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THE EFFECTS OF LIMB SPEED AND LIMB PREFERENCE ON SELECTED ISOKINETIC STRENGTH AND POWER MEASURES DURING INTERNAL AND EXTERNAL ROTATION OF THE SHOULDER

by

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(ABSTRACT)

Forty-five males volunteered to serve as subjects to investigate the effects of limb velocity and limb preference on peak torque/body weight (PTBW), torque acceleration energy (TAE), average power (AVP), and endurance ratio (ER) at isokinetic speeds of 60 and 300 degrees/second during internal and external rotation of the shoulder. Standard Cybex warm-up and test protocol were used for both test conditions. Test/retest reliability estimates ranges from r=.60-.70. Repeated Measures ANOVA revealed significant limb speed and limb preference effects on PTBW, TAE, and AVP in both exercise speed or limb preference. The data illustrate a need for an internal/external shoulder rotation normative profile specific to limb speed and limb preference.

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CHAPTER I

INTRODUCTION

The process whereby an individual attains physical fitness is multi-dimensional. One area of physical fitness which has been focused upon closely in recent years is that of muscular performance; specifically, strength, power, and muscular endurance. These factors have played a significant role in the clinical evaluation of muscular performance (Wyatt & Edwards, 1981). Various forms of resistive exercise (isotonic and isometric) continue to be utilized in the development of strength and power. In recent years, isokinetic resistance exercise has become a popular form of training for both the recreational and elite athlete. The impact of isokinetics has been substantial. There are two distinct features of isokinetic resistance exercise which set it apart from isotonic and isometric exercise. First, the maximal angular velocity at which a limb can pass through a full range of motion during an isokinetic exercise is externally controlled. Secondly, the limb is met with a resistive force which accommodates for any propulsive force as the limb passes through a full range of motion. This accommodating resistance allows a muscle group to generate maximal force at all points throughout the complete range of motion of the exercise (Wyatt & Edwards, 1981). This feature has a significant effect in muscular assessment and development, and in the area of muscular rehabilitation. (Thistle, Hislop, Moffroid, & Lowman, 1967).

Isokinetic assessment has been utilized extensively to measure the muscular performance of the lower extremities through the measurement of peak torque and peak torque to body weight ratio. Research has demonstrated an inverse relationship between the velocity of limb movement and the production of torque. As the speed of contraction, thus the velocity of movement increases, torque decreases (Wyatt & Edwards, 1981).

Others have focused upon the effects of gender, speed and limb preference. Male subjects have generally demonstrated greater absolute strength gains during isokinetic exercise, but female subjects closed the gap when body weight and body composition (lean body mass) were taken into account (Hoffman, Stauffer, & Jackson, 1979).

Statement of the Problem

Upper extremity strength and power measures such as peak torque and peak torque to body weight ratio, power, and torque acceleration energy have been recently investigated. As reported by Davies (1984) with upper extremity testing, males produced more power than their female counterparts. A similar pattern of power generation was seen by Hoffman, Stauffer, & Jackson (1979) during lower extremity testing. Hosler, Morrow, & Jackson (1978) also found a similar pattern of upper extremity isokinetic performance with respect to gender and limb speed in comparison to lower extremity performance (Wyatt & Edwards, 1981). As was reported by Ivey, Calhoun, Rusche, & Bierschenk (1984) for male subjects, there existed an inverse relationship between the torque generated and the angular velocity of the limb at which the female subjects performed the isokinetic upper body exercise.

The higher the limb velocity, the lower the torque produced. In addition to this parallel in performance with respect to gender, there also existed the same relationship with respect to torque production of the shoulder. Males consistently produced higher absolute torque levels, but this production was not statistically greater than female production when it was adjusted for actual bodyweight. These results were consistent with those reported by Hoffman, Stauffer, & Jackson (1979) when examining flexion/extension of the knee.

The purpose of this study was to determine the effect of limb speed and limb preference on the isokinetic measures of peak torque to bodyweight ratio, torque acceleration energy, average power, and muscular endurance during internal and external rotation of the shoulder joint.

Research Hypotheses

To delineate the purpose of this study, the following null hypotheses were established by the investigator:

1. Limb preference and exercise speed had no effect on peak torque/bodyweight ratio of subjects as they performed isokinetic internal/external rotation of the shoulder joint at exercise speeds of 60 and 300 degrees per second.
2. Limb preference had no effect on the torque acceleration energy of subjects as they performed isokinetic internal/external rotation of the shoulder at a limb speed of 300 degrees per second.
3. Limb preference had no effect on the average power of subjects as they performed isokinetic internal/external rotation of the shoulder at a limb speed of 300 degrees per second.
4. Limb preference had no effect on the endurance ratio of subjects as they performed isokinetic internal/external rotation of the shoulder at a limb speed of 300 degrees per second.

Significance of the Study

A major weakness of existing isokinetic research is the imbalance in the number of published studies providing data for upper extremity and lower extremity isokinetic performance. Lower extremity studies, specifically of the knee, have been dominated the focus of most isokinetic research. There exists a need to investigate upper extremity performance; specifically internal and external rotation of the shoulder. A study of the shoulder joint, more specifically the rotator (musculotendinous) cuff, has significance for physical therapy i.e. muscle rehabilitation. The musculature of rotator cuff has been a key area of interest due to its propensity for and a predisposition to injury. Those in the field of physical therapy have made strides to determine the best means of rehabilitation for the rotator cuff. But, a major ingredient in rehabilitation is a normative data base which may be used to compare an apparently healthy limb and the compromised limb. Specifically, the study reported herein would allow a compilation of data which could be used as a comparative profile when rehabilitating a compromised limb.

