distance in measuring lower extremity function. One investigative group suggested that single leg hop tests would not predict a patient's ability to return to activities of daily living or sport (Worrell, Borchert, Erner, Fritz, & Leerer, 1993). Barber et al. (1990) and Noyes et al. (1991) recommended utilizing at least two hopping tests when evaluating function. No combinations of two hop tests have been determined to be more sensitive to dysfunction and clinicians have been advised to choose any two of the four hop tests (Noyes et al., 1991). Noyes et al. (1991) also advised that hop tests be used with other assessment tools to determine the extent of lower limb function.
The lateral step-up exercise has been commonly used for closed kinetic chain rehabilitation of the knee (Palmitier et al., 1991; Shelbourne & Nitz, 1990). The lateral step-up has the subject standing with one foot on a step and the other foot on the floor. The subject then straightens out the knee of the leg on the step, bringing the other foot up to meet the step and then returning back to the starting position. This technique has not been documented as an assessment tool. Reynolds, Worrell, and Perrin (1992) have recommended that the lateral step-up be used as an assessment tool in one of two ways: counting the maximal number of repetitions at a fixed step height in a fixed amount of time which measures endurance, or one-repetition maximum at a fixed step height against resistance to measure strength.

Isokinetic Testing vs. Functional Testing

The relationship between isokinetic strength and endurance scores to functional test performance has been investigated in several studies. Sachs, Daniel, Stone, & Garfein (1989) found a strong correlation between quadriceps and hamstring strength measured isokinetically and hop distances in assessing patellofemoral problems associated with anterior cruciate ligament reconstructions. Karlsson, Lundin, Lossing, & Peterson (1991) used Lysholm's knee score and isokinetic data at 30 and 120 degrees per second for quadriceps femoris and hamstring peak torque in subjects who had sustained a partial rupture of the patellar ligament. They found a low correlation between the Lysholm knee score and quadriceps femoris strength at these lower angular velocities. Most recently, Wilk, Romanticello, Soscia, Arrigo, & Andrews (1994) looked at the relationship between functional testing (single hop for distance, timed hop, and cross-over hop for distance) and isokinetic test data and found a positive correlation at 180 and 300 degrees per second.

Lephart, Perrin, Fu, Gieck, and Irgang (1992) investigated the correlation between physical characteristics (isokinetic testing, thigh circumference, and knee range of motion) and three functional tests in anterior cruciate ligament-insufficient athletes aged 16 to 32 years. Isokinetic data included peak torque and torque acceleration energy of the
quadriceps femoris and hamstrings and reciprocal muscle group ratios at 60 degrees per second and 270 degrees per second. The three functional tests included the co-contraction, carioca, and shuttle run tests. During the co-contraction test, the subject side-stepped around the periphery of a semicircle five times while attached to heavy rubber tubing that was firmly anchored to a wall. The carioca test was performed with cross-over steps moving laterally over a twelve meter distance. The shuttle run test was performed by the subjects running four lengths of 6.1 meters, touching a line on the floor at each turn. No correlation was found between the physical characteristics and the functional tests. The authors concluded that physical characteristics alone should not be the primary criteria for determining an anterior cruciate ligament insufficient athlete's readiness to return to competition. They also stated that assessment of an athlete's functional level should include performance tests of various kinds.

Anderson et al. (1991) investigated the relationship between quadriceps femoris and hamstring torque production and the ability to perform a 40 yard dash, vertical jump, and agility run. Peak torque and average torque to body weight ratios were determined at 60 degrees per second and 180 degrees per second, concentrically, and 30 degrees per second and 90 degrees per second, eccentrically, using an isokinetic machine. The authors concluded that there was little or no relationship between the ability to generate eccentric or concentric quadriceps femoris or hamstring torque and the ability to complete the 40 yard dash, vertical jump, or the agility run.

Worrell et al. (1993) conducted a study that compared the effects of a lateral step-up exercise protocol on isokinetic peak torque of the quadriceps femoris and lower extremity functional tests. The functional tests included the leg press, maximal step-up repetitions plus 25% body weight, jump for distance, and jump for time. They concluded that an isokinetic dynamometer was unable to detect the strength gains that resulted from increases in lower extremity performance.
The ability of isokinetic tests to determine function has been questioned by many authors (Palmitier et al., 1991; Fu et al., 1992). Isokinetic testing has been criticized because open chain muscle activation differs from that found in functional closed chain movements. Also, isokinetic systems have not been able to mimic the high speeds of movement commonly seen in functional activities (Davies, 1984; Klopfer & Greij, 1988). For athletes, Roy and Irwin (1983) suggested using the outcomes of functional tests, along with strength scores, before permitting return to competition.

The purpose of this study was to determine the correlation between performance of three functional tests including, the triple hop for distance, the cross-over hop for distance, and the lateral step-up and strength and endurance measures obtained isokinetically using a Biodex® machine. This study will provide valuable information for clinicians as they set rehabilitation guidelines and determine a patient's ability to return to function.
Chapter 3
Methods and Materials

Subjects

Fifty subjects, 20 males and 30 females, ranging in age from 21 to 40 years old participated in this study. These subjects were not currently involved in intercollegiate athletics and were free of any history of hip, knee, ankle, or back injuries that required treatment by a physician. The subjects included volunteers from the Grand Valley State University Physical Therapy Program, staff members at Butterworth Rehabilitation Center, and other volunteers meeting the established criteria.

Each subject filled out a pre-test questionnaire that included items regarding medical history, present activity level, experience with an isokinetic machine, height, weight, age, and gender (Appendix C, D). Prior to testing each subject was screened by a licensed physical therapist for any hip, knee, or ankle dysfunction. Tests checking for muscle tightness, ligamentous instability, meniscal lesions, and range of motion problems were performed (Appendix E). The same physical therapist performed these tests on each subject. Subjects passing all of the screening procedures were invited to participate in this study (Appendix F). Each participant reviewed and signed a consent form (Appendix B) prior to any testing procedures. Each subject was given an identification letter to be used throughout the study. Subjects were required to wear shorts and tennis shoes during the test session.

Materials

Mean torque, total work, mean power, mean torque/body weight, total work/body weight, and average power/body weight of the quadriceps femoris and hamstrings were measured using a Biodex® isokinetic dynamometer.
Data reduction was accomplished using the Biodex® software package. The three functional tests used included the lateral step-up, cross-over hop for distance, and the triple hop for distance. The lateral step-up required a six inch step, a stop watch, and a counter. The triple hop for distance required a six meter strip of tape on the floor and a tape measure. The cross-over hop for distance required a 15 centimeter by six meter strip of tape on the floor and a tape measure.

Methods

Prior to testing the subjects were allowed a warm-up session, including five minutes on a Fitron® stationary bicycle set at 90 revolutions per minute, and self-stretching of the quadriceps femoris, hamstrings, and gastrocnemius/soleus muscles (Appendix J). Three repetitions of each stretch were held for 20 seconds.

Number randomization determined the order in which each subject visited the three functional test stations. This randomization was an attempt to prevent the learning effect that one test may have on another. Number randomization also determined which leg was tested first at each of the different stations.

The Biodex® testing was done by the same two investigators for all the participants. One investigator was in charge of data input into the computer and the other investigator was in charge of patient set-up, joint axis alignment, and stabilization procedures. The Biodex® machine was calibrated prior to each testing session.

Biodex® testing was performed using the same knee testing protocol (Appendix H) at two different positions of the hip joint: seated with 115° of hip flexion and lying supine with 0° of hip flexion. To ensure stabilization and minimization of substitution, straps were placed over each shoulder, across the lap, and over the thigh of the leg being tested. During the test, the subjects were instructed to hold on to the lap belt with their hands. The dynamometer was positioned so the axis of rotation of the dynamometer was
aligned with the approximate tibiofemoral joint axis through the lateral and medial femoral condyles. The shin pad was positioned approximately two inches proximal to the medial malleolus of the tibia. The knee range of motion was limited to 90 degrees of flexion for all subjects in order to control for total angular motion.

The subjects performed five submaximal repetitions at 90 degrees per second prior to the testing of each leg to become familiar with the machine and isokinetic resistance. The testing protocol included three different speeds (60 degrees per second, 180 degrees per second, and 300 degrees per second), with testing always occurring in that order. At 60 degrees per second, the subjects performed three submaximal and three maximal repetitions as a warm-up followed by five maximal test repetitions. At 180 degrees per second, the subjects performed three submaximal and three maximal repetitions as a warm-up followed by 10 maximal test repetitions. At 300 degrees per second, the subjects performed three submaximal and three maximal repetitions as a warm-up followed by 30 maximal test repetitions. Standardized rest periods included 15 seconds following the warm-up repetitions, 30 seconds rest between test speeds, and five minutes between each test series (Biodex® sitting, Biodex® supine, or functional tests). The subjects were given a two minute rest prior to testing the opposite leg. For their safety, subjects were informed on how to stop the testing procedure.

The functional testing stations included a lateral step-up test, a triple hop for distance test, and a cross-over hop for distance test. The two hop tests were completed twice by each leg of the subjects. The lateral step-up test was completed once on each leg. The same investigator collected data for all the subjects. During all three functional tests, the investigator was standing within one arms length for the subjects' safety. Standardized instructions and verbal commands were used (Appendix I). Prior to the testing, subjects were given the option of one or two practice trials for the hop tests and five practice repetitions for the lateral step-up.
The lateral step-up was performed to determine the maximum number of repetitions a subject completed in a one minute time period. Prior to the testing, the examiner demonstrated the test. For this test, the subjects stood next to the step with the leg to be tested on top of the step. The other extremity remained on the floor. The subjects were instructed to straighten the knee of the leg on the step. The subjects were then instructed to lower the non-exercised leg with the foot in a dorsiflexed position so the heel lightly touched the floor beside the step. If the heel did not touch the floor that repetition was not counted into the total number of repetitions. The exercised leg remained on the step throughout the entire one minute time period. This entire procedure was repeated as fast as possible for a one minute time period. A stopwatch was used to start and stop the test and a counter was used to count each repetition. A 30 second rest period was given between test trials.

