ESTIMATION OF INTERNAL CONSISTENCY AND STABILITY RELIABILITY USING ISOKINETIC SEGMENTAL CURVE ANALYSIS

by

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(ABSTRACT)

Forty normal subjects, 19 males and 21 females, between the ages of 16 and 43 years were studied to examine the reliability of Cybex knee extension curves utilizing Segmental Curve Analysis (SCA). Each subject performed a standardized isokinetic knee extension/flexion test on the Cybex II isokinetic dynamometer. Test protocol consisted of 5 maximum repetitions at a speed of 60 deg/sec. Within one week of the initial test, each subject performed a retest. During testing, all torque and angle measurement information from the Cybex was transmitted to the SCA system. The SCA system plotted, analyzed, and quantified each torque curve for seven specific parameters. The following parameters were quantified by the SCA system: (1) torque at 20 degrees, 70 degrees, and peak torque of knee extension; (2) area of the curve to 20 degrees, 70

degrees and peak torque of knee extension; and (3) area of the torque curve between 20 and 70 degree angles of knee extension. The parameters of peak torque (r=.83 to .97; R=.98 to .99), area to 70 degree angle of knee extension (r=.76 to .87; R=.96 to .98), and area between 20 and 70 degree angles of knee extension (r=.75 to .92; R=.97 to .99) appeared to be the most reliable across trials and days, and were also found to elicit the least amount of variation for both male and female subjects. Coefficients of variation on the parameters of peak torque, area to 70, area between 20 and 70 for females ranged from 15% to 18%. For males, the coefficients of variation for peak torque, area to 70, and area between 20 and 70 ranged from 23% to 27%. Variables quantifying torque and power indices in the middle segment of torque curves appeared to be most reliable as analyzed by the SCA system.

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CHAPTER I

INTRODUCTION

Since the first studies by Delorme (1945,1948), McMorris and Elkins (1954), and MacQueen (1954), much research has been conducted on the types and benefits of weight/resistive training for general fitness, athletics, and rehabilitation. Strength or the ability to produce force from one's skeletal muscular system most often determines the adaptability or susceptibility to injury of an individual to the stresses of daily and physical activity or the success of a competitive athlete. Resistive strength training has proven empirical in rehabilitation of individuals from injury or surgery, in enhancement of athletic performance, and in increased overall physical fitness.

Realization of the substantial benefits of strength training by athletes and non-athletes has led to the proliferation of a variety of resistive type training and muscular evaluative equipment. The basic dumbell/barbell sets that once ruled the strength conditioning market now receive enormous competition from companies promoting exercise and muscular strength testing equipment, including cams, spiral pulleys and speed accommodating devices. The advantages and disadvantages of each type of strength training and evaluative equipment, as well as, the type of muscular contraction involved during limb movement has enabled clinicians, athletes and exercise participants to identify particular strength equipment for specific rehabilitation and conditioning purposes.

The current procedures most widely utilized by physical therapist and clinicians for evaluation and treatment planning of orthopaedic patients involve isokinetic measurements. The concept of isokinetic exercise, developed in the late 1960's by James Perrine, involves a dynamic pre-set fixed speed, with resistance that is accommodating throughout the range of motion (Davies, 1984). The first isokinetic device, Cybex I dynamometer, was designed to achieve a controlled speed type of movement with resistance accommodating to the varying mechanical advantage points of musculoskeletal movement. Since the introduction of the concept of isokinetics and the Cybex I dynamometer, a vast amount of investigative research has been conducted supporting its clinical usage and evaluative abilities.

The Cybex I isokinetic system was designed to measure various strength and power parameters at selected speeds for the ankle, knee, hip, wrist, elbow, and shoulder joints. Since its introduction other applications of Cybex instrumentation have been developed, the most significant of which is the use of the Cybex for rehabilitation of the musculo-tendinous unit through sub-maximal, short arc, full range of motion, and varied velocity exercises. Thus, isokinetic exercises and testing devices have become very popular among those individuals in the physical therapy and sports medicine professions.

In his textbook on isokinetics, Davies (1984) noted several advantages of isokinetics, such as accommodating resistance (maximal dynamic loading of a muscle), exercise at a wide range of velocities, accommodation to pain and fatigue, reliability and validity of the equipment, and availability of objective records. Isokinetic testing devices have been utilized for athletic and industrial screening, quantification of compensation and/or disability cases, non-invasive diagnosis of joint or muscle pathologies, and rehabilitation. The Cybex isokinetic system has also been utilized for case preparation by attorneys and for presentation of evidence in legal proceedings.

The concept behind isokinetic exercise is that movement at a joint can occur at a fixed speed while the resistance of the isokinetic device varies to match the muscular force applied at every point in the range of motion. Such accommodation, resistance varying to exactly match applied force, allows for maximal dynamic loading of the musculature throughout the entire range of motion and reduced resistance when pain is experienced during joint movement.

The amount of torque produced as a joint moves through the range of motion varies because of the biomechanics of the joint (skeletal leverage system) and the physiological length-tension ratio of the musculo-tendinous unit. Thus, the measurement of actual muscular strength about a joint produces a curvelinear recording based on the interaction of the muscles and bones. The Cybex enables practioners to record torque curves with a dual channel recorder and to instantaneously analyze them with a Cybex data reduction computer.

Segmental Curve Analysis (SCA) is a special software program written by the mechanical engineering department at Virginia Tech (Wynn, 1988). The system is designed to offer a more extensive evaluation and interpretation of torque curves than can be obtained from the standard Cybex configuration. The SCA software is programmed to be utilized in conjunction with a 286 microcomputer and a Data Translation 2801 Series high-speed analog and digital data acquisition board. The SCA system is designed to record torque signals generated from the Cybex and quantify selected work and torque parameters. As with all measuring instruments, the reliability of measurements obtained using the SCA system must be verified.

The mathematical theory in which reliability is based has been explained in terms of observed score, true score, and error score. Baumgartner (1987) states that reliability theory assumes that any measurement on a continuous scale contains an inherent component of error, measurement error. Thus, an observed score or measurement in testing is the sum of the true (actual score) and an error of measurement score; reliability indicates the amount of measurement error in a set of scores.

Stability reliability may be used to estimated the reliability of instrumentation. The test-retest method can be utilized to determine the consistency of subjects as they are being measured in exercise testing. The test-retest procedure requires the testing of a subject on two or more different days. The correlation between the two or more sets of scores provides the stability reliability coefficient or an estimate of the amount of measurement error for the instrumentation.

Internal consistency refers to a consistent rate of scoring by individuals throughout a test or, when multiple trials are administrated, from trial to trial (Baumgartner, 1987). The variation or change in the scores of the individual being tested from trial to trial indicates lack of test reliability. The internal consistency reliability coefficients are an estimate of the reliability of measures within a test.

Reliability of the Cybex isokinetic device has been estimated on numerous occasions. Johnson and Siegel (1978) estimated the reliability of isokinetic movement of the knee extensors over trials and days. The reliability coefficients were quite high ranging from .93 to .99. Reliability was more affected by testing over days than trials. In 1981, the Cybex II Data Acquisition system presented transformations in measurements quantified by stylus tracings, eliminating the subjectivity of reading torque recordings from Cybex II graph recordings. Reliability of the system for dead weights was estimated to be $r=.99$ ($p<.05$) (Hart, Barber, & Davis, 1981). By 1982, the isokinetic on line data analysis system provided parameters of torque, work, and power within 10 seconds after an exercise bout. Evaluation of the system reported intraclass reliability coefficients that ranged from R=.991 to R=.999 (Richards & Cooper, 1982). Mawdsley and Knapik (1982) examined the changes in peak torque of the knee extensor muscles for a group of subjects across trials and test sessions. No significant differences were found in mean peak torque (30 deg/sec) across trials or across sessions where sessions occurred two weeks apart. In another study conducted to assess the relationship among initial peak torques and the decline in peak torque due to serial knee extension isokinetic contractions at four velocities, an intraclass reliability analysis was conducted. On initial peak torque values on the last of two testing days, the reliability was high for torque output at all four velocities (R's = .97 - .99). No significant difference occurred for each of the four velocities over the three test days. Thus, the reliability of isokinetic strength was judged to be high (Clarkson, Johnson, Dextradeur, Leszczynski, Wai, & Melchionda, 1982). These findings along with those of many other isokinetic studies confirm the reliability of the Cybex isokinetic muscle testing device.

STATEMENT OF THE PROBLEM

Although a great amount of supportive research has been published on the Cybex rehabilitative and evaluative abilities, some questions remain as to the accuracy and credibility of specific Cybex evaluative abilities. Promoters of the Cybex have suggested that the shape of the torque curve, as recorded on the dual channel recorder, can be utilized to determine specific patient pathological conditions. Clinicians are also attempting to determine whether a patient is malingering, based on the shape and consistency of the torque curves. Although numerous attempts have been made to detect malingering based on isokinetic torque curves, the procedures have been less than successful.

The purpose of this study was to develop a more extensive and sensitive isokinetic torque curve analysis system, Segmental Curve Analysis, and to evaluate its ability to consistently record, plot, and interpret isokinetic torque curves. Before this system can be evaluated for its ability to detect orthopaedic injury malingering, the reliability of the instrumentation and test protocol must be investigated. Therefore, this study was designed to examine the consistency of isokinetic knee extension torque curves of normal subjects as measured by the Segmental Curve Analysis system.

SIGNIFICANCE OF THE STUDY

Preliminary studies by Davies (1984), and Hoke, Howell, and Stack (1983) propose that various pathologies can be correlated with the shape of the Cybex curve. Such statements without conclusive data support have led some clinicians to use torque curves as a basis for planning treatment and determining pathologies.

Similarly, clinicians are attempting to detect malingering based on the configuration and consistency of isokinetic torque curves. Rothstein, Lamb, and Mayhew (1987) addressed this technique, stating that no published data exist to suggest that a clinician can determine whether a patient is malingering based on the shape of a torque curve.

The Segmental Curve Analysis system was designed and programmed to offer a more elaborate evaluation and interpretation of torque curves than can be obtained from Cybex. The Segmental Curve Analysis system consists of a 286 microcomputer interfaced with a Data Translation DT2801 Series Board programmed to collect, plot and analytically quantify specific segments of isokinetic torque curves. With the availability of a more comprehensive data analysis of torque curves generated from the Cybex isokinetic dynamometer clinicians may better judge the integrity of client performance in muscular test analysis.

RESEARCH HYPOTHESES

The following null hypotheses were tested in this study:

1. Ho: There is no test-retest correlation between the isokinetic torque measures of peak torque, torque at 20 degrees of extension and torque at 70 degrees extension when subjects were tested for knee extension on two separate days.

2. Ho: There is no test-retest correlation between the isokinetic work measures of the area of the torque curve to 20 degree angle of knee extension, area to 70 degree angle of knee extension, area to peak torque of knee extension, or area between 20 and 70 degree angle of knee extension when tested on two different days.

3. Ho: There is no internal consistency correlation between the isokinetic torque measures of peak torque, torque at 20 degrees of extension, and torque at 70 degrees of extension when observed across multiple trials.

4. Ho: There is no internal consistency correlation

between the isokinetic work measures of the area of the torque curve to 20 degree angle of knee extension, area to 70 degree angle of knee extension, area to peak torque of knee extension, or area between 20 and 70 degree angle of knee extension when observed across multiple trials.

DELIMITATIONS

The following delimitations were imposed by the investigator:

1. Forty volunteer subjects between the ages of 16 and 43 participated in this study.

2. Only knee extensor torque curves were measured.

3. Torque and work measures of the knee extensors were measured at the test speed of 60 deg/sec joint angle velocity.

4. The seven isokinetic measures of the knee extensors include:

a. Torque at 20 degree angle of knee extension.

b. Torque at 70 degree angle of knee extension.

c. Area of the curve to the 20 degree angle of knee extension.

d. Area of the curve to the 70 degree angle of knee extension.

e. Peak torque of the knee extension curve.

f. Area of the curve to peak torque.

g. Area between 20 and 70 degree angles of knee extension.

LIMITATIONS

The following limitations of the study were recognized by the investigator:

1. Some subjects experienced mild muscular fatigue after the warm-up prior to testing which may have effected performance.

BASIC ASSUMPTIONS

The following assumptions were made by the investigator:

1. It was assumed that all subjects performed with maximal effort during the Cybex knee extension test.

2. It was assumed that torque and angle measurement information from the Cybex data reduction computer was accurately transmitted to the DT2801 Series board for analysis.

3. It was assumed that the Segmental Curve Analysis system accurately measured experimental test varibles.

DEFINITIONS AND SYMBOLS

1. Angle: An angle is the figure or space outlined by the diverging of two lines from a common point or by the meeting of two planes.

2. Isokinetic: Isokinetic exercises have a fixed speed with a variable resistance that is totally accommodating throughout the range of motion.

3. Joint: A joint is the point of juncture between two bones.

4. Joint Angle: The figure or space outlined by the diverging of two bones from the point of juncture between two bones.

5. Peak Torque: Peak torque is the maximum force that a muscle can produce at any given angle and is a measurement of isokinetic strength.

6. Torque: Torque is a force that produces a rotary motion.

7. Segmental Curve Analysis (SCA): Segmental Curve Analysis is an isokinetic torque analysis system which evaluates and interprets torque curves generated from the Cybex II isokinetic dynamometer.

8. Work: Work is expressed as force x distance.

SUMMARY

Isokinetic exercise devices, particularly the Cybex, have become very popular among physical therapists and clinicians for treatment and evaluation of clients. Isokinetic exercises are characterized by movement at a controlled pre-set speed with resistance that is accommodating to the varying mechanical advantage points of the musculo-skeletal system. The measurement of actual strength about a joint (torque) by the Cybex produces a curvelinear recording (torque curve) based on the interaction of the muscles and bones during movement. Promoters of the Cybex have stated that the consistency and configuration of isokinetic torque curves can be utilized to detect or identify malingering. They suggest that a subject faking maximal exertion shows more variability in repeated tests than a person that is actually generating maximal contractions. However, difficulties have plagued practioners trying to assess the variability of Cybex torque curves. Also, there have been no published data found promoting this technique of patient evaluation. Segmental Curve Analysis was designed to offer a more extensive evaluation and interpretation of torque curves than can be obtained from the Cybex. Before this system can be presented for detection of orthopaedic injury malingering, the reliability of the instrumentation and test protocol must be investigated. Thus, the purpose of this investigation was to examine the consistency of Cybex knee extension curves generated by normal subjects utilizing the Segmental Curve Analysis system.

CHAPTER II

REVIEW OF LITERATURE

This chapter contains the following review of literature related to estimation of reliability and isokinetics: 1) Reliability Theory, 2) Stability Reliability, 3) Intraclass Reliability, 4) Isokinetics, 5) Reliability of Isokinetics, and 6) Isokinetic Torque Curves.

Reliability Theory

Historically, the development of reliability theory by Spearman in 1910 occurred as a result of psychological studies. During these early stages of reliability theory, typical procedure for estimating reliability was to correlate alternate forms of a test or to divide a test into two halves and correlate the halves. As physical educators developed tests of motor performance, modifications in these reliability estimation procedures surfaced. Specifically, it became popular for measurement specialists in physical education to correlate two trials of motor performance tests instead of correlating two forms of the same measure (Safrit, 1976). This classical test theory was avidly accepted by educators and psychologist in the United States.

Estimating the reliability of a test of motor performance by administrating the test on two different occasions and correlating the two sets of scores was recommended by books published in the 1930's (Bovard & Cozens, 1930; Glassow & Broer, 1938). These authors recognized that correlations could be high even when systematic increases or decreases occurred in the second set of scores. Subsequently, it was suggested that the means of the two sets of scores, in addition to the correlation, should be considered. However, no statistical procedures for handling such systematic changes were offered.