The study herein focused on an area for which data were lacking in the measurement of strength, power, and endurance. Other investigators, (Ivey, Calhoun, Rusche, & Bierschenk, 1984), (Moffroid, Whipple, Hofkosh, Lowman, & Thistle, 1969) have addressed various components of performance on a singular basis, i.e. strength, power, or endurance for the lower extremity. Still further investigation (Adeyanju, 1983), have addressed all three muscle performance components across more than one limb speed, but Adeyanju's focus was also on lower extremity (knee flexion/extension) performance. Although Ivey, Calhoun, Rusche, & Bierschenk (1984) published a comprehensive study with regard to isokinetic testing of shoulder strength, he did not evaluate the components of power and muscle endurance. Connelly-Maddux, Kibler, & Uhl, (1989) followed Ivey with a more comprehensive look at the shoulder in which strength, power, and endurance components were studied across the limb speeds of 60 and 180 degrees per second respectively with respect to limb preference and gender. The Connelly-Maddux study provided an excellent model for the structure of the study reported herein. Specifically, the number of subjects was increased to 45 and the endurance test was substantially modified. While the Connelly-Maddux study required that each subject perform 25 repetitions, the study herein required that each subject perform 40 repetitions. But more significant than the change in repetitions was the increase in the limb speed for the endurance test from 180 degrees/second to 300 degrees/second. Three hundred degrees/second is more conducive to speed specific skills performed by the shoulder (i.e. throwing a ball, serving in a racquet sport, etc.). The normative data base which was constructed through this study may have more clinical value because the data are speed specific to a variety of movement patterns associated with sport and exercise.

Delimitations

1. Subjects were limited to 45 males between the ages of 18-30.
2. The experimental exercise was isokinetic internal/external rotation of the shoulder at 90 degrees abduction.
3. Isokinetic test velocities were 60 degrees per second for the isokinetic measure of peak torque/bodyweight ratio, and 300 degrees per second for

peak torque/bodyweight ratio, torque acceleration energy,average power, and endurance ratio.

Limitations

1. The Cybex II isokinetic dynamometer measured functional limb speed up to 300 degrees/second. The functional speed of internal and external rotation of the shoulder during many sports oriented movement patterns exceed joint angle velocity of 300 degrees per second (Davies, 1984).
2. The Cybex II system tests joint strength,power,and endurance only in one plane.

Definitions and Symbols

1. Average Power: The measurement of total work divided by the elapsed time. The time span being from the point of initial muscle contraction until completion of the final repetition of the work bout.
2. Endurance Ratio: The percent change in work for the first eight repetitions of the exercise bout as

compared to the last eight repetitions in a forty repetition exercise bout.

3. External Rotation: Counter clockwise rotation of the shoulder, as viewed in Figure 1, brought about while the upper arm is at 90 degrees abduction and the forearm is perpendicular to the upper arm at the elbow. The movement begins with the palm parallel to the floor and ends with the palm perpendicular to the floor.

4. Internal Rotation: Clockwise rotation of the shoulder, as viewed in Figure 1, brought about while the upper arm is at 90 degrees abduction and the lower arm is perpendicular to the upper arm at the elbow. The movement begins with the palm parallel to the floor and ends with the palm perpendicular to the floor.