The triple hop for distance measured the total distance hopped on a single leg in three consecutive hops. Prior to the testing the examiner demonstrated the test. The subjects were instructed to stand at the end of a 15 centimeter by six meter strip of tape on the floor. The subjects stood with their toes at the end of the tape strip and were instructed to stand on one leg and hop forward as far as possible, three times. If the opposite leg touched the ground that trial was not counted and subjects were instructed to return to the starting point for another trial. The total distance hopped was measured from the end of the tape to the back of the weightbearing foot. The test was then repeated. The subjects had to perform the test properly within five trials or their data was not included in the study.

The cross-over hop for distance was performed on a 15 centimeter by six meter strip of tape on the floor. Prior to testing the examiner demonstrated the test. The subjects stood with their toes at the end of the tape strip and then were instructed to hop three times as far as possible, crossing over the strip with each hop. If the subject landed on the tape during the hops that trial was not counted. If the opposite leg touched the
ground that trial was not counted and subjects were instructed to return to the starting point for another trial. The total distance hopped was measured from the starting line to the back of the weight bearing foot and the test was then repeated. As for the triple hop for distance, the subject had to perform the test properly within five trials for their data to be included in the study.

Data Analysis

Data from isokinetic testing was processed by the Biodex® software package. Total work, total work/body weight, mean torque, mean torque/body weight, average power, and average power/body weight for knee flexors and extensors at 60 degrees per second, 180 degrees per second, and 300 degrees per second were calculated and transferred onto a data collection sheet designed for this study (Appendix G). Functional test data were recorded on the same data collection sheet as the isokinetic data. The mean of the two trials on each leg during the hopping tests was calculated. Data from the hop tests were normalized by dividing the mean of the distance jumped by the subject's height. The number of repetitions completed in the lateral step-up test was recorded and used to compute the total work performed by the subject (Appendix K). Total work during the lateral step-up was normalized using the total body weight.

SPSS for Windows was used for all statistical analyses. Paired t-tests (p<.05) were used to determine the difference between right-and-left sided isokinetic and functional test data. Paired t-tests (p<.05) were also used to determine the difference between supine and sit isokinetic data. Pearson Product Moment Correlation coefficients were calculated to determine the relationship between the normalized functional test scores and isokinetic performance of the quadriceps femoris and hamstrings. The following criteria were used to rank the r values: 0.00 to .25 indicated little or no correlation, .25 to .50 suggested a fair degree of correlation, .50 to .75 showed a moderate to good relationship, and values over .75 indicated an excellent correlation (Portney & Watkins, 1993). Descriptive statistics were computed for average power,
average power/body weight, mean torque, mean torque/body weight, total work, total work/body weight for knee flexor and extensor isokinetic values at 60 degrees per second, 180 degrees per second, and 300 degrees per second. Descriptive statistics were calculated for all the functional testing data as well.
Chapter 4
Results

Isokinetic knee flexor and extensor data and functional testing data were obtained from 30 females and 20 males ranging in age from 21 to 40 years. See Table 4.1 for full demographic information.

TABLE 4.1 DEMOGRAPHIC SUMMARY

<table>
<thead>
<tr>
<th>Variable</th>
<th>X</th>
<th>σ</th>
<th>r</th>
</tr>
</thead>
<tbody>
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<td>Male (n=20)</td>
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<tr>
<td>Age</td>
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<td>Height (cm)</td>
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<td>167.60-198.10</td>
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<td>Weight (lbs)</td>
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<td>23.62</td>
<td>136.00-225.00</td>
</tr>
<tr>
<td>Female (n=30)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>27.63</td>
<td>5.82</td>
<td>21.00-39.00</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165.08</td>
<td>5.65</td>
<td>149.90-177.80</td>
</tr>
<tr>
<td>Weight (lbs)</td>
<td>134.87</td>
<td>23.25</td>
<td>93.00-191.00</td>
</tr>
</tbody>
</table>

Paired t-tests (p<.05) demonstrated no difference between right- and left-side data for all isokinetic or functional tests (See Appendix L for paired t-test results). As a result, only right-sided data were used for descriptive statistic computation and the correlation tests (n=50).

Paired t-tests (p<.05) comparing right and left supine and sit isokinetic data also demonstrated no difference (See Appendix M for paired t-test results). Therefore, only sitting isokinetic data will be used for statistical analysis.

Tables 4.2 - 4.4 show the mean, standard deviation, and range for all isokinetic variables at 60, 180, and 300 degrees per second. Mean torque, mean torque/ body
weight, and total work/body weight for flexors and extensors all decreased as the speed increased. Total work values of the flexors and extensors and agonist/antagonist ratios increased as the speed increased. However, only the normalized data were used for correlation testing. Average power and average power/body weight values for flexors and extensors at 300 degrees per second were higher than the 60 degrees per second values, but lower than the values at 180 degrees per second.

Table 4.5 shows the mean, standard deviation, and range of all functional data. Although the cross-over and triple hop distance and the cross-over and triple hop distance/height were used for descriptive data, only the cross-over and triple hop distance/height were used for correlation testing. The lateral step-up repetition number and the calculated total work and total work/body weight ratio from the lateral step-up were also used for descriptive data. The lateral step-up total work/body weight value was the only one used for correlation testing.

Table 4.6 shows the correlation between the lateral step-up and the isokinetic values. The lateral step-up had a little or no correlation to various isokinetic extensor values, with no specific trend noted. Flexor average power/body weight at 60 and 180 degrees per second were the only two isokinetic variables that demonstrated a moderate to good correlation to the lateral step-up. There were no comparisons that demonstrated an excellent correlation.

Table 4.7 shows the correlation between the cross-over hop for distance and isokinetic values. There were no isokinetic values having little or no correlation to the cross-over hop for distance. Extensor mean torque/body weight and extensor average power/body weight had a higher correlation than extensor total work/body weight ratios. Extensor values demonstrated a higher correlation than flexor values. All flexor values, except average power/body weight at 60 degrees per second, demonstrated a fair correlation. Flexor average power/body weight at 60 degrees per second, extensor
**TABLE 4.2 ISOKINETIC DATA AT 60 DEGREES PER SECOND**

<table>
<thead>
<tr>
<th>Variable</th>
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<th>σ</th>
<th>r</th>
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<tbody>
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<td><strong>Male (n=20)</strong></td>
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<td></td>
<td></td>
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<td>35.90-71.30</td>
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<td>86.50</td>
<td>18.38</td>
<td>54.60-119.80</td>
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<td>AP/BW-flexors</td>
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<td>10.16</td>
<td>29.00-74.10</td>
</tr>
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<td>AP-extensors</td>
<td>165.27</td>
<td>32.52</td>
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</tr>
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<td>AP-flexors</td>
<td>94.91</td>
<td>18.30</td>
<td>67.40-126.80</td>
</tr>
<tr>
<td>MT/BW-extensors</td>
<td>80.85</td>
<td>16.30</td>
<td>48.40-122.20</td>
</tr>
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<td>28.90-51.50</td>
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<td>29.23</td>
<td>102.90-207.80</td>
</tr>
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<td>12.55</td>
<td>54.40-104.50</td>
</tr>
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<td>TW/BW-extensors</td>
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<td>14.66</td>
<td>62.10-117.50</td>
</tr>
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<td>TW/BW-flexors</td>
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<td>8.01</td>
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<td>TW-flexors</td>
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<td><strong>Female (n=30)</strong></td>
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<tr>
<td>AG/ANT</td>
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<td>37.40-81.00</td>
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<td>AP/BW-flexors</td>
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<td>21.60-56.70</td>
</tr>
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<td>AP-extensors</td>
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<td>60.80-125.10</td>
</tr>
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<td>AP-flexors</td>
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<td>248.36</td>
<td>59.92</td>
<td>136.60-357.20</td>
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</table>

AG/ANT=agonist to antagonist ratio (%)  
AP/BW=average power to body weight (%)  
MT=mean torque (ft-lbs)  
MT/BW=mean torque to body weight (%)  
TW=total work (ft-lbs)  
TW/BW=total work to body weight (%)  
AP=average power (Watts)
TABLE 4.3 ISOKINETIC DATA AT 180 DEGREES PER SECOND

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Female (n=30)</th>
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<td>( \bar{x} )</td>
<td>( \sigma )</td>
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<tr>
<td><strong>AG/ANT</strong></td>
<td>58.74</td>
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</tr>
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<td>10.32</td>
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<td>603.32</td>
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</tr>
</tbody>
</table>

AG/ANT=agonist to antagonist ratio (%), MT=mean torque (ft-lbs), TW=total work (ft-lbs)
AP/BW=average power to body weight (%), MT/BW=mean torque to body weight (%), TW/BW=total work to body weight (%)
AP=average power (Watts)
### TABLE 4.4 ISOKINETIC DATA AT 300 DEGREES PER SECOND

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<td>30.80-55.50</td>
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<td>MT/BW-extensors</td>
<td>24.77</td>
<td>6.91</td>
<td>13.20-39.60</td>
</tr>
<tr>
<td>MT/BW-flexors</td>
<td>21.46</td>
<td>5.27</td>
<td>12.10-30.10</td>
</tr>
<tr>
<td>MT-extensors</td>
<td>36.34</td>
<td>8.90</td>
<td>20.50-55.10</td>
</tr>
<tr>
<td>MT-flexors</td>
<td>31.42</td>
<td>8.83</td>
<td>17.60-41.50</td>
</tr>
<tr>
<td>TW/BW-extensors</td>
<td>36.22</td>
<td>8.86</td>
<td>15.30-52.10</td>
</tr>
<tr>
<td>TW/BW-flexors</td>
<td>23.24</td>
<td>6.34</td>
<td>11.40-36.30</td>
</tr>
<tr>
<td>TW-extensors</td>
<td>1061.76</td>
<td>276.62</td>
<td>500.20-1569.00</td>
</tr>
<tr>
<td>TW-flexors</td>
<td>645.78</td>
<td>172.10</td>
<td>347.00-1010.40</td>
</tr>
</tbody>
</table>