Burt (1955) and Stanley (1971) expanded the understanding of the mathematical theory underlying reliability by describing reliability in terms of variance within a set of obtained scores. They theorized that any score obtained by an individual contains a true component (score) and an error component (score), measurement error.

Similarly, Safrit (1976) proposed that total variance in a set of scores reflects the influence of systematic (constant factors) and random (unpredictable factors). She identified systematic factors as those associated with "true" differences among individuals (age, sex, skill level, strength, etc.), or with constant explainable "errors". Such errors, arising from the individuals themselves (improvement over test trials or over testing sessions), or from procedures and conditions that are a part of the process of administering the test and/or evaluating the test performance. Error variance was classified by Safrit as variability caused by unexplained, unpredictable factors, including, factors within the individual, factors within the measuring device, or completely unknown factors. Error variance being that which contributes to the unreliability of measurement (Safrit, 1976). Thus, Safrit (1976) ascertained that an estimation of the reliability coefficient must demonstrate which of the influencing factors contribute to true variance and which to error variance.

Reliability theory, then, assumes that any measurement on a continuous scale contains a component of error, the measurement error. Explicitly, an observed score consists of the true score and an error of measurement score; variance for a set of observed scores equals the variance of the true scores plus the variance of the error scores. The ratio of the true-score variance to the observed-score variance determines reliability. A reliability coefficient indicates the amount of measurement error or the portion of the test variance that is non-error variance (Isaac & Michael, 1981). Increases in errors of measurement result in decreases in reliability indicating lack of consistency within a set of scores.

In his textbook, Baumgartner (1982) recognized these possible sources of measurement error (error variance): 1) lack of agreement among scorers, 2) lack of consistent performance by the individuals tested, 3) failure of an instrument to measure consistently, and 4) failure of the test to follow standardized test procedures.

More importantly according to Baumgartner (1982), reliability or the consistency of a measuring instrument is dependent upon two basic factors: 1) its ability to reduce the variation attributable to measurement error, and 2) its detection of individual differences (variation of the true scores) within the group measured. Therefore, the reliability of and instrument must be examined in terms of its measurement error (error variance) and its power to discriminate among different levels of ability within the group measured (true-score variance).

If a measurement is reliable, it provides an accurate estimate of the characteristics being measured and it is precise, as well as dependable (Rothstein, 1985). The reliability of a set of scores is determined through correlation. There are several methods for establishing reliability. However, this literature review will be limited to discussion of interclass correlation (test retest method) and intraclass correlation (internal consistency).

Stability Reliability

Baumgartner (1987) defines the stability reliability coefficient as an estimate of a measuring instruments reliability. Individual measurement scores that change very little from day to day are considered stable and reliable. The correlation of scores measured with the same test or instrument on several occasions determines the stability reliability coefficient. Thus most often, the test-retest method is utilized to obtain the stability reliability coefficient.

Physical educators and motor performance test specialists have utilized the test-retest method of estimating reliability extensively. Traditionally, the Pearson Product Moment Correlation coefficient (r) has served as the stability reliability coefficient; the determinant of relationship between two sets of scores. Numerically, correlation coefficients vary between +1.00

and -1.00, a perfect positive relationship and a perfect negative relationship, respectively. A high positive relation (correlation), close to +1.00, indicates that two sets of scores have a high relationship to one another and that they share a common variance. While, a high negative relationship, close to -1.00, specifies that an increase in one set of scores is associated with a decrease in the second set of scores or vice-versa. A correlation coefficients of 0 (zero) signifies that two sets of data are totally unrelated (Johnson & Nelson, 1986). Realistically, because of the many factors that influence the variables being correlated, the coefficients seldom are a perfect +1.00, -1.00, or 0.

There are often problems interpreting correlation coefficients as to which are high, low, or average. Johnson and Nelson (1986) published a scale of general terms as to what correlations are considered high, average, or low. The following is representative of their scale: 1) r=.00 (no relationship), 2) r=+.01 to +.20 (low relationship), 3) r=+.20 to +.50 (slight to fair relationship), 4) r=+.50 to +.70 (substantial relationship), 5) r=+.71 to +.99 (high to very high relationship), and 6) r=+1.00 (perfect relationship). Rankings such as these provide rough guides to interpretation of correlation coefficients.

Nonetheless, test specialists must judge their minimum acceptance of reliability upon the purposes for which the computation was obtained.

Low stability reliability estimates may arise from: 1) different performances from subjects being tested due to fatigue, injuries, or anxiety, 2) the measuring instrument may operate differently or the procedures used to collect the measures change, and 3) the person administrating the measurement may change in the way he/she scores or perceives performances. Generally, test-retest scores are collected within 1 week, or more specifically within 1 to 3 days apart. The time period or interval between measurements is short to reduce changes in score due to maturation, practice, test comprehension etc. Even though such factors are not considered potential sources of measurement error, elimination of their potential influence may increase the faith placed on the test-retest reliability coefficient.

The stability reliability coefficient estimates a measuring instruments reliability or ability to measure scores consistently. The rest-retest method with analysis by the Pearson Product Moment Correlation technique is most often utilized to determine stability reliability.

Internal Consistency

Internal consistency refers to a consistent rate of scoring by individuals being tested throughout a test, or when multiple trials are administered, from trial to trial (Baumgartner, 1987). An internal consistency coefficient as an estimate of reliability of measures is commonly the preferred reliability procedure among exercise specialists. The advantage of this estimate of reliability is that all measurements are collected on the same day. Where, the variation in the scores or measurements from trial to trial indicates lack of test reliability.

The Pearson Product Moment Correlation has traditionally been the correlation coefficient used to estimate reliability of the test-retest method. Baumgartner (1987) opposed this practice stating that it is a interclass coefficient, limited to situations where there are two scores per person. A better method for estimating reliability supported by research from Baumgartner (1968), Feldt and McKee (1958), and Haggard (1958) is the intraclass correlation coefficient.

Kroll (1962) stated that the intraclass correlation technique offers a more advantageous method for estimation of reliability than comparable interclass correlation coefficients. He further noted that in addition to allowing an isolation and assessment of the relative importance of various variance components, it can be expected to be a more accurate statistic than interclass correlation techniques.

The intraclass correlation coefficient allows for more than 2 scores per person, is more sensitive to sources of error measurement, and presents a more realistic picture of test reliability. Uniquely, the intraclass method is the only method in which changes in the mean and standard deviation (variance) from one set of measures to the next are considered to be measurement error. The technique used to divide, or petition the variance for a set of scores is analysis of variance (ANOVA). As Stamm (1976) summarized, the intraclass correlation coefficient provides an estimate of the reliability of a test through the use of analysis of variance.

The intraclass correlation coefficient (R) indicates the reliability of the mean test score for each individual tested (Safrit, 1976). When R equals 1, there is maximum reliability; when R equals 0, there is no relationship. In summary, internal consistency, as estimated by the intraclass reliability coefficient through analysis of variance, demonstrates the consistency of measures of individuals within a test.

Isokinetics

In 1967, Hislop and Perrine initiated research on a new type of muscle contraction called an isokinetic contraction. McMorris and Elkins (1985) explained an isokinetic movement by describing a subject working against a piece of equipment or apparatus specifically designed to regulate the speed of movement. With the speed of movement constant, the apparatus allowed resistance to vary to match the force applied at every point in the range of motion. Because of the physiological length-tension ratio of the musculo-tendinous unit and the biomechanics of the joint (skeletal leverage system), the amount of torque produced as a joint goes through its range of motion varies. An isokinetic device, characteristically, can provide a controlled speed type movement with resistance matching the force produced by the varying musculo-skeletal leverage system.

The Lumax Corporation manufactured the first isokinetic device, Cybex I. Since its introduction in 1970, Cybex has become a very popular device among clinicians and physical therapist for rehabilitation, evaluation, and research. The vast amount of research conducted on Cybex has, nevertheless, facilitated many improvements from the initial design and function of the original isokinetic device.

In 1981, Hart, Barber, and Davis noted a need for improved accuracy in the existing measurement of stylus tracings developed by Cybex proponents. They introduced a system composed of a Cybex II dynamometer and a simple microprocessor that digitized the analog signal from the Cybex II. Accordingly, the purpose of this data acquisition system was to eliminate the subjectivity of reading torque recordings from typical Cybex paper recordings. The system, after digitizing the analog signal from Cybex, determined the maximum torque in millivoltage recorded over time. The estimated reliability for the data acquisition system was reported as $r=0.99$ ($p<.05$).

Richards and Cooper (1982) elaborated upon Hart et al.'s Cybex information system with their Cybex II-Apple III system. An Apple III microcomputer was interfaced to a Cybex II isokinetic dynamometer, to provide instantaneous values for torque, work, and power. Intraclass reliability coefficients for this microcomputer support system (for parameters of torque, work, and power) ranged from $r=0.991$ to $r=0.999$. Because of its time saving qualities and relatively low cost, Richards and Cooper (1982) pronounced that a microcomputer support system for the Cybex II dynamometer presents and economical, efficient means of obtaining information for clinical analysis of patients.

Reliability of Isokinetics

As with all measuring instruments, the reliability of Cybex II dynamometer has been appropriately questioned. One of the first investigations into the reliability of isokinetics was conducted by Johnson and Siegel (1978). They tested 40 female volunteers, isokinetically, for maximum force of the knee extensors. Subjects were given six test trials separated by 20 second rest interval. The intraclass correlation coefficient for the mean of the last three trials was .98. The first three trials were eliminated because they produced a significant linear trend. Consequently, Johnson and Siegel (1978) concluded that in measuring isokinetic force of the knee extensors (female population, 17 to 50 years of age), a protocol providing for 3 submaximal trials followed by 3 maximal warm-up efforts may be essential for manifestation of stable, reliable measures.

Contrasting results were presented in an investigation by Mawdsley and Croft (1982) on the effect of the presence or absence of three gradient submaximal isokinetic contractions (30 deg/sec) prior to isokinetic testing. These researchers determined that there were no significant differences in mean peak torque of maximal isokinetic contractions of the knee extensors between a group performing submaximal contractions and a group not performing these contractions, within each group and among trials. Nevertheless, the performance of submaximal contractions prior to testing adequately prevented discomfort during the test session. The investigators did find that the patterns of mean peak torque within groups were different.

The isokinetic studies by Mawdsley and Knapik (1982) on knee extensor muscles of males and females found that there were no significant differences in mean peak torque (30 deg/sec) across trials or across sessions when test session occurred two weeks apart. Similar to the 1982 studies by Mawdsly and Croft, the pattern of mean peak torque within sessions were different.

Torque Curves of Isokinetic Contractions

The rehabilitative advantages of isokinetics, the reliability of peak torque, work, and power measurements when testing muscles of the knee and elbow, in addition to the vast investigative research literature supporting Cybex, has led to widespread utilization of Cybex by physical therapist, clinicians, and researchers. Currently, a common topic among researchers has been the relationship between orthopaedic pathological conditions and Cybex torque curve configurations. Promoters of the Cybex isokinetic dynamometer have suggested that the slope of torque curves, as recorded on the dual channel recorder, can be utilized to determine specific patient pathological conditions. Preliminary studies by Davies (1984), and Hoke, Howell, and Stack (1983) theorize that various pathologies can be correlated with shape of Cybex torque curves.

Hoke et al. (1983) examined the relationship between patellofemoral compression test (Patellofemoral compression test is one of many sources used by clinicians to diagnose patellar pathologies.) and irregularity of isokinetic torque recordings. Results indicated a statistically significant relationship between irregularity of torque recordings and positive findings on the patellofemoral compression tests performed in full knee extension. Similar relationships were present between regular torque curves and negative findings on the compression test. It was concluded that assessment of the regularity of the isokinetic torque of knee extension would be a potentially valuable adjunct to evaluation of persons with disorders of the patellofemoral joint, but further research is needed to correlate isokinetic findings with other clinical signs of patellar pathology.

Davies (1984) also stated that specific position angle of pain may be detected through analysis of torque curve recordings. He supported his conclusions with the theory that isokinetics accommodate to pain. Thus as pain occurs during limb movement, the force on the dynamometer decreases and the recorder stylus (dual channel recorder) drops to accommodate to the force changes. Sensitivity of this process to detecting injury or pain location has not been demonstrated.

While various investigators have examined torque curves (Patton, 1978; Scudder, 1980), no investigators, other than Davies and Hoke et al., have directly investigated the use of Cybex to diagnose pathological conditions. However, viewing the limited amount of conclusive data, it is surprising that some clinicians are attempting to use torque curve configurations as a basis for determining pathologies. In an article addressing critical issues of isokinetic measurements, Rothstein, Lamb, and Mayhew (1987) stated that no documentation is available to determine specific pathologies.

In addition to deriving conclusions regarding pathologies, clinicians are attempting to determine whether a patient is malingering based on the shape and consistency of isokinetic torque curves. Rothstein et al. (1987)

addressed this technique also, stating that no published data exist to suggest that a clinician can determine whether a patient is malingering based on the shape of a torque curve.

In an investigation conducted by Murray, Baldwin, Gardner, Sepic, and Downs (1977), normal patterns of torque versus time of maximum isometric knee flexion and extension contraction were studied using Cybex. Murray et al. (1977) examined 1,152 torque curves generated by 48 male subjects and concluded that no single pattern could by considered representative.

Beck and Hettinger (1956) and Rohmert and Siebert (1960) reported experiencing difficulties while trying to assess whether or not a subject was faking a maximum voluntary contraction. They suggested that a subject faking maximal exertions shows more variability in repeated tests than a person that is actually generating maximal contractions.

Kromer and Marras (1980) tested 30 subjects on an isometric elbow flexion test to determine if the relationship between isometric strength build up in repeated contractions would provide objective criteria to judge whether or not a subject exerts full muscular strength in a routine test. Each subject was requested to exert 25, 50, 75, and 100% maximum voluntary contractions. The results indicated that the coefficients of variation (standard deviation/mean) were consistent for each subject group. The coefficients of variation ranged from 30-45% for both male and female subjects across the four intensities.

Numerous attempts have been made to detect malingering based on the configuration and consistency of isokinetic torque curves. However, it has been generally concluded that a single torque curve pattern cannot be normalized and identification of malingering has been less than successful.

Summary

The reliability or consistency of a measuring instrument is dependent upon its ability to reduce the variation attributable to measurement error and its detection of individual differences within a group being measured. A measuring instrument is reliable if it provides an accurate estimate of the characteristics being measured with precision. Two methods utilized for estimation of reliability are stability reliability (test-retest method) and intraclass correlation (internal consistency). Correlation of scores measured with the same test or instrument on several occasions determines the stability reliability coefficient. While internal consistency, as estimated by the intraclass reliability coefficient through analysis of variance, demonstrates the consistency of measures of individuals within a test. The reliability of peak torque, work and power measurements of various muscle group by the Cybex isokinetic dynamometer has been investigated on many occasions. The cited reliability and consistency of measurement by the Cybex, as well as a vast amount of research literature supporting Cybex, has led to widespread utilization of the Cybex and adoption of Cybex procedures by practioners. However, the validity of a proposal by Cybex proponents that patient malingering can be determined based on the shape and variability of isokinetic torque curves is being questioned. Practioners have been plagued with difficulties in attempts to assess the variability of Cybex torque curves and to date, there is no published data to suggest that practioners can determine patient malingering based on the configuration of isokinetic torque curves.