5. Peak Torque: The greatest amount of torque generated at any point during a single isokinetic muscle contraction.

6. Peak Torque/Bodyweight Ratio: The highest level of torque divided by the performer's body weight in pounds.

7. Rotator (musculotendinous) cuff: A group of five muscles (supraspinatus, infraspinatus, teres minor,

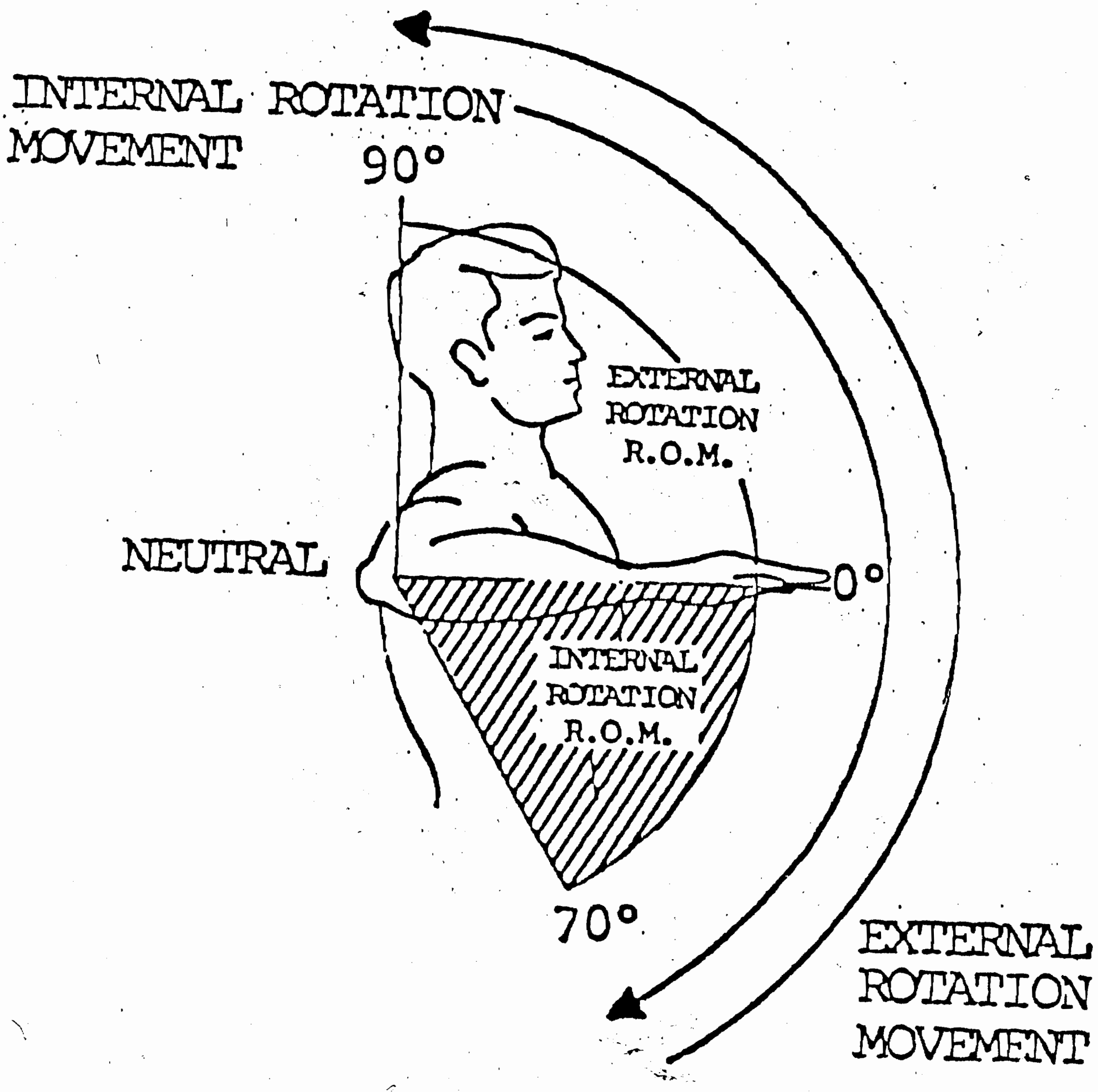

Figure 1. Internal and External Rotation of the Shoulder for Upper arm at 90 degrees abduction

teres major, and subscapularis) which arise entirely from the scapula and have their insertions on the humerus.

8. Torque Acceleration Energy: The total work executed during the first one-eighth of a second of an isokinetic muscle contraction.

Basic Assumptions

The following assumptions were made by the investigator:

1. It was assumed that all subjects gave maximal efforts during both isokinetic tests.
2. It was assumed that all subjects maintained a similar pattern of physical activity between testing sessions.
3. It was assumed all statistical assumptions were met.

Summary

A major topic of concern in the area of physical fitness is muscular performance. In addressing muscular performance; and specifically the areas of strength, power, and muscular endurance, research has revealed that the resistive exercise modality of isokinetics has been effective in both the areas of muscular performance enhancement, as well as muscular rehabilitation (Thistle, Hislop, Moffroid, & Lowman, 1967).

The versatility found in using isokinetic evaluation led to increased research activity. Various researchers used isokinetic assessment to evaluate muscular performance of lower extremities in factors including gender, limb speed, and limb preference. (Hoffman, Stauffer, & Jackson, 1979). In addition, some of those same factors were addressed with upper extremity assessment. Yet, there remains a distinct imbalance between the number and scope of published research in upper and lower body isokinetic performance.

The purpose of this investigation was to evaluate the effects of limb speed and limb preference on isokinetic strength, power, and endurance of the shoulder during internal/external rotation.

CHAPTER II

REVIEW OF LITERATURE

This chapter provides an overview of the anatomy, pathology, and biomechanics of the shoulder joint, and resistive training modalities with a specific focus on isokinetics.

Rotator Cuff

A major area of concern for those in the field of muscular performance, muscular rehabilitation, and injury prevention is the shoulder joint, and more specifically, in the musculotendinous cuff. Made up of the supraspinatus, infraspinatus, teres minor, and subscapularis muscles, this cuff, which maintains the position of the humerus within the glenoid cavity, has been the subject of extreme anatomical, biomechanical, and pathological scrutiny by the human performance/rehabilitation industry because of the critical role it plays in various upper body movements. This cuff is crucial in the execution of the throwing motion, the motion of an overhead serve found within many racket sports, or any other motion involving internal and external rotation of the shoulder.

The rotator cuff creates a protective capsule within the glenohumeral joint. As the four work in concert, the supraspinatus superiorly, the subscapularis anteriorly, and the teres minor and infraspinatus posteriorly, " they end in broad, short, flat tendons which intricately fuse with the fibrous capsule of the glenohumeral joint to form a musculotendinous mass applied to all sides of the joint except the inferior quadrant" (Simon & Hill, 1989).

Although having approximately twice the surface area of the humeral head itself, the relatively thin fibrous capsule of the glenohumeral joint does not in and of itself contribute greatly to the joint's stability. Thus, normal glenohumeral activity is dependent upon the support of ligaments and the tendinous attachment of the rotator cuff musculature. (Simon & Hill, 1989).