AG/ANT=agonist to antagonist ratio (%)  
AP/BW=average power to body weight (%)  
AP=average power (Watts)  
MT=mean torque (ft-lbs)  
MT/BW=mean torque to body weight (%)  
TW=total work (ft-lbs)  
TW/BW=total work to body weight (%)
### TABLE 4.5 SUMMARY OF FUNCTIONAL TESTING DATA

<table>
<thead>
<tr>
<th>Variable</th>
<th>Male (n=20)</th>
<th></th>
<th>Female (n=30)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\bar{X}$</td>
<td>$\sigma$</td>
<td>$r$</td>
<td></td>
</tr>
<tr>
<td>cross-over hop D/H</td>
<td>2.35</td>
<td>0.53</td>
<td>1.60-3.80</td>
<td></td>
</tr>
<tr>
<td>cross-over hop</td>
<td>430.21</td>
<td>96.10</td>
<td>312.90-726.30</td>
<td></td>
</tr>
<tr>
<td>lateral step-up TW/BW</td>
<td>47.98</td>
<td>11.38</td>
<td>31.20-71.90</td>
<td></td>
</tr>
<tr>
<td>lateral step-up TW</td>
<td>8759.43</td>
<td>2644.71</td>
<td>4725.00-14820.00</td>
<td></td>
</tr>
<tr>
<td>lateral step-up</td>
<td>76.80</td>
<td>18.20</td>
<td>50.00-115.00</td>
<td></td>
</tr>
<tr>
<td>triple hop D/H</td>
<td>2.81</td>
<td>0.51</td>
<td>2.20-4.30</td>
<td></td>
</tr>
<tr>
<td>triple hop</td>
<td>511.36</td>
<td>97.09</td>
<td>408.60-811.50</td>
<td></td>
</tr>
</tbody>
</table>

$D/H$ = distance over height  
$TW/BW$ = total work to body weight (%)  
$TW$ = total work (ft-lbs)
<table>
<thead>
<tr>
<th>Variables</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>lateral step-up(^B) at 60°/sec-extensors</td>
<td>0.3456</td>
</tr>
<tr>
<td>lateral step-up(^B) at 180°/sec-extensors</td>
<td>0.3421</td>
</tr>
<tr>
<td>lateral step-up(^B) at 300°/sec-extensors</td>
<td>0.2480</td>
</tr>
<tr>
<td>lateral step-up(^A) at 60°/sec-extensors</td>
<td>0.3943</td>
</tr>
<tr>
<td>lateral step-up(^A) at 180°/sec-extensors</td>
<td>0.3562</td>
</tr>
<tr>
<td>lateral step-up(^A) at 300°/sec-extensors</td>
<td>0.2697</td>
</tr>
<tr>
<td>lateral step-up(^C) at 60°/sec-extensors</td>
<td>0.2261</td>
</tr>
<tr>
<td>lateral step-up(^C) at 180°/sec-extensors</td>
<td>0.2418</td>
</tr>
<tr>
<td>lateral step-up(^C) at 300°/sec-extensors</td>
<td>0.0939</td>
</tr>
<tr>
<td>lateral step-up(^B) at 60°/sec-flexors</td>
<td>0.2654</td>
</tr>
<tr>
<td>lateral step-up(^B) at 180°/sec-flexors</td>
<td>0.3978</td>
</tr>
<tr>
<td>lateral step-up(^B) at 300°/sec-flexors</td>
<td>0.2787</td>
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<tr>
<td>lateral step-up(^A) at 60°/sec-flexors</td>
<td>0.5022</td>
</tr>
<tr>
<td>lateral step-up(^A) at 180°/sec-flexors</td>
<td>0.5088</td>
</tr>
<tr>
<td>lateral step-up(^A) at 300°/sec-flexors</td>
<td>0.4499</td>
</tr>
<tr>
<td>lateral step-up(^C) at 60°/sec-flexors</td>
<td>0.2929</td>
</tr>
<tr>
<td>lateral step-up(^C) at 180°/sec-flexors</td>
<td>0.3599</td>
</tr>
<tr>
<td>lateral step-up(^C) at 300°/sec-flexors</td>
<td>0.2152</td>
</tr>
</tbody>
</table>

\(^A\) = TW/BW to AP/BW (%)
\(^B\) = TW/BW to MT/BW (%)
\(^C\) = TW/BW to TW/BW (%)
### TABLE 4.7 CORRELATIONS BETWEEN THE CROSS-OVER HOP AND ISOKINETIC TESTING

<table>
<thead>
<tr>
<th>Variables</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>cross-over hop&lt;sup&gt;A&lt;/sup&gt; at 60°/sec-extensors</td>
<td>0.5612</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;A&lt;/sup&gt; at 180°/sec-extensors</td>
<td>0.6019</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;A&lt;/sup&gt; at 300°/sec-extensors</td>
<td>0.5586</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;B&lt;/sup&gt; at 60°/sec-extensors</td>
<td>0.5412</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;B&lt;/sup&gt; at 180°/sec-extensors</td>
<td>0.5248</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;B&lt;/sup&gt; at 300°/sec-extensors</td>
<td>0.4927</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;C&lt;/sup&gt; at 60°/sec-extensors</td>
<td>0.4646</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;C&lt;/sup&gt; at 180°/sec-extensors</td>
<td>0.4422</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;C&lt;/sup&gt; at 300°/sec-extensors</td>
<td>0.4240</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;A&lt;/sup&gt; at 60°/sec-flexors</td>
<td>0.4331</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;A&lt;/sup&gt; at 180°/sec-flexors</td>
<td>0.4979</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;A&lt;/sup&gt; at 300°/sec-flexors</td>
<td>0.3851</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;B&lt;/sup&gt; at 60°/sec-flexors</td>
<td>0.6019</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;B&lt;/sup&gt; at 180°/sec-flexors</td>
<td>0.4811</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;B&lt;/sup&gt; at 300°/sec-flexors</td>
<td>0.4449</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;C&lt;/sup&gt; at 60°/sec-flexors</td>
<td>0.4430</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;C&lt;/sup&gt; at 180°/sec-flexors</td>
<td>0.3945</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;C&lt;/sup&gt; at 300°/sec-flexors</td>
<td>0.3422</td>
</tr>
</tbody>
</table>

<sup>A</sup> = D/H to MT/BW  
<sup>B</sup> = D/H to AP/BW  
<sup>C</sup> = D/H to TW/BW  

AP/BW=average power to body weight (%)  
MT/BW=mean torque to body weight (%)  
TW/BW=total work to body weight (%)  
D/H=distance over height
average power/body weight at 60 and 180 degrees per second, and extensor mean
torque/body weight at 60, 180, and 300 degrees per second had a moderate to good
correlation. No extensor or flexor isokinetic values had an excellent correlation to the
cross-over hop for distance. There was no isokinetic speed that had a higher correlation
than another with the cross-over hop for distance.

Table 4.8 gives the correlation between the triple hop for distance and isokinetic
values. All correlations were moderate to good or fair. Extensor mean torque/body
weight and average power/body weight had a better correlation than extensor total
work/body weight. Extensor values demonstrated a better correlation than flexor values.
The only flexor value that demonstrated a moderate to good correlation was average
power/body weight at 60 degrees per second. There were no isokinetic values that
demonstrated an excellent correlation to the triple hop for distance. Again, there were no
isokinetic test speeds that had a higher correlation to the triple hop for distance than any
other.

Table 4.9 is a summary chart showing functional testing and isokinetic values
with little or no correlation. Lateral step-up correlations were the only functional test
correlations that qualified for this category.

Table 4.10 is a summary chart showing functional testing and isokinetic values
with fair correlation. All functional tests correlated to some isokinetic variable in this
category. More flexor than extensor and total work/body weight ratios fit into this
category.

Table 4.11 is a summary chart for functional testing and isokinetic variables with a
moderate to good correlation. Only two lateral step-up correlations (flexor average
power/body weight at 60 and 180 degrees per second) are included in this category. Eight
triple hop for distance and six cross-over hop for distance correlations are included. The
cross-over hop for distance demonstrated a moderate to good correlation to extensor
### TABLE 4.8 CORRELATIONS BETWEEN THE TRIPLE HOP AND ISOKINETIC TESTING

<table>
<thead>
<tr>
<th>Variables</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>triple hop(^A) at 60°/sec-extensors</td>
<td>0.5682</td>
</tr>
<tr>
<td>triple hop(^A) at 180°/sec-extensors</td>
<td>0.6231</td>
</tr>
<tr>
<td>triple hop(^A) at 300°/sec-extensors</td>
<td>0.5573</td>
</tr>
<tr>
<td>triple hop(^B) at 60°/sec-extensors</td>
<td>0.5607</td>
</tr>
<tr>
<td>triple hop(^B) at 180°/sec-extensors</td>
<td>0.5411</td>
</tr>
<tr>
<td>triple hop(^B) at 300°/sec-extensors</td>
<td>0.4860</td>
</tr>
<tr>
<td>triple hop(^C) at 60°/sec-extensors</td>
<td>0.4350</td>
</tr>
<tr>
<td>triple hop(^C) at 180°/sec-extensors</td>
<td>0.4325</td>
</tr>
<tr>
<td>triple hop(^C) at 300°/sec-extensors</td>
<td>0.3617</td>
</tr>
<tr>
<td>triple hop(^A) at 60°/sec-flexors</td>
<td>0.4111</td>
</tr>
<tr>
<td>triple hop(^A) at 180°/sec-flexors</td>
<td>0.5625</td>
</tr>
<tr>
<td>triple hop(^A) at 300°/sec-flexors</td>
<td>0.4679</td>
</tr>
<tr>
<td>triple hop(^B) at 60°/sec-flexors</td>
<td>0.6124</td>
</tr>
<tr>
<td>triple hop(^B) at 180°/sec-flexors</td>
<td>0.5307</td>
</tr>
<tr>
<td>triple hop(^B) at 300°/sec-flexors</td>
<td>0.4810</td>
</tr>
<tr>
<td>triple hop(^C) at 60°/sec-flexors</td>
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</tr>
<tr>
<td>triple hop(^C) at 180°/sec-flexors</td>
<td>0.3963</td>
</tr>
<tr>
<td>triple hop(^C) at 300°/sec-flexors</td>
<td>0.3213</td>
</tr>
</tbody>
</table>