CHAPTER III

JOURNAL MANUSCRIPT

Estimation of Internal Consistency and Stability Reliability Using Isokinetic Segmental Curve Analysis

Susan N. Earles-Price

ABSTRACT

Forty normal subjects, 19 males and 21 females, between the ages of 16 and 43 years were studied to examine the reliability of Cybex knee extension curves utilizing Segmental Curve Analysis (SCA). Each subject performed a standardized isokinetic knee extension/flexion test on the Cybex II isokinetic dynamometer. Test protocol consisted of 5 maximum repetitions at a speed of 60 deg/sec. Within one week of the initial test, each subject performed a retest. During testing, all torque and angle measurement information from the Cybex was transmitted to the SCA system. The SCA system plotted, analyzed, and quantified each torque curve for seven specific parameters. The following parameters were quantified by the SCA system: (1) torque at 20 degrees, 70 degrees, and peak torque of knee extension; (2) area of the curve to 20 degrees, 70 degrees and peak torque of knee extension; and (3) area of the torque curve between 20 and 70 degree angles of knee extension. The parameters of peak torque (r=.83 to .97; R=.98 to .99), area to 70 degree angle of knee extension (r=.76 to .87; R=.96 to .98), and area between 20 and 70 degree angles of knee extension (r=.75 to .92; R=.96 to .99) appeared to be the most reliable across trials and days, and were also found to

elicit the least amount of variation for both male and female subjects. Coefficients of variation for the parameters of peak torque, area to 70, area between 20 and 70 for females ranged from 15% to 18%. For males, the coefficients of variation for peak torque, area to 70, and area between 20 and 70 ranged from 23% to 27%. Variables quantifying torque and work indices in the middle segment of torque curves appeared to be most reliable as analyzed by the SCA system.

Introduction

Current procedures most widely utilized by researchers, physical therapist, and clinicians for evaluation and treatment planning of orthopaedic patients involve isokinetic measurement (Elliott, 1978; Mawsley & Croft, 1982; Sherman, 1982; Wyatt & Edwards, 1981). The concept of isokinetic exercise involves a dynamic pre-set fixed speed, with resistance that is accommodating throughout the range of motion (Davies, 1984; Hislop & Perrine, 1967; Thistle, Hislop, Moffroid, & Lowman, 1967). The first isokinetic device, Cybex I dynamometer, was designed by the Lumex Corporation to achieve a controlled speed type of movement with resistance accommodating to the varying mechanical advantage points of musculoskeletal movement (Patton, Hinson, Arnold, & Lessand, 1978). Since the introduction of the concept of isokinetics and the Cybex I dynamometer, a vast amount of investigative research has been conducted supporting its clinical usage and evaluative abilities.

Although a great amount of supportive research has been conducted on the Cybex's rehabilitative and evaluative abilities, credibility of some evaluative and testing capabilities are being questioned. Promoters of the Cybex isokinetic dynamometer have suggested that the configurations of torque curves can be utilized to determine specific patient pathological conditions (Davies, 1984). Preliminary studies theorize that various pathologies can be correlated with the shape of Cybex torque curves (Davies, 1984; Hoke, Howell, & Stack, 1983). Such statements with limited conclusive data support have led some clinicians to use torque curve configurations as a basis for planning treatment and determining pathologies. In an article addressing critical issues of isokinetic measurements, a group research physical therapists stated that no documentation is available that this method (utilization of torque curves to determine specific pathologies) is appropriate (Rothstein, Lamb, & Mayhew, 1987). Similar to deriving conclusions regarding pathologies, some clinicians are attempting to determine whether a patient is malingering based on the shape and consistency of isokinetic torque curves. It has been stated that no published data exist to suggest that a clinician can determine whether a patient is malingering based on the shape of a torque curve (Rothstein et al., 1987).

Segmental Curve Analysis (SCA) system was designed to offer a more elaborate evaluation and interpretation of torque curves than can be obtained from the standard Cybex isokinetic system (Wynn, 1988). The Segmental Curve

Analysis system consisting of a 286 microcomputer interfaced with a Data Translation DT2801 Series Board was programed to analyze specific segments of isokinetic torque curves. The purpose of this investigation was to examine the reliability of specific segments of Cybex knee extension curves generated by normal subjects utilizing the Segmental Curve Analysis system.

Methodology

Forty normal subjects, 19 males and 21 females, between the ages of 16 and 43 years volunteered to serve as subjects in this study. All subjects attended individual orientation sessions in which the nature of the study and potential benefits of participation were explained. During the orientation, subjects signed an informed consent and were screened for previous orthopaedic problems. If no history of orthopaedic problems was present, all subjects were then positioned on the Cybex and allowed to perform a standardized warm-up protocol to familiarize them with the Cybex equipment.

The Cybex and the SCA system were calibrated prior to experimental testing. Within two days after the individualized orientation, each subject performed a standardized isokinetic knee extension/flexion test on the Cybex II isokinetic dynamometer (Isolated Joint Testing, 1983). Test protocol consisted of 5 maximum repetitions at a speed of 60 deg/sec. Testing of preferred and non-preferred limbs among subjects was randomized. The position of the shin pad, number of seat pads, the height and horizontal position of the dynamometer, and limb preference was recorded during the orientation session and remained constant for both the test and the retest. Each subject performed a retest within one week of the initial test.

During the knee extension/flexion test, all torque and position angle measurement information from the Cybex data reduction computer via the Cybex dynamometer was transmitted to a 286 microcomputer. The 286 microcomputer, interfaced with a Data Translation DT2801 Series board, plotted, analyzed, and quantified each isokinetic knee extension torque curve for seven specific parameters.

The following parameters were quantified by the Segmental Curve Analysis system: (1) torque at 20 degrees, 70 degrees, and peak torque of knee extension; (2) area of the curve to 20 degrees, 70 degrees, and peak torque of knee extension; and (3) area of the torque curve between 20 and 70 degree angles of knee extension. The first and fifth torque curves from each test were disregarded from the analysis. The three remaining curves were analyzed for each test. Each of the seven parameters evaluating torque and work of the knee extensors were analyzed for consistency across multiple trials and days. A test-retest and internal consistency correlation analysis across two experimental days design was implemented. Each of the seven torque and area parameters evaluating torque and work of the knee extensors were analyzed for day to day test reliability (stability reliability) and for reliability of scores within a test (internal consistency). A correlation analysis consisting of Pearson Product Moment correlation for estimation of stability reliability and analysis of variance (ANOVA) for estimation of internal consistency (intraclass correlation) was employed. The alpha level was set at 05.

Results

A one-way analysis of variance and Duncans Multiple Range test was conducted to test for differences between sex and for differences between limb preference. Statistically significant differences were found between male and female subjects on all parameters, except, area to 20 degree angle of knee extension ($F=16.50$ to 107.47, $p<.05$). Statistically significant limb differences were found only on the parameters of torque at 20, area to 20, and area to 70 degree angle of knee extension for female subjects ($F=.4.49$ to 10.64, $p<.05$). For male subjects, statistically significant differences between limbs were found only on the parameters of torque at 20, and area between 20 and 70 degree angles of knee extension ($F=8.06$ to 10.08, $p<.05$).

The means, standard deviations, and standard error of the means for all torque and work parameters are presented in Table 1. For the purposes of analysis, the three trial means for each test were averaged to provide one criterion score.

Stability reliability (test-retest) correlation coefficients for isokinetic torque and work measures of male subjects are presented in Table 2. These results indicated that peak torque ($r=.97$) and torque at 70 degree angle of knee extension ($r=.85$) were the most reliable isokinetic torque measures for male subjects. Peak torque ($r=.83$) was also found to be reliable among female subjects. Isokinetic work measures of area to 70 degree angle of knee extension and area between 20 and 70 degree angles of knee extension indicated high test-retest reliability for male subjects ($r=.87$ and $r=.92$, respectively) and female subjects ($r=.76$ and $r=.75$, respectively).

Internal consistency was determined by the intraclass correlation method using analysis of variance (Table 3).

Table 1

Descriptive Statistics for Female and Male Subjects on the Cybex Knee Extension Test-Retest

		FEMALE			MALE		
PARAMETER	TEST	$\overline{X}$	SD	SEM	$\overline{X}$	SD	SEM
PEAK TORQUE*	1	88	14.4	4.3	154	42.7	13.5
	2	86	13.4	4.0	158	42.1	13.3
TORQUE AT 20 DEG.*	1	61	22.7	6.8	86	41.8	13.1
	2	62	19.6	5.9	93	47.0	15.0
TORQUE AT 70 DEG.*	1	58	9.1	2.7	98	32.5	10.3
	2	57	9.1	3.0	99	27.8	8.8
AREA TO ** PEAK TORQUE	1	1.05	.22	.03	1.54	.44	.07
	2	1.05	.24	.04	1.51	.37	.06
AREA TO 20 DEG. **	1	.31	.23	.04	.40	.37	.06
	2	.31	.21	.03	.35	.24	.04
AREA TO 70 DEG. **	1	2.08	.40	.06	3.21	.79	.13
	2	2.08	.40	.06	3.29	.73	.12
AREA ** BETWEEN 20 AND 70 DEG.	1	1.80	.29	.04	2.84	.65	.11
	2	1.75	.28	.04	2.98	.68	.11

Data represents averaged trials 1, 2, and 3; and pooled data for the preferred and non-preferred limbs.

*The unit of measure for the above torque parameters is ft.lbs.

**The unit of measure for the above area (work) parameters is ft.lbs.xsec.

Table 2

Pearson Correlation Coefficients for Cybex Knee Extension Torque and Work Parameters

VARIABLE	FEMALE	MALE
PEAK TORQUE	r=.83	r=.97
TORQUE AT 20 DEGREE ANGLE	r=.69	r=.60
TORQUE AT 70 DEGREE ANGLE	r=.41	r=.85
AREA TO PEAK TORQUE	r=.68	r=.66
AREA TO 20 DEGREE ANGLE	r=.58	r=.14
AREA TO 70 DEGREE ANGLE	r=.76	r=.87
AREA BETWEEN 20 & 70 DEG.	r=.75	r=.92

Data represents averaged trials 1, 2, and 3; and pooled data for the preferred and non-preferred limbs.

Table 3

Intraclass Correlation Coefficients for Cybex Knee Extension Torque and Work Parameters

VARIABLE	FEMALE	MALE
PEAK TORQUE	R=.98	R=.99
TORQUE AT 20 DEGREE ANGLE	R=.96	R=.94
TORQUE AT 70 DEGREE ANGLE	R=.91	R=.98
AREA TO PEAK TORQUE	R=.95	R=.79
AREA TO 20 DEGREE ANGLE	R=.95	R=.59
AREA TO 70 DEGREE ANGLE	R=.97	R=.97
AREA BETWEEN 20 & 70 DEG.	R=.97	R=.99

Data represents averaged trials 1, 2, and 3; and pooled data for the preferred and non-preferred limbs.

For female subjects, intraclass correlation coefficients ranged from R=.93 to R=.99. For male subjects the intraclass correlation coefficients ranged from R=.96 to R=.99, except for the parameters of area to peak torque (R=.79) and area to 20 degree angle (R=.59).

Coefficients of variation were computed for male and female subjects on all parameters. Figure 1 illustrates that for female subjects isokinetic torque and work parameters of peak torque, torque at 70 degree angle of knee extension, area to peak torque, area to 70 degree angle of knee extension, and area between 20 and 70 degree angle of knee extension produced relatively low coefficients of variation (c.v. ranging from 14.13% to 20.38%). Coefficient of variation values for male subjects are displayed in Figure 2. Peak torque, area to peak torque, area to 70 degree angle of knee extension, and area between 20 and 70 degree angles of knee extension were the variables producing the least amount of variation (c.v. range from 22.56% to 27.33%).

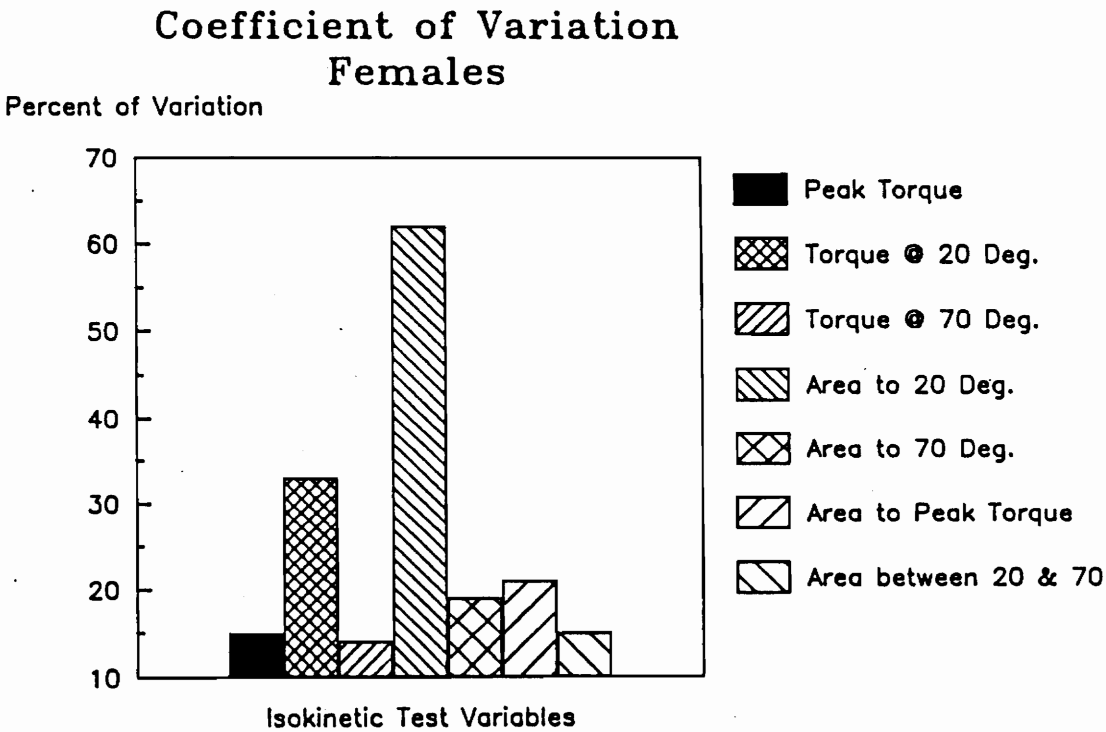

Figure 1. Coefficients of variation for female subjects on isokinetic knee extension torque and power parameters.

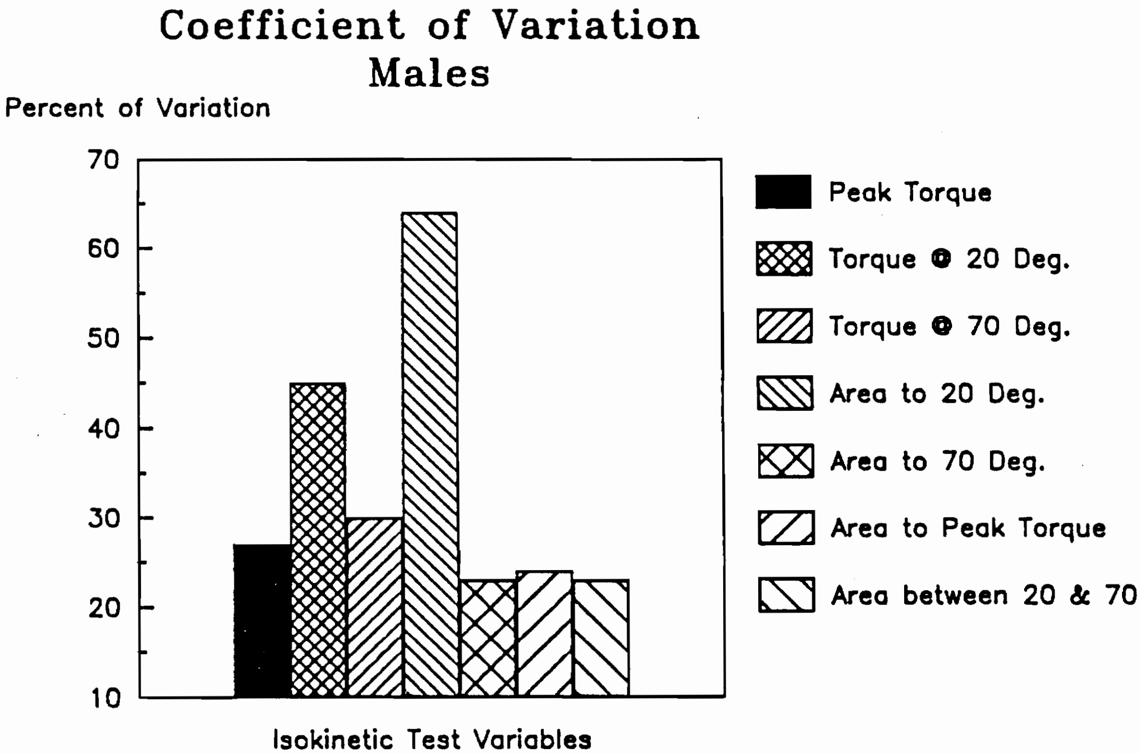

Figure 2. Coefficients of variation for male subjects on isokinetic knee extension torque and power parameters.