Stability of the joint is insured by the coracoacromial ligament, the acromioclavicular joint, and the acromion. These structures are in close proximity to the cuff itself. In addition can be found the subacromial bursa. Located between the cuff itself and the coracoacromial arch, its function is to provide protection to the rotator cuff tendons by the reduction of friction caused by the tendons pathway through the coracoacromial arch.

The cuff's vascular network is in part made up of six major arterial vessels. They are the suprascapular, anterior circumflex humeral, posterior circumflex humeral, thoracoacromial, suprahumeral, and subscapular. These vessels are aptly named for their relative position to the glenohumeral capsule.

The neuromuscular network which serves the rotator cuff is chiefly controlled by the brachial plexus. It is from these nerve fibers that innervation carries out the messages of movement (Simon & Hill, 1989).

The cuff provides strength to insure stability, yet at the same time, it must insure the necessary mobility of the glenohumeral joint. In order to guarantee peak performance, the cuff must serve each function equitably. Clearly, given the significant workload placed upon the joint, coupled with the wide range of motion that the joint moves through, the structure of the cuff must function in a precise manner. With the exception of the coracoacromial ligament superiorly, the shoulder does not have strong ligaments and capsular reinforcements to help maintain the stability. The cuff maintains the integrity of the joint by stabilizing the humeral head within the glenoid fossa, which in turn reinforces the alignment of the biomechanical fulcrum during shoulder elevation (Simon & Hill, 1989).

With such great demands placed upon the joint, there exists the possibility an excessive amount of force being placed upon the head of the fossa. This excessive force in turn predisposes the joint to degenerative changes, inflammation, pain and loss of function (Simon & Hill, 1989).

The two most common injuries with respect to the rotator cuff has been cuff impingement or a muscular tear within the glenohumeral joint. The impingement occurs when the cuff tendons (especially the supraspinatus tendons) and the tendon of the long head of the biceps is squeezed against the anterior edge of the acromion and the coracoacromial ligament. When the arm is abducted, elevated, or externally rotated, the supraspinatus tendon falls under the coracoacromial arch and may in certain instances be impinged against it (Roy & Irvin, 1983).

A tear in the cuff may be partial or complete. In many instances, it may have the same clinical features of the impingement syndrome. In fact, it has been suggested that is the tear itself which is responsible for impingement syndrome. A tear in the cuff usually results from an acute trauma most frequently involving the supraspinatus tendon, but there is evidence to suggest that the infraspinatus or tendon of the long head of the biceps may also be subject to injury. But, there also exists the possibility that these structural irregularities arise from chronic microtrauma, vascular impairment, or previous trauma which failed to manifest itself. Regardless, it is clearly evident that the shoulder and more specifically the rotator cuff is a crucial area of concern.

Muscular Fitness Modalities

In each instance of muscular fitness evaluation, there exists advantages and disadvantages of the various modalities. During the 1950's and 1960's, isometrics , once considered an extraordinary means of strength development, was soon found to be extremely limited. Although research has identified clear strength gains through the application of this technique, further research has revealed that these gains were not seen across a full range of motion. In fact, the specific strength gains were limited to the approximate joint angles at which the subject was executing the isometric contraction. Thus, the subject's performance would be limited to that specific joint angle. In addition, further research revealed that isometric training was ineffective as a means of increasing a subject's muscular power. At present, isometrics has been relegated to a supplementary role in the overall scheme of muscular evaluation. It is sometimes used by athletes who find themselves experiencing difficulty at a specific joint angle with respect to a skill specific movement. Even though inexpensive and easily executed, isometric training in and of itself has been passed by in favor of isotonic and isokinetic training (Brooks & Fahey, 1985).

The major thrust of program development has been placed upon isotonic and isokinetic exercise. Isotonic exercise has been the mostly widely accepted form of muscular fitness evaluation by most athletes and coaches because its wide variety of applicable techniques including constant, variable, and eccentric loading, as well as plyometric training.

Constant resistance exercise is seen in the classic example of the free weight bench press. A clear advantage of constant resistance exercise over that of isometric exercise is the ability to place a constant resistance across a full range of motion and not be limited to a specific joint angle. In addition, through the use of dumbbells and barbells, the isotonic exercise can be movement and skill specific to the individual's unique strength program. Although constant resistance isotonics clearly has remained as a popular training option, further research has indicated the existence of a weakness in the application of this program. An attempt has been made to account for this weakness through the implementation of variable resistance isotonics. Variable resistance isotonics is effective in changing the workload imposed on a muscle group during the exercise movement. While the constant resistance isotonic technique was able to overload the muscle only at the weakest point in the joint's range of motion, variable resistance isotonic equipment has been developed so as to impose an increasing workload on the muscle throughout its full range of motion. By changing the biomechanical advantage between the fulcrum and lever, the muscle will be loaded not only at its weakest point in the range of motion, but will be met with an increasing workload so as to maximize the muscle's potential at the point in the range of motion when it is at its strongest biomechanically. But, as efficient as variable resistant isotonics may appear, the experimental research has not demonstrated a functional advantage for variable resistance isotonics over that of constant resistance isotonics. Both have been used in the development of effective programs.

The role of eccentric loading has been found to be effective in the development of structural stability in and about the joint. Research has shown it to be an effective means of strength development, but no more so than the other forms of isotonic exercise. A negative aspect of this type of training is the occurrence of residual muscle soreness. Although strength gains are clearly apparent through this form of isotonics, the soreness as well as the availability of other various means of muscle overload has made eccentric training a supplementary technique at best.