\(^A\) = D/H to MT/BW  
\(^B\) = D/H to AP/BW  
\(^C\) = D/H to TW/BW  
AP/BW = average power to body weight (%)  
MT/BW = mean torque to body weight (%)  
TW/BW = total work to body weight (%)  
D/H = distance over height
TABLE 4.9 CORRELATIONS BETWEEN FUNCTIONAL TESTING AND ISOKINETIC TESTING: VALUES WITH LITTLE OR NO CORRELATION

<table>
<thead>
<tr>
<th>Variables</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>lateral step-up(^A) at 60°/sec-extensors</td>
<td>0.2261</td>
</tr>
<tr>
<td>lateral step-up(^A) at 180°/sec-extensors</td>
<td>0.2418</td>
</tr>
<tr>
<td>lateral step-up(^A) at 300°/sec-extensors</td>
<td>0.0939</td>
</tr>
<tr>
<td>lateral step-up(^B) at 300°/sec-extensors</td>
<td>0.2480</td>
</tr>
<tr>
<td>lateral step-up(^A) at 300°/sec-flexors</td>
<td>0.2152</td>
</tr>
</tbody>
</table>

\(^A\)=TW/BW to TW/BW
\(^B\)=TW/BW to MT/BW
MT/BW=mean torque to body weight (%)
TW/BW=total work to body weight (%)
### TABLE 4.10 CORRELATIONS BETWEEN FUNCTIONAL TESTING AND ISOKINETIC TESTING: VALUES WITH FAIR CORRELATION

<table>
<thead>
<tr>
<th>Variables</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>cross-over hop&lt;sup&gt;A&lt;/sup&gt; at 60°/sec-flexors</td>
<td>0.4331</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;C&lt;/sup&gt; at 60°/sec-extensors</td>
<td>0.4646</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;C&lt;/sup&gt; at 60°/sec-flexors</td>
<td>0.4430</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;A&lt;/sup&gt; at 180°/sec-flexors</td>
<td>0.4811</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;B&lt;/sup&gt; at 180°/sec-flexors</td>
<td>0.4979</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;C&lt;/sup&gt; at 180°/sec-extensors</td>
<td>0.4422</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;C&lt;/sup&gt; at 180°/sec-flexors</td>
<td>0.3945</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;A&lt;/sup&gt; at 300°/sec-extensors</td>
<td>0.4927</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;A&lt;/sup&gt; at 300°/sec-flexors</td>
<td>0.4449</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;B&lt;/sup&gt; at 300°/sec-flexors</td>
<td>0.3851</td>
</tr>
<tr>
<td>cross-over hop&lt;sup&gt;C&lt;/sup&gt; at 300°/sec-extensors</td>
<td>0.4240</td>
</tr>
<tr>
<td>triple hop&lt;sup&gt;B&lt;/sup&gt; at 60°/sec-flexors</td>
<td>0.3422</td>
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<tr>
<td>triple hop&lt;sup&gt;C&lt;/sup&gt; at 60°/sec-extensors</td>
<td>0.4111</td>
</tr>
<tr>
<td>triple hop&lt;sup&gt;C&lt;/sup&gt; at 60°/sec-flexors</td>
<td>0.4350</td>
</tr>
<tr>
<td>triple hop&lt;sup&gt;C&lt;/sup&gt; at 180°/sec-extensors</td>
<td>0.4162</td>
</tr>
<tr>
<td>triple hop&lt;sup&gt;C&lt;/sup&gt; at 180°/sec-flexors</td>
<td>0.4325</td>
</tr>
<tr>
<td>triple hop&lt;sup&gt;A&lt;/sup&gt; at 300°/sec-extensors</td>
<td>0.3963</td>
</tr>
<tr>
<td>triple hop&lt;sup&gt;A&lt;/sup&gt; at 300°/sec-flexors</td>
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</tr>
<tr>
<td>triple hop&lt;sup&gt;B&lt;/sup&gt; at 300°/sec-flexors</td>
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<tr>
<td>triple hop&lt;sup&gt;B&lt;/sup&gt; at 300°/sec-flexors</td>
<td>0.4679</td>
</tr>
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<td>0.3617</td>
</tr>
<tr>
<td>triple hop&lt;sup&gt;C&lt;/sup&gt; at 300°/sec-flexors</td>
<td>0.3213</td>
</tr>
<tr>
<td>lateral step-up&lt;sup&gt;1&lt;/sup&gt; at 60°/sec-extensors</td>
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<tr>
<td>lateral step-up&lt;sup&gt;2&lt;/sup&gt; at 60°/sec-extensors</td>
<td>0.3456</td>
</tr>
<tr>
<td>lateral step-up&lt;sup&gt;2&lt;/sup&gt; at 60°/sec-flexors</td>
<td>0.2654</td>
</tr>
<tr>
<td>lateral step-up&lt;sup&gt;3&lt;/sup&gt; at 60°/sec-flexors</td>
<td>0.2929</td>
</tr>
<tr>
<td>lateral step-up&lt;sup&gt;1&lt;/sup&gt; at 180°/sec-extensors</td>
<td>0.3562</td>
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<td>lateral step-up&lt;sup&gt;2&lt;/sup&gt; at 180°/sec-extensors</td>
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<tr>
<td>lateral step-up&lt;sup&gt;1&lt;/sup&gt; at 300°/sec-extensors</td>
<td>0.2697</td>
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<td>lateral step-up&lt;sup&gt;1&lt;/sup&gt; at 300°/sec-flexors</td>
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<tr>
<td>lateral step-up&lt;sup&gt;2&lt;/sup&gt; at 300°/sec-extensors</td>
<td>0.2787</td>
</tr>
</tbody>
</table>

<sup>A</sup> = AP/BW  
<sup>B</sup> = MT/BW  
<sup>C</sup> = TW/BW  
<sup>1</sup> = TW/BW to AP/BW  
<sup>2</sup> = TW/BW to MT/BW  
<sup>3</sup> = TW/BW to TW/BW  
AP/BW = average power to body weight (%)  
MT/BW = mean torque to body weight (%)  
TW/BW = total work to body weight (%)
average power/body weight ratios at 60 and 180 degrees per second, extensor mean torque/body weight ratios at 60, 180, and 300 degrees per second, and the flexor average power/body weight ratio at 60 degrees per second.

The triple hop for distance demonstrated moderate to good correlation with extensor average power/body weight at 60 and 180 degrees per second, extensor mean torque/body weight at 60, 180, and 300 degrees per second, flexor average power/body weight at 60 and 180 degrees per second, and flexor mean torque/body weight ratios at 180 degrees per second. There were no total work/body weight ratios that fit into this category. There were no correlations that were rated excellent.

**TABLE 4.11 CORRELATIONS BETWEEN FUNCTIONAL TESTING AND ISOKINETIC TESTING: VALUES WITH MODERATE TO GOOD CORRELATION**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>cross-over hop(^A) at 60°/sec-extensors</td>
<td>0.5412</td>
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<tr>
<td>cross-over hop(^A) at 60°/sec-flexors</td>
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</tr>
<tr>
<td>cross-over hop(^B) at 60°/sec-extensors</td>
<td>0.5612</td>
</tr>
<tr>
<td>cross-over hop(^A) at 180°/sec-extensors</td>
<td>0.5248</td>
</tr>
<tr>
<td>cross-over hop(^B) at 180°/sec-extensors</td>
<td>0.6019</td>
</tr>
<tr>
<td>cross-over hop(^B) at 300°/sec-extensors</td>
<td>0.5586</td>
</tr>
<tr>
<td>triple hop(^A) at 60°/sec-extensors</td>
<td>0.5607</td>
</tr>
<tr>
<td>triple hop(^A) at 60°/sec-flexors</td>
<td>0.6124</td>
</tr>
<tr>
<td>triple hop(^B) at 60°/sec-extensors</td>
<td>0.5682</td>
</tr>
<tr>
<td>triple hop(^A) at 180°/sec-extensors</td>
<td>0.5411</td>
</tr>
<tr>
<td>triple hop(^A) at 180°/sec-flexors</td>
<td>0.5307</td>
</tr>
<tr>
<td>triple hop(^B) at 180°/sec-extensors</td>
<td>0.6231</td>
</tr>
<tr>
<td>triple hop(^B) at 180°/sec-flexors</td>
<td>0.5625</td>
</tr>
<tr>
<td>triple hop(^B) at 300°/sec-extensors</td>
<td>0.5573</td>
</tr>
<tr>
<td>lateral step-up(^C) at 60°/sec-flexors</td>
<td>0.5022</td>
</tr>
<tr>
<td>lateral step-up(^C) at 180°/sec-flexors</td>
<td>0.5088</td>
</tr>
</tbody>
</table>

\(^A\)=AP/BW  \hspace{1cm} \(^B\)=MT/BW  \hspace{1cm} \(^C\)=TW/BW to AP/BW

AP/BW=average power to body weight (%)  \hspace{1cm} MT/BW=mean torque to body weight (%)  \hspace{1cm} TW/BW=total work to body weight (%)
Chapter 5

Discussion and Implications

In this study right- and left-sided data from isokinetic and functional testing were not pooled because this would have created a biased sample. Knowledge of right-sided results allows for prediction of left-sided results. Because right- and left-sided data could not be pooled, a sample size of 50 was used. Only right sided isokinetic and functional test data were reported because paired t-tests showed no difference between the right and left sides (See Appendix L). Since paired t-tests also showed no difference between supine and sitting isokinetic data (See Appendix M), this study reported only isokinetic data obtained in the sitting position. The sitting position was chosen because it is used more frequently for clinical testing.