Discussion

Few meaningful comparisons with previous studies can be made because specific segments of isokinetic torque curves have not previously been examined. However, results from isokinetic and strength studies can be compared and utilized for basis of speculation.

Significant differences in values between male and female subjects were found on six of the seven parameters analyzed. These results were in agreement with studies by Wyatt and Edwards (1981) and Hoffman, Stauffer, and Jackson (1979). Miyoshita and Kanehisa (1979) also found that males can produce greater torque values than females.

The reason for differences in torque and power among sexes as reported by Hoffman et al. (1979) are still uncertain. Differences may be related to variations in muscle mass distribution, dissimilarity in use, and quality of tissue. This theory can be supported by findings of deVries, Evans and deVries (1971), and Fugl-Meyer (1981). They concluded that muscle functional state is determined largely by genotypic factors, and that such factors can be influenced by heavy use or disuse. In this study, there were significant differences between sex on all torque curve segments, except, area to 20 degree angle of knee extension (which appeared to be an unstable measure). Thus, torque curves produced by females were significantly different than those produced by male subjects.

Analysis of variance and Duncans Multiple Range tests revealed significant differences between limbs on several parameters which is similar to results in studies by Wyatt and Edwards (1981) on normal subjects, and Goslin and Charteris (1979) on young adults. However, Wyatt only reported significant differences between dominant (preferred) and non-dominant (non-preferred) knee torque values of male subjects, not female subjects. Contrastingly, in a sample of athletes tested, no difference was reported in limb strength (Distefano, O'Neil, & Davis, 1977). These conflicting findings could be due in part to how dominance was defined by each of these investigators as theorized by Wyatt and Edwards (1981). Limb dominance was determined by different procedures in the reported investigations. In the Wyatt and Edwards study (1981), limb preference was determined by identification of the limb by each subject to be used to kick a ball through a goal, as was the procedure for this study. Goslin and Charteris (1979) defined the dominant (preferred) limb as the stronger limb.

A stability reliability correlation for consistency of seven specific points within all isokinetic knee extension torque curves identified varied results for male and female subjects. For male subjects peak torque, torque at 70 degree angle of knee extension, area to 70 degree angle of knee extension, and area between 20 and 70 degree angles of knee extension were highly reliable. For female subjects, only peak torque, area to 70 degree angle of knee extension, and area between 20 and 70 degree angle of knee extension were highly reliable across days. Clarkson, Johnson, Dextradeur, Leszczynski, Wai, and Melchionda (1982) reported similar results concerning the reliability of peak torque within testing sessions and across testing days. They reported intraclass reliability coefficients of R=.97 to R=.99 for peak torque at four different velocities, as well as, high reliability coefficients for peak torque values across testing days (r=.97 to r=.99).

The results of this study, suggests that variables quantifying torque and work indices in the middle segment of torque curves appear to be the most reliable. While segments located near the beginning of torque curves appear to be not reliable. Results of the intraclass correlations indicate that the least reliable of all parameters analyzed (within a 3 repetition test) were area to 20 degree and area to peak torque of knee extension for male subjects on their preferred limb. These finding were similar to those of Scudder (1980). He reported that differences among isokinetic values were greatest at the beginning of the range test or early in the range of motion. While, isokinetic torque output differences in the terminal portion of the curve were minimal.

It is of importance to note that the investigator experienced difficulty in accurately analyzing and quantifying points in the beginning of torque curves for males. Male subjects tended to exhibit more powerful initial exertions in production of torque curves. Thus graphically, the beginning of the torque curves for male subjects tended to be near vertical.

Viewing an enlargement of the isokinetic knee extension curves, less frequent torque sampling points were observed in the beginning of the curves. Sapega, Nickolas, Sokolow, and Saraniti (1982) reported that transient peaks or spikes appear in the initial segments of torque curves recorded with the Cybex isokinetic dynamometer. They referred to such spikes as overshoot torque. Sapega et al. also concluded from an investigation of overshoot in Cybex isokinetic dynamometry that these initial torque spikes represent the forces associated with the initial deceleration and subsequent velocity fluctuation of an initially overspeeding limb-lever system. They reported that the majority of this overspeeding occurred in the latter part of the force acceleration period, prior to the engagement of the dynamometer's resistance mechanism and that the initial torque spike represents inertial forces not true muscular tension development.

Sinacore, Rothstein, Delitto, and Rose (1983) reported that the damping circuit in the Cybex recorder is capable of suppressing overshoot artifact, but it can also suppress the muscular torque output signal as well. This statement relates to the less frequent torque output data sampling points observed in the initial part of the SCA recordings of isokinetic torque curves. The damping setting recommended by Cybex (Isolated Joint Testing, 1983) served to correct the major overshoot torque, but may have also suppressed the muscular torque output signal. Thus, the Cybex damping setting may have caused infrequent torque sampling which lead to problems for the SCA system in quantifying precise points in the initial part of knee extension torque curves. The reduced number of data sampling points in the initial segments of the SCA torque curves, the time delay between actual limb movement by the subject to the point of engagement of the Cybex dynamometer resistance mechanism, and subsequent velocity fluctuations may have contributed to the low reliability coefficients estimated for the initial segments of SCA isokinetic torque curves.

For female subjects, intraclass correlations and stability reliability correlations for parameters quantifying the middle segments of torque curves indicated that the SCA system was a reliable method for isokinetic torque curve analysis. Similarly for the male subjects, parameters quantifying the middle segment of torque curves (by the SCA system) were reliable.

In summary, examination of Cybex isokinetic knee extension torque curves by SCA identified several reliable measures within torque curve configurations. Peak torque, area to 70 degree angle, and area between 20 and 70 degree angles of knee extension yielded the most consistent values within test and across days for females. Peak torque, torque to 70 degree angle, area to 70 degree angle, and area between 20 and 70 angles of knee extension appeared to elicit reliable values in both intraclass and interclass correlations for male subjects. Calculation of coefficients of variation of peak torque, torque at 70, area to peak torque, area to 70, and area between 20 and 70 degree angles of knee extension identified these variables as containing the parameters with the least amount of variation for female subjects. Peak torque, torque at 70, area to peak torque, and area between 20 and 70 degree angles of knee extension yielded relatively low coefficients of variation for male subjects. Thus, it was concluded from this investigation that the parameters of peak torque, area to 70, and area between 20 and 70 degree angles of knee extension are the most consistent curve segments and that these variables appear to elicit the least amount of variation for both male and female subjects.

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CHAPTER IV

SUMMARY OF THE STUDY

This study investigated the reliability of Cybex isokinetic knee extension torque curves generated by normal subjects utilizing the Segmental Curve Analysis system.

Forty normal subjects volunteered to perform two knee extension/flexion tests on the Cybex isokinetic dynamometer. Test protocol consisted of 5 maximum repetitions at a speed of 60 deg/sec; both preferred and non-preferred limbs were tested. During testing procedures, all torque and position angle measurement information from the Cybex data reduction computer via the Cybex dynamometer was transmitted to a 286 microcomputer. The SCA consisting of a 286 microcomputer, interfaced with a Data Translation DT2801 Series Board, plotted, analyzed, and quantified each isokinetic knee extension torque curve for seven segmented torque and work parameters.

The following parameters were quantified by the Segmental Curve Analysis system: (1) torque at 20 degrees, 70 degrees, and peak torque of knee extension; (2) area of the curve to 20 degrees, 70 degrees, and peak torque of knee extension; (3) area of the torque curve between 20 and 70 degree angles of knee extension. Each of seven parameters evaluating torque and work of the knee extensors were analyzed for consistency across multiple trials and days.

A test-retest and internal consistency correlation analysis across two experimental days design was implemented. Statistical Analysis System (SAS) was used by the investigator to conduct the statistical analyses. Pearson Product Moment correlation (stability reliability) and analysis of variance (intraclass correlation) was calculated using the experimental variables.

A one-way analysis of variance and Duncans Multiple Range test revealed significant differences between sex on all but one parameter and significant differences in limb preference for three of the parameters for female subjects and two of the parameters for male subjects.

Results of the stability reliability correlations indicated that peak torque and torque at 70 degree angle of knee extension were the most reliable isokinetic torque measures for male subjects across days. Peak torque was the most reliable torque measure across days for female subjects. Isokinetic work measures of area to 70 degree angle of knee extension, and area between 20 and 70 degree angles of knee extension indicated high test-retest correlations for both male and female subjects.

Intraclass correlation coefficients were much higher than the stability reliability coefficients; the consistency across trials within a test was much greater than across testing days. For female subjects, intraclass correlation coefficients ranged from R=.93 to R=.99 for all test variables. For male subjects, intraclass correlation coefficients ranged from R=.96 to R=.99, except for the parameters of area to peak torque (R=.79) and area to 20 degree angle (R=.59).

Results of the coefficient of variation analysis indicated that for female subjects isokinetic torque and work parameters of peak torque, torque at 70, area to peak torque, area to 70, and area between 20 and 70 degree angles of knee extension appeared to elicit relatively low variability. Coefficients of variation of the variables peak torque, area to peak torque, area to 70, and area between 20 and 70 degree angles of knee extension yielded the least amount of variation for male subjects.

Research Implications

The results of this study indicate that the parameters of peak torque, area to 70, and area between 20 and 70 degree angles are the most reliable across multiple trials and days, and that they elicit the least amount of variation in the torque curve for both male and female subjects. Clarkson, Johnson, Dextradeur, Leszczynski, Wai, and Melchionda (1982) reported similar results concerning the reliability of peak torque across testing days and across trials. They reported intraclass reliability coefficients of R=.97 to R=.99 for peak torque at four velocities, as well as, high reliability coefficients for peak torque values across testing days.

Analysis of the results of this study suggests that variables quantifying torque and work indices in the middle segment of torque curves appeared to be the most reliable. Segments located near the beginning of torque curves appeared to be much less reliable. Results of the intraclass correlations indicate that the least reliable of all parameters analyzed were area to 20 degree and area to peak torque of knee extension for male subjects on their preferred limb. These findings were similar to those of

Scudder (1980) who reported that differences among isokinetic values were greatest at the beginning of the range of motion tested. Scudder (1980) also stated that isokinetic torque output differences in the terminal portion of the curve were minimal.

In the present study, small transient peaks and less frequent torque output data sampling points were observed in the initial torque curve segments. Similar transient peaks or spikes in the initial segments of Cybex torque curves were reported by Sapega, Nicholas, Sokolow, and Saraniti (1982). They referred to such spikes as overshoot torque. Sapega et al. (1982) suggested that these initial torque spikes represent the forces associated with the initial deceleration and subsequent velocity fluctuations of an initially overspeeding limb-lever system. They reported that the majority of this overspeeding occurred in the latter part of the free acceleration period, prior to the engagement of the dynamometer's resistance mechanism and that the initial torque spike represents inertial forces not true muscular tension development.

The damping circuit in the Cybex recorder as reported by Sinacore, Rothstein, Delitto, and Rose (1983) is capable of suppressing overshoot artifact. However, Sinacore et al. (1983) stated that while the Cybex recorder is suppressing the overshoot artifact, it may also be suppressing the muscular torque output signal as well. This may explain the less frequent torque output data sampling points observed in the initial segments of the SCA recordings of isokinetic torque curves. The damping setting recommended by Cybex (Isolated Joint Testing, 1983) attempted to correct the majority of the overshoots torque, but may have also suppressed the muscular torque output signal. Thus the Cybex damping setting may have caused infrequent torque sampling points which led to problems for the SCA system in quantifying precise points in the initial segments of knee extension torque curves. The reduced number of data sampling points in the initial segments of the SCA torque, the time delay period between actual limb movement by the subject to the point of engagement of the Cybex dynamometer resistance mechanism, and subsequent velocity fluctuations may have contributed to low reliability coefficients in the initial segments of SCA isokinetic torque curves.

The results of this study contribute information regarding reliability of specific segments of Cybex isokinetic torque curves, as quantified by the Segmental Curve Analysis system. This system was designed to offer a more elaborate evaluation and interpretation of torque curves than can be obtained from Cybex. It was concluded from this study, that the SCA system is a reliable method for analyzing and quantifying curve segments located in the middle of isokinetic torque curves.

Recommendations for Future Research

The following recommendations for further study are suggested:

1. Further investigation of the reliability and variation of parameters located in the middle and latter portions of isokinetic torque curves using normal subjects.
2. A similar study investigating the reliability and variation of torque and work parameters of the knee extensors in an injured population with the purpose of identifying differences, if any, among the reliability and variation of the curves segments produced by normal and injured subjects.
3. A follow-up study designed to investigate the reliability of the torque and work parameters using subjects instructed to fake maximal knee extension contractions. The purpose of which would be to identify differences, if any, among the consistency of the torque curves produced by normal, injured, and faking subjects.

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APPENDIX A

DETAILED METHODOLOGY

METHODOLOGY

Selection of Subjects

Nineteen male and twenty-one female subjects between the ages of 16 and 43 years volunteered to serve as subjects in this study. Participants were recruited from physical education classes at Virginia Polytechnic Institute and State University. The subjects were screened for orthopaedic problems such as injury, surgery, or trauma to the hip joint, knee joint, or surrounding musculature (Appendix B). The subjects were asked not to have participated in any type of physical exercise on the day of testing (prior to testing). All subjects denied use of any medication or drug that would hamper performance in the study.

Experimental Procedures

Each subject was scheduled for three experimental sessions in the Muscular Function Laboratory. The first session served as an individualized orientation at which time the nature of the study and potential benefits and/or risks of participation were explained (Appendix B). During the orientation, each subject signed an informed consent for a protocol approved by the Human Subjects

Committee of Virginia Polytechnic Institute and State University and was screened for previous orthopaedic problems (Appendix C). If no history of orthopaedic problems was present, the subject was positioned on the Cybex and stabilized according to standard Cybex procedures (Appendix B). The subject was then allowed to perform a standardized warm-up protocol to familiarize him/her to the Cybex equipment (Appendix B). The position of the shin pad, number of seat pads, the height and horizontal position of the dynamometer for each limb, and limb preference was recorded during the orientation session and remained constant for each subject during the test and the retest (Appendix B). Limb preference was determined by asking the subject to select the limb that they would use to kick an extra point or field goal in football. Testing order of limb preference was randomized.

The Cybex and SCA system were calibrated and put on line prior to experimental testing. Within two days after the individualized orientation, each subject was scheduled for their first experimental testing session.

This testing session required each subject to perform a standardized isokinetic knee extension/flexion test on the Cybex isokinetic dynamometer as stated in the Isolated

Joint Testing and Exercise Manual (1983) on both limbs. The standardized warm-up protocol utilized in the orientation was performed by each subject prior to testing of each limb. While testing, the subject was stabilized and positioned according to the recorded values obtained in the orientation. The subject was seated and his/her lower leg was secured to the long input adapter. Belts were fastened around the chest, waist, and thigh. Arms were crossed over chest. The test protocol consisted of 5 maximal repetitions at a speed of 60 deg/sec. Standardized instructions for testing were administered to all subjects (Appendix B). Each subject performed a retest of the same procedures within one week of the initial test.