> " The implosive technique of plyometric training has become an accepted accessory to any muscular fitness program which intends to develop speed as well as power. This technique couples a rapid lengthening of the muscle during eccentric loading followed by an immediate concentric contraction. This technique has gained a strong following from the track and field athlete because of its ability to heighten the excitability of the nervous system for improved reactive ability of the neuromuscular mechanism." (Stone & O'Bryant, 1984, p. 132).

As the neuromuscular reaction time between an eccentric and concentric contraction is improved, the speed at which the specific movement is executed is increased. This in turn results in an improved level of speed. With this type of ballistic movement comes a clear opportunity for speed and power enhancement (i.e. sprint or jumping ability). But, with this great opportunity to maximize speed and power performance comes the risk of suffering serious injury. Because of the ballistic nature of the activity, a tremendous amount of force is routinely placed upon the knee joint. The shock absorption properties of the medial and lateral meniscus as well as collateral and cruciate ligaments of the knee are repeatedly tested during plyometric training. The stress placed upon the knee joint by this training method has translated into a high incidence of lower limb injury (Stone & O'Bryant, 1984).

Isokinetics

Despite the significant roles that both isotonic and isometric modalities have played with respect to muscular fitness evaluation, it has been the impact of isokinetics which has been the most evident during the last two decades (Rothstein, Lamb, & Mayhew, 1987).

There are three clear advantages which may in part explain the expanded role which isokinetics has taken in the human performance field. First, isokinetic resistance exercise provides a fixed velocity at which a limb can pass through a full range of motion. This velocity is controlled externally through a dynamometer. Secondly, the limb is met with a resistive force which accommodates for the controlled velocity of the contraction as it passes through a full range of motion. Because of its ability to have an external control of limb velocity, isokinetics could be used to enhance muscular performance at a specific joint angle velocity. A specific case in point would be the use of isokinetic training of the internal and external rotation of the shoulder in a throwing motion for a pitcher in baseball. Researchers (Stone & O'Bryant, 1984), have clearly demonstrated that in order to improve the execution of a particular movement, both the angle at which the movement is performed, as well as the limb speed at which the movement is executed must be practiced. The implementation of an isokinetic resistance program serves to execute both of those aspects of specific skill acquisition. In addition, from a rehabilitative point of view, because an accommodating resistive force is instituted, the muscle may be fully loaded throughout its range of motion, but never forced to exceed the level that a compromised or recovering limb could withstand. The recovering limb can be loaded and exercised without the danger an injurious relapse. Finally, with the advent of the Cybex Corporation Inc. of Ronkonkoma , New York has come a means of muscular evaluation which has been extremely concise, sensitive, and reliable with respect to isokinetic performance (Burdett & Van Swearingen, 1987). In fact, because of its test- retest reliability, it has been suggested that an injured athlete's uncompromised limb may be used to generate isokinetic torque criteria (e.g. percentages.) to determine when the patient may progress in rehabilitation or return to competition (Rothstein, Lamb, & Mayhew, 1987).

Early isokinetic clinical history was dominated by research of the lower limbs, with the quadriceps and hamstring receiving the majority of interest. Muscular strength of the lower limbs has been evaluated through recorded values of the peak torque and peak torque to body weight ratio. In addition, research has focused upon the power and endurance parameters of average power, torque acceleration energy, and muscular endurance ratio respectively. Beyond those specific measures, the question arose as to the effects of limb speed, limb preference (dominant versus non-dominant), and gender, as well as body composition with respect to those aforementioned parameters.

Limb Speed

Wyatt and Edwards (1981) reported an inverse relationship between limb speed and torque production with respect to lower extremities. This outcome was confirmed by Ivey, Calhoun, Rusche, & Bierschenk (1984) and Connelly-Maddux, Kibler, & Uhl (1989) for upper extremities during the execution of an isokinetic test of internal and external rotation of the shoulder at 90 degrees abduction.

Because of the strong connection between isokinetic strength and power measures, the outcomes witnessed with respect to average power and torque acceleration energy strongly paralleled to those of peak torque production and peak torque to body weight ratio with respect to limb speed. Again, an inverse relationship existed between the muscle's ability to generate power and the speed at which the limb passes through a range of motion. As the limb speed increased, its ability to generate torque over time, and torque acceleration energy decreased. This outcome was confirmed by Bernie & Brodie (1986) in lower extremity testing, and Connelly-Maddux, Kibler, & Uhl (1989) in upper extremity testing.

While strength and power parameters have followed somewhat of an anticipated pattern with respect to limb speed, the endurance ratio has been the most difficult parameter to evaluate. Because of the muscle's inability to generate a high level of force as the limb speed is increased, it has left a degree of uncertainty with respect to the interpretation of endurance data at higher limb speeds. It has been suggested that because torque production levels are so low at the higher limb speeds, there exists the possibility of misinterpretation. By definition, an isokinetic clinician's role in the endurance ratio test procedure is to allow for a comparison between a specified number of initial repetitions and the same number of final repetitions. But there appears to be an inherent weakness in the structure of this testing protocol. If the subject has an unusually low level of production from his initial repetitions, then his concluding repetitions will be closer in value production to the initial ones, and therefore an artificially high endurance ratio would be observed. In some instances, this has left an impression that individuals having the greatest levels of initial torque production also had the lowest percentage with respect to their respective endurance ratios. Thus, the overall reliability of this isokinetic measure has been viewed in a moderate light at best. (Burdett & Swearingen, 1987).