Davies (1984) has reported normative values for males and females age 15-45 for average power/body weight and agonist/antagonist ratios at 60, 180, and 300 degrees per second (see Appendix N for specific values). In qualitatively comparing the results of this study to the values published by Davies, the authors found that the male agonist/antagonist ratios were slightly lower than the normative data. However, the female agonist/antagonist ratios were comparable to the normative data. A sample size of only 20 males may partially explain the difference between the normative male isokinetic values published by Davies and the data reported here.

Total work to body weight, mean torque to body weight and average power to body weight were the isokinetic variables selected for correlation to the functional tests for a number of reasons. These variables are most often used in the clinical setting. Also, previous studies have not correlated these isokinetic variables to functional test scores. Since participants must control their body weight when performing functional tests, the
authors hypothesized that isokinetic variables normalized to body weight might show a
closer correlation to function. Finally, total work to body weight, mean torque to body
weight, and average power to body weight were used in this study because the authors
hypothesized "average" or "total" values would be more accurate in assessing true muscle
performance in contrast to peak torque values which only demonstrate peak performance
during one repetition (Ferring, Ellenbecker, & Derscheid, 1990; Perrin, 1993).

Correction for gravity was factored in to the isokinetic data to give more accurate
measures of muscle force (Perrin, 1993; Winters, Wells, & Orr, 1981). The authors chose
to use gravity correction based on research in which quadriceps femoris strength was
underestimated by 4-43% and hamstring strength was overestimated by 15-510% based

In an attempt to avoid fatigue, the order in which each person was tested was
random. The role of leg dominance and the learning effect were also accounted for by
randomizing which leg each individual started with and then making sure that individual
started with that same leg on each test.

**Interpretation of Statistical Outcomes**

In correlating isokinetics with functional testing data, the lateral step-up was the
only functional test with little or no correlation (r = 0.00-0.25) to any of the isokinetic
values (average power to body weight, mean torque to body weight, and total work to
body weight). There were many variables to control. For example, it was difficult to
control lateral dipping of the hip and substitution with the gluteus medius of the test leg
side. Also, it was hard to monitor if the subject touched the floor with the non-tested leg,
if the subject was bouncing off his/her heel, or if the tested knee was going into full
extension at the "top" portion of the test. To date, no reliability or validity studies have
been done for the lateral step-up. Although lateral step-up exercise is used frequently in
the clinic, lateral step-up testing should not be used until more research has been
performed to establish its validity and reliability.
Average power to body weight and mean torque to body weight ratios had a better correlation than total work to body weight ratios to the cross-over hop for distance and triple hop for distance tests. This may be explained partially by the fact that average power and mean torque to body weight values are computed based on an "all or none" response of the muscles rather than a sum total of each repetition. Average power to body weight and mean torque to body weight may be more indicative of the quick, explosive muscle force production necessary for the functional activities tested. A total work value is a representation of a sum of all work over all repetitions which may explain why total work to body weight did not correlate well to the cross-over and triple hop for distance.

Knee extensor isokinetic values had a better correlation to the cross-over and triple hop for distance than knee flexor values. This was consistent with the results of a study by Wilk et al., 1994. During closed chain functional testing, the hamstrings and quadriceps femoris muscles contract (Worrel et al., 1993). The quadriceps femoris muscles are forced to eccentrically control the knee flexion moment caused by the body weight, and also must concentrically act to propel the body forward or up with knee extension. The hamstrings are forced to eccentrically control the hip flexion moment caused by the body weight, and also must concentrically act to propel the body forward or up with hip extension. Because only concentric measures of muscle performance around the knee were measured, extensor measurements were better correlated to the functional tests than hamstring measurements. If hip concentric measures and knee eccentric measures had been measured, the results might have been different.

No test speed (60, 180, or 300 degrees/second) was more indicative of functional performance than the other. Although 300 degrees per second has been identified as the angular velocity of the knee during natural or normal velocity ambulation (Davies, 1984), 60, 180, and 300 degrees per second were not fast enough speeds to simulate joint angular velocities of the knee during the cross-over hop for distance, triple hop for distance, and
the lateral step-up. If the dynamometer was able to compute isokinetic variables at higher speeds the isokinetic measurements might be more indicative of muscle performance.

**The results as compared to theory**

There are a number of possible reasons isokinetic data did not correlate highly to function. First, isokinetic dynamometers can only test a joint in one plane. In this study, sagittal plane knee flexion and extension were tested isokinetically. But the knee has six degrees of motion allowing movement in the sagittal plane, frontal plane, and transverse planes (Norkin & Levangie, 1992). Functional tests are designed to challenge the knee in multiple planes of movement (Fu et al., 1992) and simulate everyday activity.

Another explanation for the low and varied correlation between isokinetics and functional tests is the difference in the type of muscle action being tested. Isokinetic dynamometers can test muscles in both the eccentric and concentric mode, but not both at the same time. Since most activities of daily living require combined eccentric and concentric contractions of the same muscle, assessment with isokinetics may not accurately predict true function (Fu et al., 1992; Palmitier et al., 1991).

Lastly, the concept of the kinetic chain may be used to explain the weak correlation between isokinetics and function. Isokinetic testing is open chain, whereas functional testing is closed chain. Performance during isokinetic testing does not require control of one's height, body weight, gravity and momentum as functional testing does. Therefore, an individual could theoretically perform well isokinetically, but do poorly when challenged functionally. Closed chain activity requires muscle control through multi-plane movement and proprioceptive input for appropriate concentric and eccentric contraction of muscles (Fu, et al., 1992; Palmitier, et al., 1991). Thus it seems that no testing method alone can accurately assess muscle performance (Roy & Irwin, 1983).

**Comparison of results with other work**

Comparing this study to past studies is difficult because previous investigations did not look at the same variables that were included in this study. All published articles
comparing isokinetics to functional testing utilized either concentric or eccentric peak torque, torque acceleration energy, and total work. This study investigated the relationship of isokinetic variables normalized to body weight (average power/body weight, mean torque/body weight, and total work/body weight) with functional test values normalized to height or body weight. Previous studies used only the distances jumped during the hopping tests or the number of repetitions completed with the lateral step-up. The authors hypothesized that normalization using height and weight would result in a better indicator of performance of lower extremity function because hopping, jumping, and agility tests require participants to control their body weight in space. Normalized functional test values were also used to facilitate more accurate comparisons of muscle performance between individuals of varying heights and weights.

Many authors have investigated the correlation between isokinetic knee testing and functional testing with conflicting results. Several authors found a positive correlation between isokinetic knee testing and athletic performance testing. Sachs, Daniel, Stone, and Garfein (1989) found a moderate to good correlation (r = 0.59) between extensor peak torque (60 degrees per second) and the one-legged hop for distance test in patients three to seven years post anterior cruciate ligament reconstruction. Barber, Noyes, Mangine, McCloskey, and Hartman (1990) found a positive correlation between extensor peak torque (60 degrees per second) and the single leg hop for distance, single leg hop for time, and the cross-over hop for distance in normal and anterior cruciate ligament deficient knees. Wilk et al. (1994) found a moderate correlation (r = 0.41-0.64) between extensor peak torque values (180 degrees per second and 300 degrees per second) and functional tests including the single leg timed hop, one-legged hop for distance, and the cross-over triple hop in anterior cruciate reconstructed knees (twenty-one to thirty weeks after surgery). Tegner, Lysholm, Lysholm, and Gillquist (1986) found a positive correlation between concentric knee extensor values (180 degrees per second) and hopping and
running drills (running in a figure of eight, stair running, and slope running) in anterior cruciate deficient patients.

In contrast, other authors have demonstrated little or no correlation between isokinetic knee testing and functional testing. Anderson et al. (1991) found no statistical relationship between concentric peak torque measures (60 degrees per second and 180 degrees per second) or eccentric peak torque measures (30 degrees per second and 90 degrees per second) and the agility run, vertical jump, and the 40 yard dash in college-aged male athletes. Lephart et al. found no correlation ($r = 0.32$ to $0.42$) between hamstrings/quadriceps femoris ratios (60 degrees per second and 270 degrees per second) and the co-contraction test, carioca test, and the shuttle run test in anterior cruciate insufficient athletes ten to thirty-six months after injury. Delitto et al. (1993) investigated 30 anterior cruciate ligament reconstructed knees (twenty-two to ninety-seven months post-surgery) and found weak correlation ($r=0.09$ to $0.459$) between concentric or eccentric knee peak torque or work variables and two functional tests consisting of the one legged hop and the vertical jump. Wilk et al. (1994) found no correlation between knee flexor peak torque, hamstrings/quadriceps femoris ratios (180 degrees per second and 300 degrees per second) and performance on the single leg timed hop, one-legged hop for distance, and the cross-over triple hop in anterior cruciate reconstructed knees twenty-one to thirty weeks after surgery. Worrel et al. (1993) demonstrated no increase in isokinetic extensor peak torque (90 degrees per second) in healthy subjects following four weeks of closed chain exercise. During the same time period, however, hop for distance, hop for time, leg press, and step-up repetition showed significant increases.

**Limitations**

There were several limitations in this study. For the functional testing the authors attempted to minimize variability by having one tester throughout the entire study. However, this may not have reduced the human error in measuring the distance hopped or in calculating the mean of the distances hopped in the two hop tests. Neither inter-tester
nor intra-tester reliability testing was performed therefore, similar results are not assured when testing is carried out by a different examiner.

The isokinetic testing may have introduced some error as it was difficult to stabilize the subjects. Poor stabilization can result in the development of different length-tension relationships affecting torque production (Johnson, 1981). Without proper stabilization, Garrick (1980) showed data can vary as much as 25%.

Limitations of the sample included that the authors were unable to account for any lower extremity injuries sustained by participants that had not been treated by a physician. Therefore, lingering proprioceptive deficits could affect the functional test results which could influence the end results. This was a sample of convenience leaving the authors little variability in the age of the subjects. To be specific, about 50% of the subjects were between the ages of 20 and 25 and about 25% of the subjects were over 30. Also, because the authors chose a specific age group (20-40) there is no way to know how subjects younger or older than that range would score on the tests.