A Data Translation DT2801 Series high speed analog and digital system was used to record the torque and position signals generated by the subjects as they performed the experimental tests. Measurement information from the Cybex data reduction computer via the Cybex dynamometer was transmitted to a 286 microcomputer. The microcomputer, interfaced with a Data Translation DT2801 Series board, plotted, analyzed and quantified each isokinetic knee extension torque curve for selected parameters.

During the flexion movement of the first maximal test repetition for each subject, the data acquisition mode of the SCA system was initiated by the microcomputer. At the completion of each maximal knee extension/flexion test, torque curves were plotted and saved to disk for later analysis. Raw data is placed in Appendix D.

The torque curves were analyzed using a special software program (SCA) developed by the mechanical engineering department at VPI&SU (Wynn, 1988). Upon entering the data analysis mode, the SCA microcomputer program automatically searched and quantified selected torque and work (area) parameters within knee extension torque curves. Figures 1 and 2 illustrate the technique used by the SCA system to analyze selected curve segments.

The following parameters were analyzed and quantified by the SCA system: (1) torque at 20 degrees, 70 degrees, and peak torque of knee extension curves; (2) area of the knee extension curve to 20 degrees, 70 degrees, and peak torque; and (3) area of the torque curve between 20 and 70 degree angles of knee extension. The first and fifth torque curves from each knee extension test were disregarded. The remaining curves were analyzed for each test. All extracted torque and work values were then

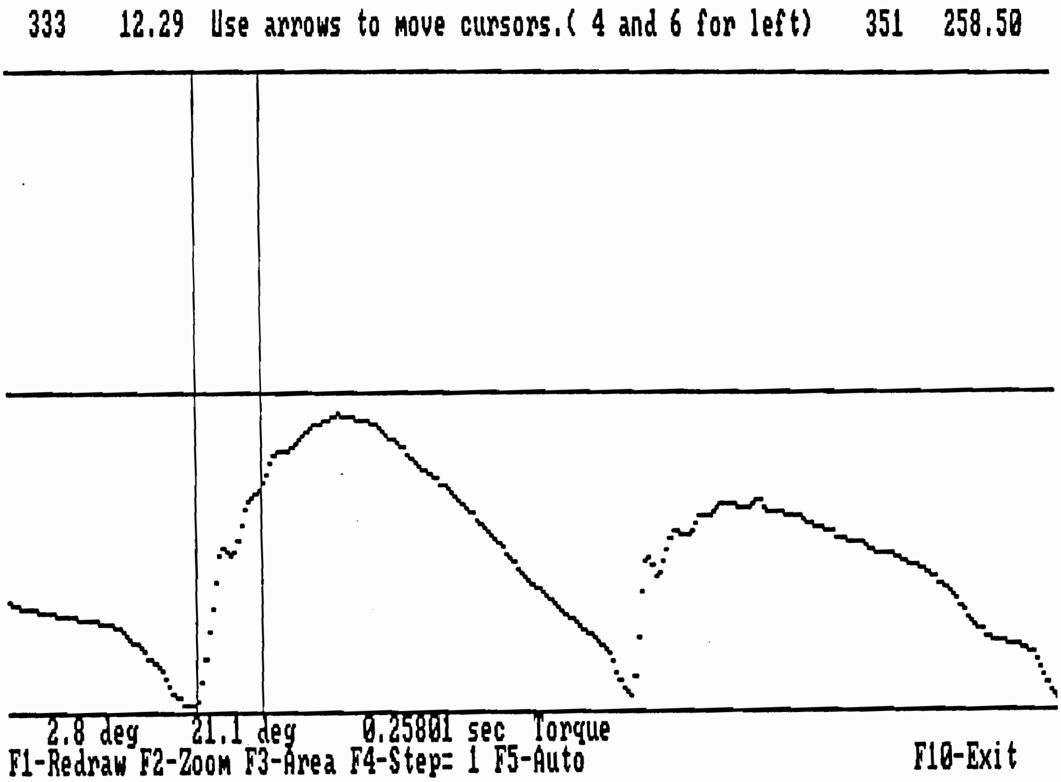

Figure 3. The SCA system identifies the beginning of the knee extension torque curve and the 20 degree angle of knee extension.

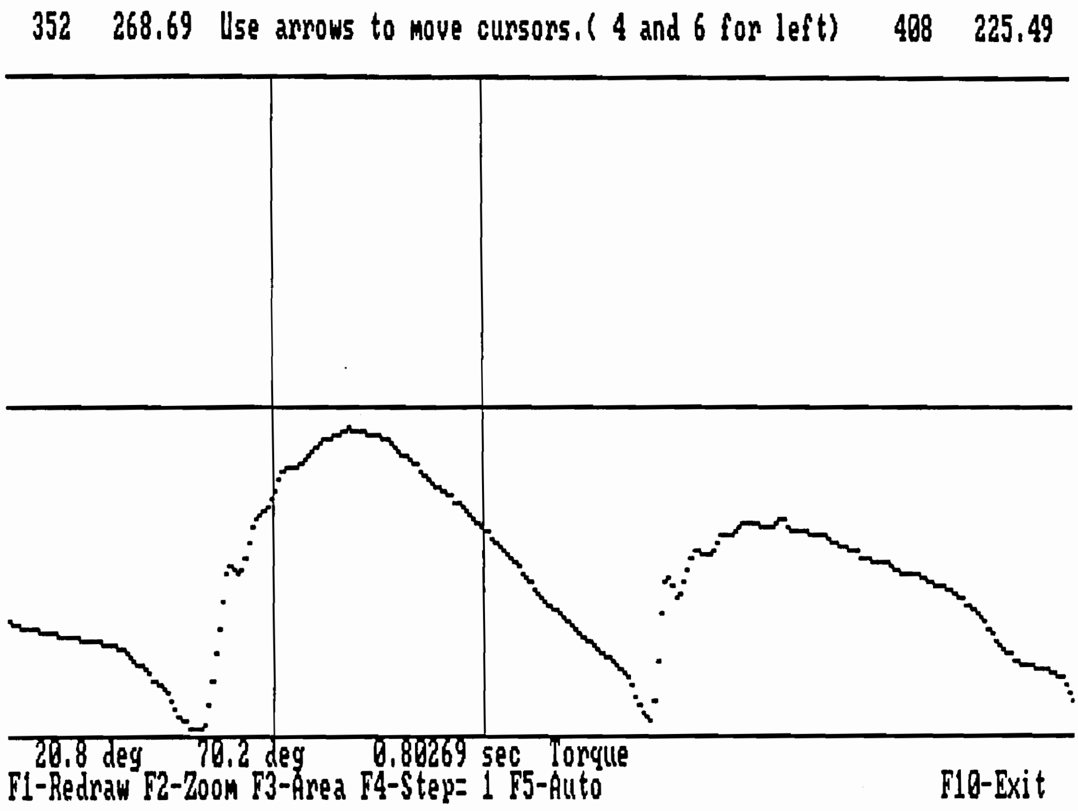

Figure 4. The SCA system identifies the 20 and 70 degree angle of knee extension.

entered for additional analysis on the mainframe computer.

Research Design

A test-retest and internal consistency correlation analysis across two experimental days design was implemented.

Statistical Analysis

Each of the seven torque and area parameters evaluating torque or work of the knee extensors were analyzed for day to day test reliability (stability reliability) and for reliability of scores within a test (internal consistency). A correlation analysis consisting of Pearson Product Moment correlation (test-retest method) for estimation of stability reliability and analysis of variance (ANOVA) for estimation of internal consistency (intraclass correlation) was implemented. The alpha level was set at .05.

One-way analysis of variance and Duncans Multiple Range test was conducted to test for differences between mean scores for male and female subjects. Statistically significant differences were found between the mean scores of males and females on all parameters, except area to 20 degree angle of knee extension. The means of the seven parameters by sex are presented in Table 1 (Appendix E).

One-way analysis of variance and Duncans Multiple Range test were conducted to test for differences between mean scores of preferred and non-preferred limbs for male and female subjects. For female subjects, statistically significant differences were found between mean scores of preferred and non-preferred limbs on the parameters of area to 70, area to 20, and torque at 20 degree angle of knee extension (Appendix E, Table 2). Statistically significant differences were found between mean scores of male preferred and non-preferred limbs on the parameters of torque at 20, and area between 20 and 70 degree angles of knee extension (Appendix E, Table 3).

Statistically significant differences were found between sex and limb preference on certain torque and work parameters. Therefore, most statistical analyses were conducted with data sorted by sex and limb. For simplification data, on occasion were pooled on limb preference.

Descriptive statistics of mean, standard deviation, and standard error of the means for all torque and work parameters were computed (Appendix F, Tables 4 and 5). For the purposes of descriptive statistics, the three maximal knee extension trials for each test were averaged to provide one criterion score.

Stability reliability estimates were determined for each of the seven torque curve parameters by correlating the test (day 1) and retest (day 2) scores. Pearson Product Moment correlation analysis was utilized. The three trials within each knee extension test were averaged for one criterion score per test. Correlation coefficients were determined for males and females on both limbs and presented in Table 6 (Appendix G).

Stability reliability correlation coefficients for isokinetic torque measures of male subjects indicated that peak torque (r=.97, preferred; r=.97, non-preferred) and torque at 70 degree angle of knee extension (r=.89, preferred; r=.80, non-preferred) were the most reliable torque measures. However, for female subjects only peak torque (r=.83, preferred; r=.84, non-preferred) were highly reliable from test-retest correlations.

Stability reliability correlation coefficients for isokinetic work measures of male subjects indicated that area to 70 degree angle of knee extension (r=.82, preferred; r=.92, non-preferred) and area between 20 and 70 degree angles of knee extension (r=.91, preferred; r=.93, non-preferred) were the most reliable work measures across days. Similar to the male subjects, isokinetic work measures for female subjects of area to 70 degree angle of knee extension (r=.84, preferred; r=.71, non-preferred) and area between 20 and 70 degree angles of knee extension (r=.71, preferred; r=.79, non-preferred) indicated a high degree of reliability. Additional Pearson Product correlations were calculated for males and females with scores for limbs pooled (Appendix G, Table 7). These data again indicated that peak torque (r=.97) and torque at 70 degree angle of knee extension (r=.85) are the most reliable isokinetic torque measures for male subjects. While, peak torque (r=.83) appeared to be reliable among female subjects. Isokinetic work measures of area to 70 degree angle of knee extension and area between 20 and 70 degree angles of knee extension indicated high test retest correlation for male subjects (r=.87 and r=.92, respectively) and female subjects (r=.76 and r=.75, respectively).

The reliability estimates for trials within a test were determined by calculating an intraclass reliability. A criterion score for each trial (1, 2, and 3) was computed by averaging trials 1, 2, and 3 from day 1 with trials 1, 2, and 3 from day 2. One-way analysis of variance was computed on the three trial criterion scores. From the ANOVA results, internal consistency coefficients for male and female subjects by limb preference were calculated. Results are presented in Appendix H, Table 8.

Intraclass correlations for female subjects on preferred and non-preferred limbs ranged from R=.93 to R=.99. For male subjects on preferred and non-preferred limbs, intraclass correlation coefficients ranged from R=.93 to R=.99, except for the parameters of area to peak torque (R=.62) and area to 20 degree angle of knee extension (R=.20) on the preferred limb.

Internal consistency coefficients were determined for male and female subjects with mean scores for limbs pooled (Appendix H, Table 9). For female subjects, intraclass correlation coefficients ranged from R=.93 to R=.99. For male subjects, intraclass correlation coefficients ranged from .96 to .99; except for the parameters of area to peak torque (R=.79) and area to 20 degree angle (R=.59).

Coefficients of variation were calculated for all torque and work parameters (Appendix I, Table 10). Results indicated that for female subjects isokinetic torque and work parameters of peak torque, torque at 70 degree angle of knee extension, area to peak torque, area to 70 degree angle of knee extension, and area between 20 and 70 degree angles of knee extension yielded relatively low coefficients of variation (c.v. ranging from 14.13% to

20.05%). Coefficients of variation values for male subjects identify peak torque, area to peak torque, area to 70 degree angle of knee extension, and area between 20 and 70 degree angles of knee extension were the variables producing the least amount of variation (c.v. range from 22.56% to 27.33%).

APPENDIX B

SUBJECT SCREENING FORM

ORIENTATION PROCEDURES

STABILIZATION FORM

CYBEX TEST PROTOCOL

Cybex Test Screening Form

Name:______________________________ Date:__________

Age:_______ Sex: M F

Address:____

Phone:____

1. Have you experienced any type of knee pain within the past 6 months? YES NO If so, please describe.

____

____

2. Have you ever sustained an injury or trauma, or had surgery to your knee joint, hip joint or the muscles surrounding these joints? YES NO If so, please explain. ____

____

____

3. If you have had injury, surgery or trauma to your hip joint, knee joint, or the surrounding musculature, do you feel that you have fully recovered from it? YES NO Do you feel that the involved limb has been adequately rehabilitated? YES NO

4. Do you feel in any way that you have orthopaedic or medical problems that may hamper your performance in this Cybex knee extension test? YES NO If yes, please elaborate. ____

____

____

5. Are you taking any type of medication at this time? YES NO Please explain.

I agree to not participate in any type of physical exercise on the day of testing (prior to testing).

____
Signature of Participant

____
Date

ORIENTATION PROCEDURES

1. Explain test: "You will perform a maximal knee extension/flexion test on both limbs, 5 repetitions at a speed of 60 deg/sec. Within one week you will repeat the test.

2. Sign Consent Form.

3. Fill out Cybex Test Screening Form.

4. Explain RPE: Instructions for reporting your feelings of effort during the exercise test.

During the knee extension test it is important for us to know how hard or difficult the exercise feels to you. These feelings of effort will be taken after each leg extension trial. Keep in mind that you are describing your body "feelings of effort" for each trial.

The chart shows a set of terms and related numbers from which you can choose a rating for each leg extension trial. While you perform the test, this chart will be positioned in front of you. Simply say the rating that best describes how difficult each trial felt to you.

5. Position subject in the Cybex. Record position.

6. Subject performs the orientation protocol.

   a. 5 sub-maximal repetitions at 120 deg/sec.
   b. 2 maximal repetitions at 120 deg/sec.
   c. 30 seconds rest.
   d. 5 sub-maximal repetitions at 90 deg/sec.
   e. 2 maximal repetitions at 90 deg/sec.
   f. 30 seconds rest.
   g. 5 sub-maximal repetitions at 60 deg/sec.
   h. 2 maximal repetitions at 60 deg/sec. Observe torque curves. If curves are consistent, repeat procedures for other limb. If curves are not consistent repeat steps g & h.

7. Schedule for testing.

CYBEX KNEE EXTENSION/FLEXION TEST STABILIZATION FORM

Name: ______________________________ Date: ________

Age: ________________ Sex: M F Body Weight: __

Limb tested: P NP

Stand Height:__________

Shin Pad (no# hole):_________

Horizontal Measure:____________

Number of Back Pads:__________

Limb tested: P NP

Stand Height:____________

Shin Pad (no# hole):___________

Horizontal Measure:____________

Number of Back Pads:________________

CYBEX TEST PROTOCOL

1. Secure subject.
2. Set-up procedures for the dual channel recorder & Cybex computer.
3. When computer display reads "Trial Repetitions at 60"

ADMINISTER THE FOLLOWING WARM-UP

1. 5 sub maximal trials at 120 deg/sec
2. 2 maximal trials at 120 deg/sec
3. 5 sub maximal trials at 90 deg/sec
4. 2 maximal trials at 90 deg/sec
5. 30 second rest period
6. 5 sub maximal trials at 60 deg/sec
7. Turn recorder on to 25 mm/sec
8. 2 maximal trials at 60 deg/sec
9. Observe torque curves. If consistent curves are present, go to step 11.
10. Repeat steps 6-9.
11. Enter <return> on cybex computer and start test.