Limb Preference

In examining the effect of limb preference on upper extremity performance, Connelly-Maddux, Kibler, & Uhl (1989) concluded that the isokinetic peak torques produced by individual's dominant (preferred) and non-dominant (non-preferred) shoulder musculature did not exhibit a statistically significant difference in performance. This particular outcome further reinforced similar results reported by Ivey, Calhoun, Rusche, & Bierschenk (1984) as well as Alderink & Kuck (1986).

The lower extremity review was not as clear cut with respect to limb preference and its effect on peak torque production. Goslin & Charteris (1979) found significant difference between preferred and non-preferred limb, while Burnie & Brodie (1986) found no difference.

With respect to the power parameters of average power and torque acceleration energy, Goslin & Charteris (1979) reported a significant difference in power production between preferred and non-preferred limbs, Burnie & Brodie (1986) reported no difference.

Upper extremity testing also revealed mixed results. Connelly-Maddux, Kibler, & Uhl (1989) found no significant difference between the preferred and non-preferred limbs with respect to total work and power, but the torque acceleration energy results were significantly different.

With respect to muscular endurance, isokinetic research has been varied. This is probably the result of the absence of a standard isokinetic endurance testing protocol. Two factors which bore significantly upon the perceived level of endurance was the limb speed, and the number of exercise repetitions. Neither factor has been standardized, thus all results are relative to the individual protocol. Connelly-Maddux, Kibler, & Uhl (1990) found there to be a statistically significant difference between the preferred and non-preferred shoulder during endurance ratio testing, but Ivey, Calhoun, Rusche, & Bierschenk (1984) using the same test protocol found no significant difference between the preferred and non-preferred limbs.

Although more focus on upper extremity performance has been observed in recent years, there still exists a demand for a normative data base for isokinetic strength, power, and muscular endurance parameters.

Summary

A major area of concern for those in the field of muscular performance, muscular rehabilitation, and injury prevention is the shoulder joint, and more specifically, in the musculotendinous cuff.

Made up of the supraspinatus, infraspinatus, teres minor, and subscapularis muscles, this cuff, which maintains the position of the humerus within the glenoid cavity, has been the subject of extreme anatomical, biomechanical, and pathological scrutiny by the human performance/rehabilitation industry because of the critical role it plays in various upper body movements. Because of its obvious significance in the execution of many upper body movements, it appears further anatomic, biomechanic, and pathologic research is necessary.

The field of isokinetics has gained tremendous popularity and acceptance by human performance professionals. Because of its unique feature of a fixed limb speed and accommodating resistive force, isokinetics has proven to be a valuable tool in the fields of human performance and physical rehabilitation.

The value of isokinetics is exemplified when being applied to the rehabilitation of the rotator cuff. Isokinetic's ability to change to various limb speeds allows for exercise bouts at a specific limb speed. This feature is crucial in analysis of shoulder irregularities. It allows the shoulder to be met with resistance at a level commensurate with the muscle's ability to generate force. As the muscle's ability to generate force increases, so too will the modality's ability to present resistance against that muscular force. Thus, the muscle will be met with the most challenging of workloads, while at the same time being protected against the likelihood of recurring injury. Isokinetic research is needed to develop a normative data base for the human performance and physical rehabilitation industry.

The role of limb speed as a factor in isokinetic research has been consistent for strength and power performance, but inconsistent for endurance performance. Wyatt & Edwards (1981) reported an inverse relationship between limb speed and torque production with respect to lower extremities. This outcome was confirmed by Ivey, Calhoun, Rusche, & Bierschenk (1984) and Connelly-Maddux, Kibler, & Uhl (1989) for upper extremities during the execution of an isokinetic test of internal and external rotation of the shoulder at 90 degrees abduction.

Again, an inverse relationship existed between the muscle's ability to generate power and the speed at which the limb passes through a range of motion. As the limb speed increased, its ability to generate torque over time, and torque acceleration energy decreased. This outcome was confirmed by Burnie & Brodie (1986) of lower extremity testing, and Connelly-Maddux, Kibler, & Uhl (1989) with upper extremity testing.

Endurance ratio was the most difficult variable to evaluate. Because of the muscle's inability to generate a high level of force as the limb speed is increased, it has left a degree of uncertainty with respect to the interpretation of endurance data at higher limb speeds. It has been suggested that because torque production levels are so low at the higher limb speeds, there exists the possibility of misinterpretation. Thus the reliability of this isokinetic measure with respect to limb speed has been viewed in a moderate light at best (Burdett & Van Swearingen, 1987).

CHAPTER III

Journal Manuscript

INTRODUCTION:

Early isokinetic research focused on lower extremity testing. Researchers were concerned with the specific effects of limb speed, limb preference, gender, and body composition on the parameters of peak torque, peak torque to body weight ratio, torque acceleration energy average power, and endurance ratio. Thistle, Hislop, Moffroid, & Lowman (1967) were among the first to suggest an inverse relationship between the ability of the muscle to produce torque and the angular velocity of the limb motion in question and its ability to pass through a fixed range of motion at a fixed limb velocity. As limb velocity increased, torque production decreased. This inverse relationship has been documented repeatedly for lower extremity tests by Moffroid, Whipple, Hofkosh, Lowman & Thistle (1969), Hoffman, Stauffer, & Jackson (1979), Wyatt & Edwards (1981), and Burnie & Brodie (1986). Ivey, Calhoun, Rusche, & Bierschenk (1984) and Connelly-Maddux, Kibler, & Uhl (1989) found a similar relationship with upper extremity testing as well.