The activity score from the pre-test questionnaire was not used in the data analysis because of it's subjectivity in indicating the subjects' true activity level (ie: what one individual may feel is strenuous activity may be considered light activity to another). Because the survey used did not have a clear and specific distinction between activity categories, the activity score was not an accurate indicator of activity level.

The testing sequence was rigorous and fatigue may have been a factor, in spite of the testing randomization. Optimally, subjects would have performed each testing series (supine isokinetic, sitting isokinetic, and functional testing) at one week intervals, but this was not possible secondary to time constraints. The learning effect may also have been a limitation. A few of the subjects had previous experience with isokinetic testing while others did not. Additionally, the learning that took place between limbs could not be adequately determined or controlled.
Clinical Significance of Outcomes

Although the lateral step-up exercise is used frequently in the clinic, our results suggest that it is not a good functional test. Clinicians should choose functional tests that have been shown to be valid and reliable, such as the hop tests (Booher et al., 1993).

Clinicians can use either the supine or sitting position for isokinetic testing. This is in contrast to the findings of Anderson et al. (1991). They suggested testing knee isokinetic strength in supine because it more closely resembled length-tension ratios in the muscles during function.

No test speed (60, 180, or 300 degrees per second) was more indicative of functional performance. Clinicians should make bilateral comparisons of isokinetic scores at the same speed, but should not assume that one speed is a better indicator of functional performance.

There was no difference between the distance jumped in the cross-over hop for distance and triple hop for distance. Although one might assume these two tests are similar, clinicians are reminded that this was a test on normal subjects. The authors propose that clinicians might see a difference in performance of these two hop tests with an injured subject. For example, take a subject with a complete tear of the lateral collateral ligament of the knee. Functional testing of this individual may show little deficit with the triple hop for distance as this is primarily a sagittal plane dominant activity. Since the deficit affects frontal plane stability, the cross-over hop for distance may show decreased performance when compared to the triple hop for distance. It is recommended that clinicians use a functional test that stresses the body in more than one plane to get a good assessment of functional performance.

Based on our results it appears that average power/body weight and mean torque/body weight are better correlated to functional tests than total work/body weight. Clinicians should use total work/body weight ratios cautiously when predicting athletic performance.
Although average power/body weight and mean torque/body weight have a better correlation to functional tests, no isokinetic value used in this study had an excellent correlation to functional performance. Clinically, isokinetics alone are often used to determine if an athlete is ready to return to competition. The results of this study and the results of other studies, previously mentioned, show that isokinetic scores should be used in conjunction with functional test performance for determining return to activity.

Further research is needed. The authors recommend correlating the results of males with females, stratifying the results by age, testing different age groups, using different functional tests, and testing individuals who are recovering from a variety of lower extremity pathology. Further work comparing sitting and supine knee isokinetic testing results are needed. Finally, functional testing studies should be done to establish a normative database.

Conclusion

The purpose of this study was to determine if there was any correlation between lower extremity functional testing and knee isokinetic testing. The results showed that there was not a strong correlation between isokinetic testing at 60, 180, and 300 degrees per second and the triple hop for distance, cross-over hop for distance, and the lateral step-up. As a result of this study, it is recommended that isokinetic testing be used in conjunction with functional testing when obtaining objective measures of strength and endurance in the lower extremity.
Reference List


Appendix A

Glossary of Terms

Agonist to antagonist ratio: the ratio of the peak torque of the agonist to the antagonist.

Average power: the calculation of total work performed within a single or several repetitions divided by the time required to perform the work. This is expressed in watts.

Mean torque: the average of all the peak torque from several consecutive torque curves.

Mean torque to body weight: a percentage expressing a ratio of the mean torque to body weight.

Peak torque: the single highest point on the torque graph generated during an exercise set.

Single repetition work: the work performed during one repetition.

Torque acceleration energy: the energy it takes to accelerate the limb to the preset speed of the isokinetic machine.

Total work: the sum of all the work performed during an exercise set. This is calculated by summing up the area under the torque curves.

Total work to body weight: a percentage expressing the total work divided by the subject’s body weight.
Appendix B

CONSENT FORM

TITLE OF STUDY
"The Correlation Between Isokinetic Testing of the Quadriceps and Hamstrings and Closed Chain Functional Testing of the Lower Extremity"

INVESTIGATORS
This research study is being carried out under the supervision of Jolene Bennett MA, PT, ATC, at the following institution: Butterworth Rehabilitation Center. Grand Valley State University graduate students Kristin Brinks, Ronda DeLong and Toni Stout will be assisting in the research project. This study will include 25 females and 25 males age 20-40.

PURPOSE OF STUDY
The purpose of this study is to compare two different isokinetic test positions of the lower extremity, specifically the knee, to three closed chain functional tests of the lower extremity. The knowledge gained in this study will help physical therapists and physicians more accurately measure functional strength and endurance of the leg.

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, experience with an isokinetic machine, height, weight, age and gender. You will be screened by a licensed physical therapist for any hip, knee, or ankle dysfunction. Tests checking for muscle tightness, ligamentous instability, menisci lesions and range of motion deficits will be performed. You will be excluded from the study under the following conditions; 1. any history of hip, knee, ankle, or back injury which required treatment by a physician, 2. unable to attain the Thomas test position with at least 90 degrees of knee flexion, 3. unable to attain 65 degrees of straight leg raise, 4. if given a positive test value for ligament laxity or menisci test, 5. if you are currently participating in intercollegiate athletics.

Three different stations will be used for data collection. They include Biodex test at 0 degrees hip flexion, Biodex test at 115 degrees hip flexion and a functional testing station with two different hopping activities and a step-up activity. Computer randomization will determine the order in which subject will visit the three stations. A separate computer randomization will also be performed to determine which leg will be tested first at each of the stations.

Prior to testing you will be lead through a warm-up session. The warm-up session will include five minutes on a Fitron stationary bicycle set at 90RPMs and self-stretching of the quadriceps, hamstrings, gastrocnemius and soleus muscles. The stretches will be performed as instructed with three repetitions held for 20 seconds each.

Page 1 of 1 Subject's Initials_______
Biodex testing will be done at 0 degrees and 115 degrees of hip flexion using the same testing protocol. To familiarize you with the machine and isokinetic resistance, five submaximal repetitions will be performed at 90 degrees per second prior to testing each leg. The testing protocol includes data collection at 60, 180 and 300 degrees per second with the slowest (60 degrees per second) speed being tested first. At 60 degrees per second, you will perform three submaximal and three maximal repetitions as a warm-up followed by five maximal test repetitions. At 180 degrees per second, you will perform three submaximal and three maximal repetitions as a warm-up followed by 10 maximal test repetitions. At 300 degrees per second, you will perform the same amount of submaximal and maximal warm-up repetitions followed by 30 maximal test repetitions. Standardized rest periods including 10 seconds following the warm-up repetitions and a 30 second rest period between test speeds will be used. A two minute rest will be used prior to testing the opposite leg.

The three functional tests include a lateral step-up test, a triple hop for distance test and a cross-over hop for distance test. Each of these tests will be completed twice by both legs. You will be given two practice trials for the hop tests and three practice repetitions for the lateral step-up test prior to testing. Standardized rest periods of 30 seconds will be given between test sessions using alternating legs during each specific test.

RISKS
Pregnant women should not participate in this study.

You will be able to stop the Biodex testing procedure at any time by hitting the red stop button or by not completing the repetition.

Throughout all three functional tests, the investigator will be standing within one arms length for your safety.

You may experience muscle soreness following the test which is common after physical activity and strength testing.

PRIVACY
You will be given a subject number to be used as identification throughout the study and your identity will be kept confidential.

If the results of this study are written in a scientific journal or presented at a scientific meeting, your name will not be used.

FINANCIAL COMPENSATION
In the event of injury resulting from the research procedures, proper first aid treatment will be administered by the investigators and/or physicians at the Butterworth Med+Center. Butterworth Med+Center and Hospital will not provide care and/or hospitalization without cost.
CONTACTS/QUESTIONS

This study is being directed by Jolene Bennett MA, PT, ATC.

The following is the name, address and telephone number of the person to contact for answers to pertinent questions about the research study, about your rights as a research subject:

NAME: Linda Pool
ADDRESS: Butterworth Hospital  
          100 Michigan NE  
          Grand Rapids, MI 49503  
TELEPHONE #: (616) 774-1291

VOLUNTARY PARTICIPATION

Your decision about whether to or not to participate in this study is voluntary. If you decide to participate, you may withdraw from the study at any time.

STATEMENT OF PHYSICAL THERAPIST OBTAINING INFORMED CONSENT

I have fully explained this research study to the subject, ___________________________. In my judgment, there was sufficient access to information, including risks and testing procedures, to make an informed decision.

DATE__________  PT's Signature: ____________________________
                        Jolene Bennett MA, PT, ATC

DATE__________  Subject's Signature__________________________

Patient's Name ____________________________  (print)

DATE__________  Witness' Signature__________________________

Witness' Name ____________________________  (print)

Page 3 of 3  Subject's Initials______

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Appendix C

Pretesting Questionnaire

Number: _____  Age: ____  Sex: ______Male ______Female

Birthdate: _______

Check the items that apply to your current level of exercise and/or sports activity level:

**Competitive/Strenuous Activities**
I participate in these activities (practice or competition) 4-7 days/week for 15-20 minutes:

- Basketball, Volleyball, Football, Gymnastics, Soccer
- Tennis, Racquetball, Handball, Baseball, Softball, Ice Hockey, Field Hockey, Skiing, Wrestling, Ballet
- Running, Cycling(racing), Swimming, Aerobics
- Weight Training
- Walking
- Other:

**Major Recreational-League Sports**
I participate in these activities (practice or competition) 1-3 days/week for at least 15-20 minutes:

- Basketball, Volleyball, Football, Gymnastics, Soccer
- Tennis, Racquetball, Handball, Baseball, Softball, Ice Hockey, Field Hockey, Skiing, Wrestling, Ballet
- Running, Cycling(racing), Swimming, Aerobics
- Weight Training
- Walking
- Other:

**Recreational**
I participate in these activities (practice or competition) no more than 1-3 x/month for at least 15-20 minutes:

- Softball, Baseball, Basketball, Volleyball, Football, Soccer, Field Hockey, Gymnastics, Tennis, Racquetball, Skiing
- Weight Training
- Walking
- Other:
**Light Recreational**
I participate in these activities 1-3 x/month for at least 15-20 minutes:

- Bowling
- Golf
- Swimming
- Light Cycling
- Dancing
- Light Skiing
- Hiking
- Walking
- Other:

**No Recreational Pursuits**

- I do not participate in recreational activities

During activity I would rate my intensity level at _____ on the perceived exertion scale (see next sheet).