TEST PROTOCOL

1. Turn recorder speed on (25 mm/sec).
2. Tell subject to "give me 5 repetitions, each as hard and fast as possible."
3. Make sure the subject is in the correct starting position (heel against the pad). Give the command "Ready . . . . Begin"
4. When "End of Test" is displayed on the computer, turn the dual channel recorder off. Check with the data acquisition technician if the data were recorded by the 286 computer.
5. Follow same procedures for testing remaining limb.

APPENDIX C

INFORMED CONSENT

CERTIFICATE

OF

APPROVAL FOR RESEARCH

INVOLVING HUMAN SUBJECTS

Division of HPER

The Human Subjects Committee of the Division of Health, Physical Education and Recreation has reviewed the research proposal of

Susan N. Earles-Price

entitled Estimation of Internal Consistency and Stability Reliability Using Isokinetic Segmental Curve Analysis.

The members have judged the subjects participating in the related experiment (not to be at risk) as a result of their participation.

(If a risk proposal) Procedures have been adopted to control the risks at acceptably low levels. The potential scientific benefits justify the level of risk to be imposed.

Members of Divisional
Human Subjects Committee

Chairman	Date
	Date
	Date

REQUEST FOR APPROVAL OF RESEARCH PROPOSAL
IN THE DIVISION OF HPER

Submitted to

Dr. Charles Baffi
Chairman, Division Human Subjects Committee and/or
Chairman, Institutional Review Board

by

Susan N. Earles-Price
Principal Investigator

TITLE: Estimation of Internal Consistency and Stability Reliability Using Isokinetic Segmental Curve Analysis

BACKGROUND/SCIENTIFIC JUSTIFICATION: Current procedures used by physical therapist and clinicians for evaluation of orthopaedic patients are Cybex II isokinetic measurements. Promoters of the Cybex II isokinetic dynamometer have suggested that the shape and consistency of torque curves from the Cybex data reduction computer (CDRC) can be utilized to determine malingering. No published data exist to suggest a clinician can determine patient malingering based on shape of CDRC torque curves. The Segmental Curve Analysis (SCA) system was designed and programmed to offer a more extensive evaluation and interpretation of torque curves than can be obtained from the CDRC.

PURPOSE: The purposes of this investigation are:
1.) To examine the consistency of isokinetic knee extension torque curves of normal subjects as measured by the SCA.
2.) To determine the reliability of the SCA in measuring nine specific torque and work parameters of isokinetic torque curves.

EXPERIMENTAL METHODS AND PROCEDURES: Approximately 40 volunteer subjects will perform a test-retest of the standardized isokinetic knee extension test on the Cybex II isokinetic dynamometer. Test protocol will consist of 3 maximal repetitions at a speed of 60 deg/sec. Data curves from each repetition will be analyzed for nine torque and work parameters by SCA. The nine parameters evaluating torque, speed, and area of each knee extension repetition (3 rep. per test; 2 test per subject) for each subject will be analyzed for variability across repetitions and for variability between tests.

STATEMENT DESCRIBING LEVEL OF RISK TO SUBJECTS: Participation in this activity involves risks of injury, including but not limited to strains, delayed muscle soreness, abrasions, possible muscle fatigue, and even the possibility of death.

PROCEDURES TO MINIMIZE SUBJECT RISK (IF APPLICABLE):
1.) Standardized testing procedures will be followed.
2.) Cybex orientation for subjects prior to testing will be conducted.
3.) Permission to withdraw from the experiment should the subject feel the activities will be injurious to his/her health.

RISK BENEFIT RATIO (IF RISK PROJECT): Personal benefits expected from participation in this experiment will be:
1.) Diagnostic evaluation of knee flexors and extensors; bilateral comparison to determine specific torque deficits.
2.) Opposing muscle group ratios will be calculated. Subject data will be applied to normative data.

HUMAN PERFORMANCE LABORATORY

Division of Health, Physical Education and Recreation
Virginia Polytechnic Institute and State University

INFORMED CONSENT

I, ________________________ , do hereby voluntarily agree and consent to participate in a testing program conducted by the personnel of the Human Performance Laboratory of the Division of Health, Physical Education and Recreation of Virginia Polytechnic Institute and State University.

The purpose of this test includes: To measure peak torque (strength) of the knee flexors and extensors.

I voluntarily agree to participate in this testing program. It is my understanding that my participation will include:

1. Cybex isokinetic knee extension/flexion strength test on both preferred and non-preferred limbs.

2. Test speed includes: 60 deg/sec @ 5 repetitions

I realize that my participation in this activity involves risks of injury, including but not limited to strains, delayed muscle soreness, abrasions, possible muscle fatigue, and even the possibility of death. I hereby assume all of the delineated risks of injury, all other possible risks of injury and even death which could occur by reason of my participation.

Certain personal benefits may be expected from participation in this experiment. These include:

1. Diagnostic evaluation of knee flexors and extensors. Bilateral comparisons will be made to determine specific torque deficits.

2. Opposing muscle group ratios will be calculated. Subject data will be applied to normative data.

I understand that I may abstain from participation in any part of the experiment or withdraw from the experiment should I feel the activities might be injurious to my health. The experimenter may also terminate my participation should he feel the activities might be injurious to my health.

I understand that it is my personal responsibility to advise the researchers of any preexisting medical problems that may affect my participation or of any medical problems that might rise in the course of this experiment and that no medical treatment or compensation is available if injury is suffered as a result of this research. A telephone is available which would be used to call the local hospital for emergency service.

I have had an opportunity to ask questions. Any questions which I have asked have been answered to my complete satisfaction. I subjectively understand the risks of my participation in this activity and knowing and appreciating these risks I voluntarily choose to participate, assuming all risks of injury or even death due to my participation.

Scientific inquiry is indispensable to the advancement of knowledge. Your participation in this experiment provides the investigator the opportunity to conduct meaningful scientific observations designed to make significant education contribution.

Date ________________ Time _______________ a.m./p.m.

Participant Signature ____

Witness ____
HPL Personnel

Project Director _________________________ Telephone ________

HPER Human Subjects Chairman Dr. Charles Baffi
Tel: 961-6561

Dr. Charles Waring, Chairman, Institutional Review Board for Research Involving Human Subjects. Phone 961-5283.

APPENDIX D

RAW DATA

LEGEND

T20 = Torque at 20 degree angle of knee extension

T70 = Torque at 70 degree angle of knee extension

A20 = Area of torque curve to 20 degree angle of knee extension

A70 = Area of torque curve to 70 degree angle of knee extension

PT = Peak torque of the knee extension curve

APT = Area of torque curve to peak torque of knee extension

A27 = Area of torque curve between 20 and 70 degrees of knee extension

RAW DATA: CYBEX KNEE EXTENSION

FEMALES PREFERRED LIMB DAY 1

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
1	20	1	52	118	.10	2.00	203	1.04	1.91
		2	117	112	.20	2.40	215	1.30	2.21
		3	131	108	.26	2.30	202	1.25	2.90
2	29	1	185	87	.70	2.32	190	.82	1.67
		2	170	93	.45	2.43	197	.78	2.02
		3	170	98	.32	2.37	195	.88	2.08
3	25	1	114	156	.16	2.41	211	1.39	2.27
		2	122	161	.18	2.30	206	1.42	2.14
		3	114	165	.16	2.32	207	1.47	2.18
4	21	1	13	142	.01	2.01	195	.80	2.01
		2	21	144	.01	2.03	196	1.00	2.02
		3	19	140	.01	2.06	199	1.06	2.06
5	21	1	76	120	.06	1.95	171	1.03	1.90
		2	100	121	.12	2.09	173	1.24	1.98
		3	108	122	.19	1.94	168	1.14	1.77
6	24	1	136	141	.18	2.15	167	1.35	2.00
		2	131	137	.17	2.00	159	1.13	1.85
		3	131	125	.19	1.90	149	1.14	1.74
7	20	1	117	90	.44	2.05	151	1.08	1.64
		2	118	98	.47	2.54	145	1.30	2.10
		3	126	90	.48	2.00	152	1.04	1.55

FEMALES PREFERRED LIMB DAY 1 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
8	19	1	162	113	.58	2.43	187	1.10	1.88
		2	143	108	.49	2.38	177	1.10	1.93
		3	151	108	.59	2.38	174	1.11	1.83
9	25	1	173	112	.71	2.70	185	1.47	2.03
		2	165	114	.63	2.59	181	1.37	2.00
		3	154	109	.66	2.51	174	1.51	1.88
10	26	1	140	98	.36	2.19	172	1.10	1.86
		2	153	108	.46	2.35	181	1.26	1.91
		3	139	107	.41	2.27	167	1.35	1.90
11	23	1	163	150	.29	2.73	240	1.29	2.48
		2	180	142	.38	2.71	235	1.25	2.37
		3	176	137	.40	2.73	231	1.35	2.37
12	19	1	112	109	.12	1.93	175	1.09	1.83
		2	91	109	.09	1.86	174	.99	1.79
		3	71	110	.05	1.86	174	.80	1.83
13	20	1	44	116	.06	1.32	136	.88	1.27
		2	30	119	.02	1.42	147	.82	1.41
		3	16	112	.01	1.22	135	.68	1.22
14	30	1	120	133	.30	2.17	173	1.36	1.90
		2	110	134	.28	2.04	165	1.33	1.78
		3	115	111	.28	1.94	152	.99	1.69
15	24	1	49	101	.06	1.39	134	.69	1.34

FEMALES PREFERRED LIMB DAY 1 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
15	24	2	80	112	.10	1.58	139	.61	1.50
		3	62	105	.06	1.49	131	.71	1.44
16	20	1	138	112	.37	2.23	169	.93	1.89
		2	149	112	.41	2.29	174	.86	1.92
		3	155	106	.52	2.30	176	1.17	1.81
17	22	1	82	102	.11	1.73	157	.84	1.64
		2	113	88	.23	1.62	139	.90	1.42
		3	65	79	.09	1.50	142	.76	1.42
18	21	1	154	102	.52	2.17	163	.86	1.68
		2	138	94	.41	1.97	161	.77	1.59
		3	151	95	.41	2.08	167	.83	1.70
19	21	1	89	101	.07	1.83	178	.90	1.77
		2	113	99	.16	1.90	175	.86	1.76
		3	86	103	.08	1.77	172	.85	1.71
20	26	1	140	76	.56	2.06	155	.91	1.53
		2	127	76	.39	1.77	133	.53	1.40
		3	133	92	.49	2.08	151	.85	1.63
21	34	1	110	108	.26	1.87	147	1.16	1.63
		2	106	103	.22	1.88	149	.92	1.69
		3	109	94	.30	1.80	142	.90	1.53

RAW DATA CYBEX KNEE EXTENSION

FEMALES NON-PREFERRED LIMB DAY 1

SUB	AGE	TRIAL	T20	T70	A20	270	PT	APT	A27
1	20	1	161	117	.39	2.50	211	1.35	2.19
		2	164	104	.39	2.40	206	1.28	2.10
		3	158	101	.38	2.40	203	1.17	2.01
2	29	1	214	116	.77	2.89	220	1.00	2.17
		2	200	116	.68	2.80	209	1.21	2.15
		3	192	128	.52	2.79	210	0.95	2.31
3	25	1	183	127	.60	2.95	2.22	1.62	2.39
		2	185	131	.69	3.00	223	1.53	2.36
		3	167	115	.48	2.83	215	1.35	2.36
4	21	1	104	133	.13	2.02	187	0.94	1.92
		2	91	137	.11	2.00	178	.96	1.89
		3	97	130	.12	2.05	189	1.01	1.95
5	21	1	124	121	.24	1.97	156	1.00	1.75
		2	128	133	.26	2.09	169	1.16	1.86
		3	108	119	.19	1.84	151	1.15	1.68
6	24	1	129	127	.10	2.17	176	0.58	2.09
		2	130	131	.15	2.07	171	0.64	1.94
		3	119	132	.11	1.94	164	0.46	1.86
7	20	1	190	83	.92	2.76	197	1.37	1.88
		2	180	81	.78	2.57	194	1.18	1.83
		3	172	92	.72	2.39	185	1.14	1.70

FEMALES NON-PREFERRED LIMB DAY 1 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
8	19	1	197	94	1.05	2.87	203	1.35	1.86
		2	187	94	.96	2.72	193	1.24	1.81
		3	180	85	1.01	2.75	188	1.32	1.78
9	25	1	120	148	.17	2.20	194	1.19	2.05
		2	113	133	.10	1.94	171	1.21	1.87
		3	113	143	.17	2.00	177	1.26	1.85
10	26	1	98	145	.12	1.94	179	0.92	1.84
		2	88	136	.12	2.03	177	1.11	1.93
		3	90	137	.13	1.82	174	1.06	1.71
11	23	1	186	117	.47	2.75	229	1.42	2.32
		2	186	131	.50	2.79	232	1.37	2.32
		3	168	133	.48	2.65	208	1.23	2.20
12	19	1	93	107	.15	1.76	160	.94	1.62
		2	83	108	.08	1.64	151	.73	1.58
		3	84	100	.12	1.55	136	.87	1.45
13	20	1	53	95	.09	1.09	105	.95	1.01
		2	57	101	.09	1.41	120	.81	1.34
		3	67	90	.12	1.42	125	.86	1.32
14	30	1	111	112	.41	2.07	159	1.27	1.69
		2	106	111	.31	2.00	157	1.40	1.72
		3	105	105	.40	1.95	149	1.38	1.58

FEMALES NON-PREFERRED DAY 1 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
15	24	1	93	106	.20	1.75	144	1.05	1.57
		2	92	110	.16	1.74	141	.86	1.59
		3	69	111	.12	1.62	145	.96	1.51
16	20	1	125	115	.29	1.98	170	.98	1.72
		2	133	107	.30	2.06	169	.90	1.79
		3	129	114	.34	2.06	163	.91	1.74
17	22	1	110	95	.27	1.97	169	1.16	1.72
		2	112	100	.28	1.65	169	1.16	1.72
		3	107	93	.27	1.82	146	.90	1.57
18	21	1	125	87	.59	1.90	143	.85	1.35
		2	122	111	.42	1.90	138	1.09	1.50
		3	127	112	.51	2.15	151	1.39	1.66
19	21	1	19	130	.01	1.62	171	.83	1.62
		2	28	126	.01	1.64	175	.81	1.63
		3	17	116	.01	1.70	174	.93	1.70
20	26	1	121	104	.35	1.88	137	.91	1.55
		2	120	108	.36	1.93	138	.78	1.60
		3	108	99	.30	1.76	130	.92	1.49
21	34	1	87	106	.18	1.53	131	.93	1.37
		2	78	107	.14	1.44	137	.94	1.31
		3	71	102	.14	1.41	128	.80	1.29

RAW DATA CYBEX KNEE EXTENSION

FEMALES PREFERRED LIMB DAY 2

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
1	20	1	120	96	.30	2.00	165	1.16	1.71
		2	105	95	.24	1.80	143	0.88	1.54
		3	105	80	.20	1.70	152	0.84	1.55
2	29	1	176	105	.37	2.41	194	0.90	2.07
		2	176	101	.42	2.44	191	0.81	2.06
		3	166	110	.38	2.33	185	0.77	1.98
3	25	1	168	102	.58	2.48	191	1.29	1.93
		2	162	102	.46	2.49	196	1.29	2.06
		3	171	89	.68	2.35	184	1.21	1.71
4	21	1	49	136	.02	2.08	202	0.93	2.07
		2	53	134	.02	2.14	205	1.12	2.13
		3	31	136	.01	2.08	188	0.75	2.08
5	21	1	85	104	.04	1.76	174	0.81	1.74
		2	79	121	.03	1.80	171	0.93	1.78
		3	90	133	.04	1.92	187	1.24	1.89
6	24	1	136	100	.30	1.93	154	0.83	1.65
		2	136	80	.31	1.88	155	1.00	1.59
		3	126	87	.28	1.85	149	0.73	1.59
7	20	1	123	94	.42	2.07	142	1.33	1.68
		2	90	99	.24	1.72	130	1.09	1.50