This inverse relationship was consistent with respect to gender as well. Both male and female subjects produced lower levels of torque as their limb speeds increased.

Other gender related comparisons of isokinetic performance focused on the value of absolute torque production. Males consistently produced higher levels of torque during lower (Hoffman, Stauffer, & Jackson, 1979), as well as upper extremity testing (Connelly-Maddux, Kibler, & Uhl, 1989). But further research revealed that in many instances, when torque was taken into account with respect to the subjects' body weight(peak torque to body weight ratio), no statistical difference was reported between male and females. The one notable exception to this result was recently reported by Connelly-Maddux, Kibler, & Uhl (1989). Their data suggest that even after adjustment for body weight, males still demonstrated a statistically significant advantage over the female subjects with respect to upper extremity testing.

While the effects of limb speed on isokinetic torque production have been well documented, the results with respect to limb preference has been less conclusive. Published data regarding the effects of limb preference(dominant versus non-dominant limb) have been mixed, both for lower and upper extremity performance. While Goslin & Charteris (1979) reported significant differences between preferred and non-preferred limbs for peak torque and torque acceleration energy, a similar experiment conducted by Burnie & Brodie (1986) reported no significant difference between the preferred and non-preferred lower extremity. Ivey, Calhoun, Rusche, & Bierschenk (1984) and Connelly-Maddux, Kibler, & Uhl (1989) reported similar results with respect to upper extremity testing. Both studies reported non-significant differences between preferred and non-preferred limbs.

The purpose of the study reported herein was to investigate the effects of limb velocity and limb preference on the isokinetic measures of peak torque to body weight ratio, torque acceleration energy, average power, and endurance ratio at limb velocities of 60 and 300 degrees per second as the subjects performed internal and external rotation of the shoulder.

Methods and Procedures

Forty-five males between the ages of 18 and 30 years volunteered to serve as subjects in this study. The subjects were given the opportunity to confirm their participation in the study by signing a written consent form.

Limb preference was determined by instructing the subject to select the limb they would use if throwing a football for distance. The order of limb testing was then randomized.

The orientation session began with a subject being individually positioned on the Cybex and stabilized according to a standard isokinetic warm-up and Cybex testing protocol (Cybex II, Bayshore, N.Y.). The subject was then instructed to perform a standard warm-up set of 5 repetitions of internal rotation and 5 repetitions of external rotation of the shoulder at each of the experimental velocities. The position of the upper body exercise and testing table (UBXT), the offset input adapter with shoulder testing accessory, the horizontal handgrip, shoulder rotation support, the height and horizontal position of the dynomometer for each limb were recorded during this session.

The Cybex and Data Reduction Computer (CDRC) system were calibrated and placed on-line prior to experimental testing.

The initial testing session required each subject to perform standardized isokinetic shoulder internal and external rotation with both upper extremities. These were executed with the upper arm in 90 degree abduction. Standardized instructions for testing were given each subject. The test protocol consisted of 5 maximal repetitions at an angular velocity of 60 degrees/second. Peak torque was recorded during this test.

Following a one minute rest period, the subject was instructed to execute 40 maximal repetitions at a limb velocity of 300 degrees/second. The isokinetic parameters of average power (AVP), torque acceleration energy(TAE), and endurance ratio (END) were measured during this test. A two minute rest period was allowed before the subject repeated both the 5 repetition and the 40 repetition tests on the other limb. Each subject returned to the laboratory within 30 days to perform a retest using the same procedures.

Results

Test/retest reliability estimates were calculated using Pearson Product Moment correlations. Table 1 displays the reliability estimates for all isokinetic measures recorded during both internal and external rotation of the shoulder. A repeated measures ANOVA was then conducted to determine if any statistically significant differences existed between the subjects' performances across testing days. No significant difference was found between any of the isokinetic measures, therefore, the two data sets were merged for subsequent statistical analysis. An alpha value of 0.05 was used for all statistical tests.

Internal Rotation

Exercise Speed

A one-way repeated measures ANOVA was used to determine the effects of exercise speed on the peak torque/body weight ratio (PT/BW) of subjects as they performed internal rotation of the shoulder at 60 and

Table 1

PEARSON PRODUCT MOMENT RELIABILITY ESTIMATES FOR INTERNAL/EXTERNAL ROTATION OF THE SHOULDER

	INTERNAL				EXTERNAL			
LIMB PREF.	PREF.		NON-PREF.		PREF.		NON-PREF.	
	EXERCISE SPEED(DEG./SEC.)							
	60	300	60	300	60	300	60	300
PT/BW	r=.70	r=.59	r=.70	r=.57	r=.68	r=.60	r=.72	r=.59
AVP		r=.52		r=.64		r=.58		r=.64
TAE		r=.66		r=.65		r=.66		r=.70
END		r=.68		r=.50		r=.56		r=.34

PT/BW = PEAK TORQUE TO BODYWEIGHT RATIO
AVP = AVERAGE POWER
TAE = TORQUE ACCELERATION ENERGY
END = ENDURANCE RATIO

300 degrees/second.