Are you presently involved in any intercollegiate athletics? Y N

Have you ever had any of the following problems that required treatment by a physician? Please circle all that apply.

- ankle injury Y N
- cardiac condition Y N
- knee injury Y N
- pulmonary problems Y N
- hip injury Y N
- neuromuscular disease Y N
- back injury Y N
  - ie: MS, Parkinson's

Do you have any medical condition that may affect your performance during the testing procedures? Y N (if yes, please explain) ________________

Are you pregnant? Y N

List any medications you are currently taking including over the counter drugs:

Have you ever used an isokinetic device for testing or exercise purposes? Check one: ___________ yes ___________ no
Appendix D

Perceived Exertion Scale

While performing exercise of activities of daily living, it is helpful to determine how hard you are working. Below is a scale which can be used to determine the intensity of your work.

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>nothing at all (sitting or lying still)</td>
</tr>
<tr>
<td>1</td>
<td>very light</td>
</tr>
<tr>
<td>2</td>
<td>light</td>
</tr>
<tr>
<td>3</td>
<td>moderate</td>
</tr>
<tr>
<td>4</td>
<td>somewhat hard</td>
</tr>
<tr>
<td>5</td>
<td>hard</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>very hard</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>very, very hard</td>
</tr>
</tbody>
</table>
Appendix E

Subject Screening Procedure

Subject: ____________  Examiner: ____________  Date: ______
Height: ____________  Weight: ______

Hip/Knee/Ankle
Flexibility Testing:
Thomas Test (Hip Flexor):
R HIP Subject can attain Thomas Test Position: Y N
Thomas Test Position with Knee Flexed: <90° > 90°
L HIP Subject can attain Thomas Test Position: Y N
Thomas Test Position with Knee Flexed: <90° > 90°

Gastrocnemius/Soleus:
Right Knee Extended: neutral 1-10° >10°
Right Knee Flexed: neutral 1-10° >10°
Left Knee Extended: neutral 1-10° >10°
Left Knee Flexed: neutral 1-10° >10°

Straight Leg Raise (Hamstrings): R _____ L ______

Squat Screening Test: + -

Knee
Ligament Tests:
Lachman's (ACL):
R  L  
+  +  +
Posterior Drawer (PCL):
R  L  
+  +  +
Varus/Valgus Stress Test:
(Collateral L) R  L  
+  +  +
Joint Line Tenderness:
R  L  
+  +  +
Mc Murray's Test (Meniscus):
R  L  

Ankle
Ligament Tests:
Anterior Drawer:
R  L  
+  +  +
Posterior Drawer:
R  L  
+  +  +
Inversion/Eversion Test:
Inversion +  +  +
Eversion +  +  +

(Rateral Ligament Laxity)
Appendix F

Conditions for Exclusion from the Study

Subjects will be excluded from the study under the following conditions:

1. If the subject has any history of hip, knee, ankle, or back injury which has required treatment by a physician.

2. If the subject is unable to attain the Thomas Test position with at least 90° of knee flexion.

3. If the subject is unable to attain at least 65° in the straight leg raise.

4. If the subject is given a + for any of the ligament laxity tests.

5. If the subject is given a + for any of the meniscal tests.

6. If the subject is currently participating in intercollegiate athletics.

7. If the subject has had a baby within the last year.
Appendix G

Data Collection Sheet

Subject Number _____ Date_____ Gender____ Age______

Height ___________ Weight ___________

**Triple Hop for Distance**

Right Leg

Test 1 cm.  Test 2 _______cm  Mean ___

Left Leg

Test 1 cm  Test 2 _______cm  Mean ___

**Cross-over Hop for Distance**

Right Leg

Test 1 cm  Test 2 _______ cm  Mean ___

Left Leg

Test 1 cm  Test 2 cm  Mean ____

**Lateral Step-up**

Right Leg

Test 1 _total number of repetitions

Computed total work: ____________

Left Leg

Test 1 _total number of repetitions

Computed total work: ____________
Isokinetic Data Hip Flexion at 0°

Subject Number: _____

Test Speed 60°/sec

Right Leg

Extension: Torque/ Body Weight _____  Total Work __________

Total Work/Body Weight__________  Power/Body Weight_____

Average Power _____  Average Power/Body Weight _____

Flexion: Torque/ Body Weight __  Total Work __________

Total Work/Body Weight__________  Power/Body Weight_____

Average Power _____  Average Power/Body Weight _____

Left Leg

Extension: Torque/ Body Weight _____  Total Work __________

Total Work/Body Weight__________  Power/Body Weight_____

Average Power _____  Average Power/Body Weight _____

Flexion: Torque/ Body Weight _______  Total Work _________

Total Work/Body Weight__________  Power/Body Weight_____

Average Power _______  Average Power/Body Weight _____
Isokinetic Data Hip Flexion at 0°

Subject Number: _____

Test Speed  180°/sec

Right Leg

Extension: Torque/ Body Weight _____  Total Work ____________

Total Work/Body Weight _______  Power/Body Weight____

Average Power ____  Average Power/Body Weight ____

Flexion: Torque/ Body Weight __  Total Work ____________

Total Work/Body Weight _______  Power/Body Weight____

Average Power ____  Average Power/Body Weight ____

Left Leg

Extension: Torque/ Body Weight _____  Total Work ____________

Total Work/Body Weight _______  Power/Body Weight____

Average Power ____  Average Power/Body Weight ____

Flexion: Torque/ Body Weight _______  Total Work ____________

Total Work/Body Weight _______  Power/Body Weight____

Average Power ____  Average Power/Body Weight ____
Isokinetic Data Hip Flexion at 0°

Subject Number: ____

Test Speed  300°/sec

Right Leg

Extension: Torque/ Body Weight _____  Total Work ____________

Total Work/Body Weight _______  Power/Body Weight _____

Average Power _____  Average Power/Body Weight ____

Flexion: Torque/ Body Weight __  Total Work ____________

Total Work/Body Weight _______  Power/Body Weight____

Average Power _____  Average Power/Body Weight ____

Left Leg

Extension: Torque/ Body Weight _____  Total Work ____________

Total Work/Body Weight _______  Power/Body Weight _____

Average Power _____  Average Power/Body Weight ____

Flexion: Torque/ Body Weight _______  Total Work ____________

Total Work/Body Weight _______  Power/Body Weight____

Average Power _____  Average Power/Body Weight ____
Isokinetic Data Hip Flexion at 115°

Subject Number: _____

Test Speed 60°/sec

Right Leg

Extension: Torque/Body Weight ______ Total Work __________

Total Work/Body Weight ________ Power/Body Weight____

Average Power ____ Average Power/Body Weight____

Flexion: Torque/Body Weight __ Total Work __________

Total Work/Body Weight_________ Power/Body Weight____

Average Power ____ Average Power/Body Weight____

Left Leg

Extension: Torque/Body Weight ______ Total Work __________

Total Work/Body Weight ________ Power/Body Weight____

Average Power ____ Average Power/Body Weight____

Flexion: Torque/Body Weight ______ Total Work __________

Total Work/Body Weight_________ Power/Body Weight____

Average Power ____ Average Power/Body Weight____
Isokinetic Data Hip Flexion at 115°

Subject Number: ____

Test Speed 180°/sec

Right Leg

Extension: Torque/Body Weight ______ Total Work ____________

Total Work/Body Weight _______ Power/Body Weight_____

Average Power ____ Average Power/Body Weight ____

Flexion: Torque/Body Weight __ Total Work ____________

Total Work/Body Weight _______ Power/Body Weight_____

Average Power ____ Average Power/Body Weight ____

Left Leg

Extension: Torque/Body Weight ______ Total Work ____________

Total Work/Body Weight _______ Power/Body Weight_____

Average Power ____ Average Power/Body Weight ____

Flexion: Torque/Body Weight ______ Total Work ____________

Total Work/Body Weight _______ Power/Body Weight_____

Average Power ____ Average Power/Body Weight ____
Isokinetic Data Hip Flexion at 115°

Subject Number: _____

Test Speed  300°/sec

Right Leg

Extension: Torque/ Body Weight _____  Total Work __________

Total Work/Body Weight_______  Power/Body Weight____

Average Power _____  Average Power/Body Weight _____

Flexion: Torque/ Body Weight __  Total Work __________

Total Work/Body Weight_______  Power/Body Weight____

Average Power _____  Average Power/Body Weight _____

Left Leg

Extension: Torque/ Body Weight _____  Total Work __________

Total Work/Body Weight_______  Power/Body Weight____

Average Power _____  Average Power/Body Weight _____

Flexion: Torque/ Body Weight _______  Total Work __________

Total Work/Body Weight_______  Power/Body Weight____

Average Power _____  Average Power/Body Weight _____
Appendix H

Instructions for Isokinetic Testing

INTRODUCTION:

At this station you will perform a strength and endurance test on an isokinetic machine. During isokinetic testing, the resistance varies and does not remain constant. The harder you push against the machine, the harder it will push against you; so you must kick and pull as fast and as hard as you can for the test to be accurate.

The test will consist of three different test speeds. The difference between speeds will feel much like the difference when you shift gears on a bicycle. On the slower speeds, you won't be able to move your leg very fast because you will feel a lot of resistance; just like in a high gear on a bicycle. But at faster speeds, you will be able to kick a lot faster before you feel the resistance; just like when you pedal at a lower gear.