FEMALES PREFERRED LIMB DAY 2 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
7	20	3	98	102	.27	1.72	134	1.13	1.48
8	19	1	157	116	.49	2.48	192	1.43	2.02
		2	155	115	.55	2.35	187	1.41	1.83
		3	152	103	.49	2.33	175	1.11	1.87
9	25	1	157	142	.54	2.61	195	1.67	2.10
		2	154	131	.56	2.60	181	1.57	2.07
		3	147	140	.48	2.37	174	1.55	1.92
10	26	1	157	109	.51	2.24	180	1.28	1.77
		2	155	101	.42	2.19	180	1.04	1.80
		3	156	105	.41	2.23	175	1.24	1.85
11	23	1	169	127	.34	2.62	227	1.13	2.32
		2	197	130	.50	2.75	226	1.32	2.29
		3	1 61	141	.36	2.54	218	1.17	2.22
12	19	1	103	130	.10	1.79	161	1.08	1.71
		2	97	121	.13	1.80	162	1.11	1.69
		3	66	119	.05	1.73	161	1.04	1.69
13	20	1	115	93	.26	1.75	136	1.10	1.52
		2	93	83	.16	1.71	138	0.85	1.57
		3	105	88	.21	1.68	128	.59	1.49
14	30	1	147	127	.46	2.45	186	1.52	2.02
		2	127	137	.40	2.32	170	1.37	1.95

FEMALES PREFERRED LIMB DAY 2 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
14	30	3	127	115	.46	2.10	154	1.23	1.67
15	24	1	9	104	.01	1.10	112	0.71	1.10
		2	13	110	.01	1.23	119	0.69	1.23
		3	9	116	.01	1.27	130	0.90	1.27
16	20	1	138	134	.29	2.09	174	1.22	1.83
		2	132	120	.24	2.13	166	0.91	1.92
		3	134	128	.26	2.07	161	0.71	1.83
17	20	1	71	113	.07	1.83	175	.7 7	1.79
		2	81	114	.12	1.70	162	.81	1.60
		3	74	99	.09	1.62	154	.74	1.55
18	21	1	160	73	.64	2.31	174	1.14	1.71
		2	152	70	.46	2.02	162	0.69	1.60
		3	153	73	.46	1.99	168	.79	1.56
19	21	1	62	111	.04	1.74	156	1.02	1.71
		2	101	104	.11	1.77	152	0.96	1.69
		3	67	110	.05	1.62	153	0.88	1.59
20	26	1	113	78	.35	1.64	135	0.83	1.31
		2	107	65	.29	1.36	116	0.38	1.09
		3	118	91	.33	1.82	145	0.92	1.51
21	34	1	88	101	.11	1.52	144	0.74	1.43
		2	8 8	94	.11	1.55	143	0.99	1.47
		3	77	81	.09	1.44	131	.74	1.37

RAW DATA CYBEX KNEE EXTENSION

FEMALES NON-PREFERRED LIMB DAY 2

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
1	20	1	111	96	.23	1.78	146	0.69	1.57
		2	149	100	.34	2.00	170	0.85	1.68
		3	101	92	.17	1.78	162	.91	1.63
2	29	1	130	175	.15	2.43	207	1.23	2.31
		2	117	170	.08	2.28	201	1.12	2.22
		3	126	164	.11	2.35	201	1.24	2.26
3	25	1	163	111	.57	2.55	187	1.21	2.01
		2	167	107	.63	2.58	195	1.33	1.98
		3	167	88	.56	2.43	188	1.16	1.90
4	21	1	127	124	.23	2.09	183	.79	1.88
		2	109	131	.17	2.15	199	1.12	2.01
		3	108	123	.15	2.09	187	1.14	1.97
5	21	1	90	134	.05	1.89	170	1.05	1.85
		2	79	133	.05	1.78	167	1.26	1.74
		3	72	132	.04	1.73	163	1.06	1.70
6	24	1	192	90	.77	2.62	195	1.05	1.89
		2	174	86	.90	2.54	177	1.09	1.68
		3	175	96	.69	2.52	183	1.07	1.87
7	20	1	161	104	.62	2.51	181	1.36	1.93
		2	161	104	.68	2.54	177	1.40	1.90
		3	154	110	.61	2.46	177	1.25	1.88

FEMALES NON-PREFERRED LIMB DAY 2 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
8	19	1	169	105	.75	2.62	193	1.30	1.90
		2	166	88	.81	2.53	182	1.29	1.75
		3	165	92	.79	2.59	184	1.35	1.84
9	25	1	153	146	.43	2.61	192	1.65	2.22
		2	150	139	.51	2.53	185	1.61	2.05
		3	145	131	.48	2.37	172	1.55	1.92
10	26	1	148	125	.36	2.25	182	1.05	1.93
		2	155	127	.40	2.36	188	1.11	2.00
		3	150	111	.40	3.32	179	1.11	1.95
11	23	1	175	152	.44	2.90	223	1.58	2.50
		2	143	155	.27	2.62	220	1.37	2.38
		3	158	143	.38	2.71	224	1.76	2.37
12	19	1	96	113	.17	1.88	162	1.00	1.73'
		2	96	106	.16	1.74	146	0.85	1.60
		3	89	102	.13	1.61	141	0.86	1.50
13	20	1	110	110	.29	1.86	143	1.31	1.60
		2	107	110	.24	1.74	138	1.00	1.52
		3	99	117	.19	1.53	134	1.00	1.36
14	30	1	135	104	.60	2.45	174	1.49	1.88
		2	127	106	.43	2.17	168	1.31	1.77
		3	109	93	.48	2.09	144	1.11	1.63

FEMALES NON-PREFERRED DAY 2 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
15	24	1	72	88	.12	1.38	123	0.73	1.27
		2	62	94	.10	1.47	126	0.78	1.39
		3	85	100	.16	1.47	123	0.73	1.33
16	20	1	140	113	.38	2.11	161	1.00	1.76
		2	130	115	.29	1.97	155	0.88	1.71
		3	128	114	.30	1.92	149	0.78	1.65
17	22	1	127	102	.55	2.07	144	1.10	1.56
		2	118	104	.40	1.86	133	0.84	1.48
		3	116	107	.54	2.08	140	1.19	1.57
18	21	1	139	99	.35	2.02	162	0.84	1.70
		2	125	93	.27	1.85	161	.78	1.60
		3	147	96	.35	2.05	176	0.80	1.73
19	21	1	109	97	.15	1.71	163	0.73	1.58
		2	99	111	.12	1.81	158	0.59	1.71
		3	109	103	.11	1.70	164	0.75	1.61
20	26	1	80	92	.18	1.27	105	0.76	1.11
		2	78	110	.16	1.43	128	1.10	1.29
		3	93	105	.20	1.57	134	1.01	1.39
21	34	1	79	100	.14	1.45	129	0.96	1.33
		2	67	110	.10	1.35	132	0.96	1.27
		3	62	105	.08	1.40	131	0.92	1.33

RAW DATA CYBEX KNEE EXTENSION

MALES PREFERRED LIMB DAY 1

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
1	43	1	204	166	.50	3.28	262	1.56	2.83
		2	212	174	.56	3.13	254	1.52	2.62
		3	217	163	.64	3.14	252	1.51	2.55
2	22	1	233	159	.42	3.09	289	1.33	2.72
		2	176	169	.13	2.86	276	1.38	2.77
		3	203	173	.30	2.89	277	1.53	2.63
3	26	1	318	159	1.24	4.23	326	1.43	3.06
		2	309	149	1.20	4.23	323	1.96	3.10
		3	312	150	1.19	4.06	316	1.81	2.94
4	26	1	107	338	.05	3.99	475	2.03	3.96
		2	39	330	.01	4.06	456	2.21	4.05
		3	64	320	.02	3.80	416	1.89	3.79
5	28	1	172	182	.18	1.88	248	.69	1.73
		2	131	174	.11	1.82	242	1.01	1.74
		3	157	168	.16	1.82	228	.91	1.69
6	21	1	22	206	2.14	4.83	296	3.33	2.69
		2	43	221	.01	2.69	304	1.22	2.68
		3	109	209	.06	3.06	295	1.31	3.02
7	19	1	25	270	2.33	5.54	342	3.97	3.22
		2	136	267	.07	3.44	334	2.07	3.40
		3	169	246	.11	3.45	328	1.69	3.37

MALES PREFERRED LIMB DAY 1 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
8	20	1	255	154	.64	3.54	306	1.87	2.95
		2	256	159	.68	3.63	300	1.71	3.00
		3	247	168	.67	3.42	293	1.60	2.80
9	25	1	250	214	.27	3.77	384	1.85	3.55
		2	254	223	.25	3.66	377	1.72	3.46
		3	262	214	.30	3.83	375	1.23	3.58
10	24	1	75	221	.03	3.06	338	.93	3.04
		2	65	228	.02	3.06	330	.94	3.05
		3	95	237	.04	3.31	343	.96	3.29
11	43	1	199	142	.65	2.86	210	1.06	2.25
		2	187	139	.57	2.90	220	1.42	2.37
		3	189	128	.71	2.90	203	1.73	2.23
12	23	1	228	207	.56	4.08	372	1.74	3.58
		2	271	179	.50	3.89	364	1.65	3.44
		3	297	176	.66	3.86	347	1.18	3.27
13	16	1	99	111	.07	2.32	214	1.02	2.28
		2	104	135	.10	2.19	199	1.01	2.11
		3	125	128	.13	2.26	213	1.02	2.17
14	19	1	204	126	.63	3.11	225	1.88	2.52
		2	196	134	.62	2.97	214	1.44	2.39
		3	185	144	.50	2.66	199	1.56	2.20

MALES PREFERRED LIMB DAY 1 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
15	29	1	224	149	.48	3.46	294	1.44	3.03
		2	229	163	.48	3.16	283	1.34	2.73
		3	202	164	.34	3.03	268	1.28	2.72
16	24	1	67	166	.07	1.93	195	1.25	1.87
		2	93	147	.10	2.09	197	1.49	2.01
		3	81	139	.08	2.08	209	.93	2.02
17	26	1	82	117	.14	1.86	173	1.09	1.74
		2	112	103	.18	2.01	176	.98	1.86
		3	110	122	.15	2.03	185	1.15	1.90
18	22	1	149	208	.09	2.99	315	1.12	2.94
		2	199	202	.24	3.29	338	1.37	3.09
		3	153	204	.15	3.13	327	1.63	3.01
19	23	1	23	400	3.37	6.94	470	5.15	3.57
		2	34	323	.01	3.86	505	1.88	3.86
		3	29	314	.01	3.98	494	1.52	3.98

MALES NON-PREFERRED DAY 1

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
1	43	1	181	159	.48	3.16	251	1.60	2.72
		2	206	181	.66	3.34	260	1.79	2.72
		3	215	173	.74	3.45	250	1.45	2.75
2	22	1	184	181	.27	3.16	285	1.47	2.93
		2	195	187	.25	3.31	309	1.64	3.10
		3	169	192	.24	3.05	279	1.38	2.84
3	26	1	345	132	1.79	4.41	360	1.43	2.69
		2	340	122	1.72	4.42	348	1.45	2.78
		3	326	123	1.51	3.99	331	1.38	2.55
4	26	1	93	274	.04	4.44	473	1.97	4.42
		2	195	276	.12	4.45	454	1.83	4.36
		3	176	260	.11	4.23	434	1.81	4.16
5	28	1	53	143	.02	2.50	258	.94	2.49
		2	145	138	.11	2.70	260	1.00	2.61
		3	136	163	.14	2.79	245	1.02	2.54
6	21	1	100	179	.06	2.93	269	1.19	2.89
		2	186	181	.26	3.17	373	1.38	2.95
		3	198	171	.33	3.37	281	1.60	3.09
7	19	1	189	210	.21	3.38	319	1.76	3.21
		2	197	224	.28	3.28	304	1.80	3.04
		3	227	193	.47	3.20	272	1.82	2.77

MALES NON-PREFERRED DAY 1 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
8	20	1	256	156	.52	3.88	334	2.09	3.41
		2	287	163	.65	3.88	326	1.84	3.29
		3	280	161	.69	3.85	321	1.66	3.22
9	25	1	271	191	.47	4.01	321	1.66	3.22
		2	301	197	.61	4.01	378	1.60	3.45
		3	282	191	.49	3.96	365	1.53	3.53
10	24	1	229	274	.27	3.79	364	2.19	3.58
		2	227	279	.25	3.73	367	1.54	3.52
		3	224	266	.20	3.49	342	1.58	3.33
11	43	1	121	174	.22	2.37	209	1.55	2.18
		2	136	173	.31	2.40	200	1.51	2.12
		3	121	171	.22	2.35	190	1.53	2.15
12	23	1	247	215	.50	3.99	341	1.96	3.54
		2	292	239	.87	3.82	334	1.94	3.01
		3	240	201	.52	3.95	320	1.78	3.47
13	16	1	73	112	.05	1.75	183	.93	1.72
		2	17	117	.01	1.52	171	.83	1.52
		3	67	99	.04	1.86	195	.94	1.84
14	19	1	162	155	.39	2.78	232	1.42	2.42
		2	172	166	.40	2.83	235	1.74	2.47
		3	163	143	.36	2.70	224	1.42	2.37

MALES NON-PREFERRED DAY 1 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
15	29	1	160	214	.24	3.36	334	1.98	3.16
		2	167	243	.26	3.03	306	1.59	2.81
		3	161	210	.16	3.05	308	1.88	2.92
16	24	1	73	143	.05	2.05	217	1.08	2.02
		2	90	137	.12	2.08	218	1.02	1.98
		3	111	133	.15	2.30	213	1.04	2.18
17	24	1	105	110	.19	1.85	161	.88	1.69
		2	88	92	.14	1.78	162	.73	1.66
		3	109	100	.15	1.83	164	.69	1.70
18	22	1	35	250	.01	2.99	367	1.61	2.98
		2	92	242	.05	3.04	316	1.77	3.01
		3	43	229	.09	3.35	359	1.64	3.29
19	23	1	97	287	.04	3.44	487	1.93	3.41
		2	17	379	.01	3.52	473	1.87	3.52
		3	21	321	.01	3.77	474	1.91	3.77

MALES PREFERRED LIMB DAY 2

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
1	43	1	107	194	.16	2.97	259	1.37	2.83
		2	169	178	.30	2.96	252	1.49	2.70
		3	163	180	.27	3.00	262	1.48	2.77
2	22	1	229	169	.37	3.31	287	1.57	2.98
		2	221	156	.54	3.20	264	1.61	2.70
		3	218	172	.49	3.19	270	1.91	2.74
3	26	1	355	168	.93	4.28	382	1.53	3.42
		2	364	163	.97	4.25	380	1.50	3.35
		3	339	164	.80	3.99	354	1.22	3.26
4	26	1	45	314	.01	3.93	458	2.01	3.93
		2	31	302	.01	3.77	431	2.05	3.76
		3	46	307	.02	3.59	397	1.85	3.58
5	28	1	190	159	.31	2.88	259	1.17	2.61
		2	167	156	.22	2.73	243	1.08	2.54
		3	157	161	.18	2.88	254	1.54	2.73
6	21	1	33	280	1.98	4.91	355	3.37	2.93
		2	44	253	.02	3.04	334	1.38	3.02
		3	51	248	.02	3.13	329	1.40	3.12
7	19	1	35	249	.01	3.15	339	1.48	3.14
		2	118	257	.06	3.39	330	1.96	3.35
		3	74	225	.03	2.96	286	.87	2.95