During the test, each leg will be tested separately and follow the same protocol. After you are positioned, you will be given five practice repetitions to familiarize yourself with the isokinetic machine. Then the actual testing will take place. At each of the three speeds, you will perform three less than maximum and three maximum contractions followed by the test repetitions. At the first speed, you will do five repetitions; at the second speed, you will do ten repetitions; and at the last speed, you will do thirty repetitions. You will then switch legs and do the same protocol on the opposite leg. Throughout the test, you will be cued as to what will you need to do at that particular time.

We will now set you up for the test. At any time you can stop the test by hitting the red stop button or by not completing any more repetitions.

TEST: "We will now position you for the test."

1. SET-UP:
   a. Check the balance on the machine.
b. Position the subject in supine or 115° hip flexion.
c. Line up the Biodex® with the femoral condyles. May need to adjust the seat.
d. Stabilize subject with the straps. For the ankle, ask "Can you still bring your foot and toes up toward your head".
c. Pull straps tight. "These should feel snug but not so tight that they are cutting off your circulation."
d. Meanwhile, information will be typed into the computer.

2. SETTING THE ROM: "Just relax while I move your leg up and down to set the range of motion for the machine".
a. Set the reference angle at 90° by measuring with a goniometer.
b. Measure to 0° and set the ROM buttons.

3. MEASURE THE GRAVITY EFFECT: "Now we are going to measure how heavy your leg is. I'm going to straighten your leg and then I want you to totally relax your leg." ...."Okay. Totally relax your leg."

4. "You will now be given five repetitions to get used to the isokinetic machine. Kick and pull to get used to the machine. You may start when I say start and stop when I say stop. Are you ready? Start!.....Stop!"
   15s "Are any of the straps too tight or too loose?"

5. TEST at 60:
   a. Practice and scaling. "Now I would like you to perform three less than maximum and three maximum repetitions as a warm-up to get used to this speed. You may start when I say start and stop when I say stop. Are you ready? Start!.....Stop!"
   15s b. "Now hold your leg in the start position. You will now do five test repetitions kicking and pulling as fast and as hard as you can. You may start when I say start and stop when I say stop. Are you ready?" 30s Start!.....Stop!"

6. TEST at 180:
a. Practice and scaling. "Again, you will perform three less than maximum and three maximum repetitions as a warm-up to get used to the medium speed. You may start when I say start and stop when I say stop. Are you ready? Start!....Stop!"

b. "Now hold your leg in the start position. You will now do ten test repetitions kicking and pulling as fast and as hard as you can. You may start when I say start and stop when I say stop. Are you ready? Start!....Stop!"

7. TEST at 300:
   a. Practice and scaling. "Again, you will perform three less than maximum and three maximum repetitions as a warm-up to get used to the fast speed. You may start when I say start and stop 15s when I say stop. Are you ready? Start!....Stop!"
   b. "Now hold your leg in the start position. You will now do thirty test repetitions kicking and pulling as fast and as hard as you can. You may start when I say start and stop when I say stop. Are you ready? Start!....Stop!"

8. "This completes the testing for this leg. We will now go through the same protocol on the opposite leg. You may now get off of the seat and sit on the seat on the other side.

2 minutes

9. POSITIONING:
   a. Check the chair number and the ankle height number.
   b. Measure the hip angle.
   c. Line up the Biodex® with the femoral condyle.
   d. Stabilize with the straps. For the ankle, ask "Can you still bring your foot and toes up toward your head".
   e. Pull straps tight. "These should feel snug but not so tight that they are cutting off your circulation."

10. MEASURE THE GRAVITY EFFECT: "Now we are going to measure how heavy your leg is. I'm going to straighten your leg and then I want you to totally relax your leg." ......
    "Okay. Totally relax your leg."
11. "You will now be given five repetitions to get used to the isokinetic machine. Kick and pull to get used to the machine. You may start when I say start and stop when I say stop. Are you ready? Start!....Stop!"

15s
"Are any of the straps too tight or too loose?"

12. TEST at 60:
   a. Practice and scaling. "Now I would like you to perform three less than maximum and three maximum repetitions as a warm-up to get used to this speed. You may start when I say start and stop when I say stop. Are you ready? Start!....Stop!"

15s
b. "Now hold your leg in the start position. You will now do five test repetitions kicking and pulling as fast and as hard as you can. You may start when I say start and stop when I say stop. Are you ready?" Start!....Stop!"

13. TEST at 180:
   a. Practice and scaling. "Again, you will perform three less than maximum and three maximum repetitions as a warm-up to get used to the medium speed. You may start when I say start and stop when I say stop. Are you ready? Start!....Stop!"

15s
b. "Now hold your leg in the start position. You will now do ten test repetitions kicking and pulling as fast and as hard as you can. You may start when I say start and stop when I say stop. Are you ready?" Start!....Stop!"

14. TEST at 300:
   a. Practice and scaling. "Again, you will perform three less than maximum and three maximum repetitions as a warm-up to get used to the fast speed. You may start when I say start and stop when I say stop. Are you ready? Start!....Stop!"

15s
b. "Now hold your leg in the start position. You will now do thirty test repetitions kicking and pulling as fast and as hard as you can. You may start when I say start and stop when I say stop. Are you ready?" Start!....Stop!"
Appendix I

Instructions for Functional Testing

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.

If the opposite leg or any arm touches the ground during the three hops test, that trial will not be counted. You must return to the start line for another trial. You will get a maximum of five test attempts.

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 in the final position until instructed to return back to the start position for the next trial. You may put your other leg on the floor when instructed to do so.
4. 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 have to repeat the 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.
Cross-over Hop for Distance

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

If the opposite leg or any arm touches the ground during the three hops test, that trial will not be counted. You must return to the start line for another trial. You will be given a maximum of five 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 be sure that you do not jump on the tape or that trial will not be counted.
3. Remain in the final position until instructed to return back to the start position for the next trial. You may put your other leg down when instructed to do so.
4. 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 have to repeat the 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.
Lateral Step-up

The purpose of this test is to determine the total number of repetitions completed in a one minute time period on a step six inches high. You will be given five practice repetitions to familiarize yourself with the test.

1. Stand with the leg to be tested next to the step. Put your hands on your hips. You must keep your hands level.
2. Place the leg to be tested on the step and leave the other leg on the floor next to the step.
3. Straighten out the knee of the leg that is on the step bringing the other leg up to meet the step.
4. Next lower the non-exercised leg to the floor with your foot flexed (toes toward the ceiling) and lightly touch that heel to the floor without putting any weight on that foot.
5. Repeat this motion as many times as you can in one minute.
6. You will begin when I say begin and stop when I say stop.
7. You will be given the time at 30 seconds.

Reminder: If your heel does not touch the ground that repetition will not be counted. Do not push off with your heel, touch it lightly.
Appendix J

Stretching Protocol

Hamstring Stretch
1. Sit with the leg to be stretched extended across the treatment table, placing your opposite foot on the floor.
2. Lean your body forward toward your thigh, keeping your back straight, so the movement occurs only at the hip.
3. Continue to lean forward until you feel a "stretch" in the back part of the leg on the table.
4. Hold for 20 seconds.
5. Repeat steps 1-4 two more times.
6. Repeat above with opposite leg.

Quadriceps Stretch
1. Lay on your stomach on the treatment table.
2. Bend the knee of the leg to be stretched.
3. Grab your ankle on that side and pull your heel toward your bottom until a stretch is felt in the front of your thigh.
4. Hold that stretch for 20 seconds.
5. Repeat steps 1-4 two more times.
6. Repeat above with opposite leg.

Gastrocnemius Stretch
1. Stand with your hands against the wall with the leg to be stretched behind you.
2. Turn the foot of the leg to be stretched inward.
3. Lean forward on your front leg and bend your knee keeping the heel of the foot behind you on the floor and the knee straight.
4. Hold this position for 20 seconds. Do not bounce.
5. Repeat two more times.
6. Repeat on the opposite leg.

Soleus Stretch
1. Stand with your hands against the wall with the leg to be stretched behind you.
2. Turn the foot of the leg to be stretched inward.
3. Lean forward on your front leg and bend your knee keeping the heel of the foot behind you on the floor and the knee bent this time.
4. Hold this position for 20 seconds. Do not bounce.
5. Repeat two more times.
6. Repeat on the opposite leg.
Appendix K

Total Work Formula

Total work = (mass)(gravity)(height)

Weight = (mass)(gravity)

Total work = (weight)(height)

Total work = Total work(up) + Total work(down)

Total work(up) is positive work, total work(down) is negative work.

Lehmkuhl and Smith (1983) reported the energy cost of positive work was from 2.5 to 6 times greater than the cost of negative work.

Total work(down) = (.25)Total work(up)

Total work = (weight)(height) + (.25)(weight)(height)

Total work = (ft-lbs)

Height = 6 inches = .50 feet

Total work = (weight)(.50) + (.25)(weight)(.50)

Total work = (weight)(.50) + (.1250)(weight)

Total work(all) = (Total work for one repetition)(number of repetitions)

Total work(all) = (number of repetitions)((weight)(.50) + (.1250)(weight))
VALUES FOR PAIRED T-TEST OF THE RIGHT AND LEFT LEG DATA FOR FUNCTIONAL AND ISOKINETIC TEST DATA

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AG/ANT = Agonist to antagonist ratio  
AP = Average power  
AP/BW = Average power to body weight  
D/H = Distance to height  
MT = Mean torque  
MT/BW = Mean torque to body weight  
TW = Total work  
TW/BW = Total work to body weight
Appendix M

VALUES FOR THE PAIRED T TEST OF SIT AND SUPINE ISOKINETIC DATA

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AG/ANT=Agonist to antagonist ratio  
AP=Average power  
AP/BW=Average power to body weight  
MT=Mean torque  
MT/BW=Mean torque to body weight  
TW=Total work  
TW/BW=Total work to body weight
Appendix N

NORMATIVE ISOKINETIC DATA FOR MALES AND FEMALES
AGE 15-45

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AP/BW = average power to body weight (%)
H/Q = hamstrings to quadriceps ratio (%)