MALES PREFERRED LIMB DAY 2 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
8	20	1	143	232	.09	3.41	340	1.86	3.36
		2	147	235	.09	3.33	333	1.85	3.27
		3	76	228	.03	3.26	328	1.88	3.24
9	25	1	305	185	.57	4.00	359	1.66	3.50
		2	294	176	.54	4.04	335	1.39	3.56
		3	304	189	.58	4.05	349	1.51	3.53
10	24	1	329	200	.73	3.92	355	1.01	3.26
		2	323	210	.60	3.83	362	1.01	3.29
		3	354	199	.86	3.97	358	.93	3.18
11	43	1	137	166	.22	2.70	231	1.72	2.51
		2	121	179	.18	2.40	219	1.59	2.25
		3	138	164	.26	2.45	208	1.44	2.22
12	23	1	264	200	.51	3.86	349	1.67	3.40
		2	290	213	.64	4.06	355	1.70	3.48
		3	280	230	.58	3.94	341	1.73	3.42
13	16	1	9	154	1.28	3.38	219	2.21	2.10
		2	16	147	.01	2.10	212	1.16	2.10
		3	16	141	.01	1.97	206	1.02	1.97
14	19	1	172	145	.42	2.80	221	1.55	2.41
		2	175	108	.44	2.58	205	1.19	2.18
		3	18 0	125	.47	2.70	210	1.17	2.28

MALES PREFERRED LIMB DAY 2 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
15	29	1	229	156	.45	3.28	294	1.37	2.88
		2	220	165	.45	3.19	297	1.66	2.79
		3	207	153	.39	3.03	273	1.55	2.68
16	24	1	13	171	.01	1.72	204	1.12	1.72
		2	5	166	.00	1.83	211	1.01	1.83
		3	16	180	.01	1.95	227	1.06	1.95
17	26	1	193	99	.62	2.51	195	1.31	1.94
		2	184	88	.49	2.30	189	.53	1.85
		3	180	94	.49	2.19	182	.53	1.74
18	22	1	200	190	.18	3.25	333	1.24	3.11
		2	189	205	.23	3.48	351	1.39	3.28
		3	190	195	.12	3.55	366	1.27	3.47
19	23	1	29	308	.01	4.15	497	1.88	4.14
		2	24	306	.01	4.31	478	1.58	4.31
		3	27	309	.01	4.08	465	1.64	4.07

MALES NON-PREFERRED LIMB DAY 2

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
1	43	1	213	188	.53	3.44	264	1.99	2.95
		2	217	179	.68	3.53	256	2.07	2.90
		3	213	188	.57	3.53	269	2.02	3.00
2	22	1	219	141	.63	3.42	260	1.32	2.84
		2	220	152	.59	3.41	264	1.44	2.86
		3	215	163	.58	3.33	264	1.48	2.80
3	26	1	227	214	.22	3.76	353	1.77	3.59
		2	241	223	.27	3.63	354	1.70	3.41
		3	247	207	.25	3.64	355	1.23	3.43
4	26	1	383	228	.66	4.65	459	1.79	4.07
		2	399	216	.73	5.10	486	2.12	4.45
		3	393	208	.82	5.05	473	2.18	4.31
5	28	1	183	142	.27	2.63	257	1.02	2.40
		2	162	136	.23	2.74	251	1.06	2.54
		3	166	130	.23	2.76	251	.97	2.56
6	21	1	224	229	.16	3.49	347	1.17	3.37
		2	180	217	.10	3.49	339	1.63	3.43
		3	234	221	.35	3.66	330	1.64	3.35
7	19	1	194	237	.17	3.72	384	2.24	3.59
		2	187	241	.12	3.44	338	1.57	3.36
		3	175	205	.11	2.94	301	1.14	2.87

MALES NON-PREFERRED DAY 2 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
8	20	1	283	185	.63	3.96	339	2.17	3.39
		2	273	171	.58	3.93	336	1.98	3.40
		3	300	167	.86	4.11	340	1.76	3.31
9	25	1	243	210	.25	3.59	382	1.38	3.39
		2	258	200	.36	3.75	381	1.52	3.44
		3	247	205	.27	3.69	361	1.43	3.47
10	24	1	232	283	.28	3.91	385	2.11	3.67
		2	242	262	.36	3.90	373	2.1	3.59
		3	203	263	.19	3.86	361	1.95	3.72
11	43	1	153	179	.35	2.67	217	1.73	2.36
		2	242	262	.36	3.90	373	2.11	3.59
		3	203	263	.19	3.86	361	1.95	3.72
12	23	1	248	223	.53	3.95	342	1.90	3.47
		2	240	205	.58	3.70	314	1.77	3.16
		3	253	198	.65	3.90	320	1.79	3.30
13	16	1	112	86	.14	1.83	177	.57	1.71
		2	138	94	.17	1.94	187	.77	1.80
		3	134	89	.18	1.96	186	.62	1.80
14	19	1	187	140	.43	2.74	223	1.14	2.34
		2	174	132	.44	2.66	219	1.17	2.26
		3	178	121	.45	2.57	202	1.10	2.16

MALES NON-PREFERRED DAY 2 CONT.

SUB	AGE	TRIAL	T20	T70	A20	A70	PT	APT	A27
15	29	1	202	223	.30	3.50	349	2.08	3.24
		2	171	226	.25	3.32	336	1.86	3.10
		3	167	235	.23	3.30	321	1.93	3.10
16	24	1	123	167	.09	2.67	268	1.30	2.60
		2	124	148	.10	2.45	245	1.19	2.38
		3	106	169	.07	2.65	267	1.37	2.60
17	26	1	106	130	.15	1.92	170	1.02	1.80
		2	90	121	.10	1.72	161	.85	1.64
		3	92	122	.10	1.73	167	.87	1.65
18	22	1	262	152	.43	3.65	344	1.38	3.27
		2	231	154	.36	3.73	358	1.44	3.42
		3	264	174	.42	3.78	365	1.28	3.41
19	23	1	171	317	.10	4.26	476	1.98	4.20
		2	81	294	.03	4.37	482	1.72	4.36
		3	109	312	.05	4.07	443	1.96	4.04

APPENDIX E

Table 1

Mean Values for Cybex Knee Extension Torque and Work Parameters

PARAMETER	MALE	FEMALE
PEAK TORQUE (ft.lbs.)	*156	*87
TORQUE AT 20 DEGREE ANGLE (ft.lbs.)	*90	*61
TORQUE AT 70 DEGREE ANGLE (ft.lbs.)	*98	*58
AREA TO PEAK TORQUE (ft.lbs.xsec.)	*1.5263	*1.0499
AREA TO 20 DEGREE ANGLE (ft.lbs.xsec.)	0.3726	0.3098
AREA TO 70 DEGREE ANGLE (ft.lbs.xsec.)	*3.2478	*2.0588
AREA BETWEEN 20 & 70 DEG. (ft.lbs.xsec)	*2.9108	*1.7740

*Significant difference between sex at the .05 level.

*Data represents pooled scores from day 1 and day 2 tests, and preferred and non-preferred limbs.

Table 2

Summary ANOVA for Torque and Work Differences Between Preferred and Non-Preferred Limbs for Females

Parameter	Source	DF	Type III SS	F Value	PR>F
Peak Torque	Limb	1	2.03175	0.02	0.8788
Torque at 20 Degree Angle	Limb	1	1913.34	6.07	0.0155*
Torque at 70 Degree Angle	Limb	1	328.669	3.37	0.0692
Area to Peak Torque	Limb	1	0.04496	3.43	0.0672
Area to 20 Degree Angle	Limb	1	0.10002	10.64	0.0015*
Area to 70 Degree Angle	Limb	1	0.09148	4.49	0.0367*
Area Between 20 & 70 Deg.	Limb	1	0.00724	0.71	0.4015

*Significant at the .05 level.

Table 3

Summary ANOVA for Torque and Work Differences Between Preferred and Non-Preferred Limbs for Males

Parameter	Source	DF	Type III SS	F Value	PR>F
Peak Torque	Limb	1	285.7917	1.59	0.2108
Torque at 20 Degree Angle	Limb	1	17937.72	10.08	0.0021*
Torque at 70 Degree Angle	Limb	1	179.3778	0.48	0.4903
Area to Peak Torque	Limb	1	0.000425	0.00	0.9493
Area to 20 Degree Angle	Limb	1	0.121716	1.75	0.1890
Area to70 Degree Angle	Limb	1	0.005067	0.05	0.8156
Area Between 20 & 70 Deg.	Limb	1	0.196253	8.06	0.0056*

*Significant at the .05 level.

APPENDIX F

Table 4

Descriptive Statistics for Female Subjects on the Cybex Knee Extension Test Retest

PARAMETER	TEST	$\bar{X}$	SD	SEM
PEAK TORQUE*	1	88	14.4	4.25
	2	86	13.4	3.95
TORQUE AT 20 DEGREE ANGLE*	1	61	22.7	6.81
	2	62	19.6	5.93
TORQUE AT 70 DEGREE ANGLE*	1	58	9.1	2.73
	2	57	9.1	3.02
AREA TO** PEAK TORQUE	1	1.05	.22	.03
	2	1.05	.24	.04
AREA TO 20** DEGREE ANGLE	1	.31	.23	.04
	2	.31	.21	.03
AREA TO 70** DEGREE ANGLE	1	2.08	.40	.06
	2	2.04	.40	.06
AREA BETWEEN** 20 & 70 DEG	1	1.80	.29	.04
	2	1.75	.28	.04

Data represents averaged trials 1, 2, and 3; and pooled data for the preferred and non-preferred limbs.

*The unit of measure for above torque parameters is ft.lbs.

**The unit of measure for above area (work) parameters is ft.lbs.x sec.

Table 5

Descriptive Statistics for Male Subjects on the Cybex Knee Extension Test Retest

PARAMETER	TEST	$\bar{X}$	SD	SEM
PEAK TORQUE*	1	154	42.7	13.50
	2	158	42.1	13.25
TORQUE AT 20	1	86	41.8	13.14
DEGREE ANGLE*	2	93	47.0	14.99
TORQUE AT 70	1	98	32.5	10.26
DEGREE ANGLE*	2	99	27.8	8.75
AREA TO**	1	1.54	.44	.07
PEAK TORQUE	2	1.51	.37	.06
AREA TO 20**	1	.40	.37	.06
DEGREE ANGLE	2	.35	.24	.04
AREA TO 70**	1	3.21	.79	.13
DEGREE ANGLE	2	3.29	.73	.12
AREA BETWEEN**	1	2.84	.65	.11
20 & 70 DEG.	2	2.98	.68	.11

Data represents averaged trials 1, 2, and 3; and pooled data for the preferred and non-preferred limbs.

*The unit of measure for the above torque parameters is ft.lbs.

**The unit of measure for the above area (work) parameters is ft.lbs.x sec.

APPENDIX G

Table 6

Pearson Correlation Coefficients for Cybex Knee Extension Torque and Work Parameters

	FEMALES		MALES	
PARAMETER	PREF	NON-PREF	PREF	NON-PREF
PEAK TORQUE	r=.83	r=.84	r=.97	r=.97
TORQUE AT 20 DEGREE ANGLE	r=.81	r=.57	r=.66	r=.55
TORQUE AT 70 DEGREE ANGLE	r=.36	r=.48	r=.89	r=.80
AREA TO PEAK TORQUE	r=.82	r=.55	r=.55	r=.86
AREA TO 20 DEGREE ANGLE	r=.72	r=.48	r=.09	r=.19
AREA TO 70 DEGREE ANGLE	r=.84	r=.71	r=.82	r=.92
AREA BETWEEN 20 & 70 DEG.	r=.71	r=.79	r=.91	r=.93

*Trials 1, 2, and 3 were averaged for the criterion score per test.

**Pref = Preferred Limb; Non-Pref = Non-Preferred Limb

Table 7

Pearson Correlation Coefficients for Cybex Knee Extension Torque and Work Parameters

VARIABLE	FEMALE	MALE
PEAK TORQUE	r=.83	r=.97
TORQUE AT 20 DEGREE ANGLE	r=.69	r=.60
TORQUE AT 70 DEGREE ANGLE	r=.41	r=.85
AREA TO PEAK TORQUE	r=.68	r=.66
AREA TO 20 DEGREE ANGLE	r=.58	r=.14
AREA TO 70 DEGREE ANGLE	r=.76	r=.87
AREA BETWEEN 20 & 70 DEG.	r=.75	r=.92

*Data represents averaged trials 1, 2, and 3; and pooled data for the preferred and non-preferred limbs.

APPENDIX H

Table 8

Intraclass Correlation Coefficients for Cybex Knee Extension Torque and Work Parameters

	FEMALE		MALE	
PARAMETER	PREF	NON-PREF	PREF	NON-PREF
PEAK TORQUE	R=.9835	R=.9845	R=.9951	R=.9957
TORQUE AT 20 DEGREE ANGLE	R=.9812	R=.9929	R=.9848	R=.9754
TORQUE AT 70 DEGREE ANGLE	R=.9560	R=.9707	R=.9940	R=.9938
AREA TO PEAK TORQUE	R=.9265	R=.9368	R=.6242	R=.9607
AREA TO 20 DEGREE ANGLE	R=.9806	R=.9893	R=.2066	R=.9777
AREA TO 70 DEGREE ANGLE	R=.9806	R=.9823	R=.9285	R=.9925
AREA BETWEEN 20 & 70 DEG.	R=.9505	R=.9816	R=.9926	R=.9913

*Pref = Preferred Limb; Non-Pref = Non-Preferred.

Table 9

Intraclass Correlation Coefficients for Cybex Knee Extension Torque and Work Parameters

VARIABLE	FEMALE	MALE
PEAK TORQUE	R=.9763	R=.9956
TORQUE AT 20 DEGREE ANGLE	R=.9577	R=.9378
TORQUE AT 70 DEGREE ANGLE	R=.9124	R=.9791
AREA TO PEAK TORQUE	R=.9468	R=.7908
AREA TO 20 DEGREE ANGLE	R=.9487	R=.5922
AREA TO 70 DEGREE ANGLE	R=.9743	R=.9704
AREA BETWEEN 20 & 70 DEG.	R=.9748	R=.9903

*Data represents averaged trials 1, 2, and 3; and pooled data for the preferred and non-preferred limbs.

APPENDIX I

Table 10

Coefficients of Variation for Cybex Knee Extension Torque and Work Parameters

PARAMETER	FEMALE	MALE
PEAK TORQUE	15.24%	27.33%
TORQUE AT 20 DEGREE ANGLE	32.13%	44.96%
TORQUE AT 70 DEGREE ANGLE	14.13%	29.82%
AREA TO PEAK TORQUE	20.38%	24.31%
AREA TO 20 DEGREE ANGLE	62.12%	63.48%
AREA TO 70 DEGREE ANGLE	18.34%	22.96%
AREA BETWEEN 20 & 70 DEG.	15.05%	22.56%

VITA

Susan N. Earles-Price was born on October 10, 1961 in Marion, Virginia. She was reared in various parts of southwest Virginia, attending high school in Shawsville. She received a Bachelor of Science degree in sports management, with concentrations in athletic training and pre-physical therapy, from James Madison University in Harrisonburg, Virginia. While at JMU, she ran cross country, indoor track, and outdoor track for four years.

While managing a nautilus center, she was offered a "free meal" from a prospective member. In October of 1985, she and the prospective member, Thomas G. Price, were married. In August of 1985, Susan entered the exercise physiology program at Virginia Tech. During the first year of which, she and Tom, surprisingly became parents (Kendall Susan Price). Upon completion of her Masters of Science degree in exercise physiology/muscular function at Virginia Tech, Susan plans to continue rehabilitation work with orthopaedic patients and to coach runners in either a high school or collegiate setting.

Susan N. Earles-Price