A significant difference ($p<.05$) in PT/BW was found in both limbs for the two exercise speeds. The preferred limb at 60 degrees/second ($\bar{x}=.4554$) was significantly greater than the preferred limb at 300 degrees/second ($\bar{x}= .3078$). A signficant difference was also observed in the non-preferred limb between exercise speeds of 60 degrees ($\bar{x}=.4090$) and 300 degrees/second ($\bar{x}=.2836$).

Limb Preference

A one-way repeated measures ANOVA was used to determine the effect of limb preference on PT/BW ratio at both exercise speeds during internal rotation. At 60 degrees/second, a significant difference ($p<.05$) between the performances of the preferred ($\bar{x}=.4554$) and non-preferred ($\bar{x}=.4090$) limbs were recorded for PT/BW ratio. At 300 degrees/second, a significant ($p<.05$) difference between the performances of the preferred ($\bar{x}=.3078$) and non-preferred ($\bar{x}=.2836$) limbs was also found.

The relationship between limb preference and the isokinetic measures of average power(AVP) and torque acceleration energy (TAE) was determined by a repeated measures analysis of variance. Significant ($p<.05$) differences in AVP between the preferred ($\bar{x}=123.51$ watts) and non-preferred limbs ($\bar{x}=114.98$ watts) were found. TAE was also significantly different for both the preferred ($\bar{x}=13.50$ watts/sec.) and non-preferred ($\bar{x}=12.27$ watts/sec.) limbs.

The relationship between limb preference and endurance ratio (END) was determined by a repeated measures analysis of variance. Unlike the isokinetic measures of PT/BW, AVP, and TAE, endurance was not a function of limb preference. There was no significant difference between the preferred ($\bar{x}=.6599$) and non-preferred ($\bar{x}=.6810$) limbs at the exercise speed of 300 degrees/second.

External Rotation

Exercise Speed

A one-way repeated measures ANOVA was used to determine the effects of exercise speed on PT/BW ratio of subjects as they performed external rotation of the shoulder at 60 and 300 degrees/second. The PT/BW ratio of the preferred limb ($\bar{x}$=.3094) at 60 degrees/second was significantly ($p<.05$) higher than the preferred limb ($\bar{x}$=.2129) at 300 degrees/second. A significant ($p<.05$) difference was also recorded when testing the non-preferred limb. At 60 degrees/second, PT/BW performance ($\bar{x}$=.2986) was significantly higher than that produced at 300 degrees/second ($\bar{x}$=.2036).

Limb Preference

A one-way repeated measures ANOVA was used to determine the effect of limb preference on PT/BW ratio at both exercise speeds during external rotation.

At 60 degrees/second, a significant ($p<.05$) difference between the performance of the preferred ($\bar{x}$=.3104) and non-preferred limb ($\bar{x}$=.2982) was found. There was no significant difference found for the preferred ($\bar{x}$=.2129) and non-preferred limb ($\bar{x}$=.2036) at 300 degrees/second.

The relationship between limb preference and the isokinetic measures of AVP and TAE were determined by a repeated measures analysis of variance. Significant differences were found for AVP. The AVP generated by the preferred limb ($\bar{x}$=77.93 watts) was significantly ($p<.05$) higher than that of the non-preferred limb ($\bar{x}$=71.89 watts). There was no significant difference between the preferred ($\bar{x}$=10.09 watts/sec.) and non-preferred limb ($\bar{x}$=9.78 watts/sec.) for TAE at the exercise speed of 300 degrees/second.

No significant difference in limb preference was found in the endurance ratio of the preferred limb ($\bar{x}$=.5524) and non-preferred ($\bar{x}$=.5562) limb.

Discussion

In comparing exercise velocity, higher reliability estimates were noted for the slower limb speed of 60 degrees/second for PT/BW ratio for both the preferred (r=.70) and non-preferred (r=.70) limbs. At 300 degrees/second, both the preferred (r=.59) and non-preferred (r=.57) limbs produced lower reliability estimates. These results appear consistent with the research reported by Burdett & Van Swearingen (1987).

These results can be explained by closely examining the experimental testing protocol. Each subject was evaluated at 60 degrees/second using a five repetition test. The 300 degrees/second test was evaluated by a forty repetition test. Research has demonstrated that a higher probability of clinically reliable (i.e. r>.80) estimates are expected when the test protocol consists of a small number of repetitions (Burdett & Van Swearingen, 1987).

In comparing the reliability estimates of measures associated with limb preference, three of the four measures produced higher reliability estimates for the preferred limb. This finding may be explained in part, by the fact that the preferred limb was more frequently neuromuscularly innervated and therefore developed a higher trained neuromuscular pathway from which to produce greater reproducibility of the experimental task.

Highest reliability estimates were found for the strength measure of PT/BW ratio (r=.57-.72). The lowest reliability estimates were found for the endurance ratio (r=.34-.50). These findings appear consistent with the research published by Montgomery & Douglas (1989) and Burdett & Van Swearingen (1987).

Without a standardized operational definition and test protocol for isokinetic measures, inconsistent and less than desirable reliability estimates will appear in the literature. For example, numerous operational definitions have been used for endurance ratio. For this specific study, 40 repetitions were selected to induce local muscular fatigue. Other researchers (Davies, 1983) have suggested 25 as an appropriate number of repetitions to produce muscular fatigue. Without consistent testing protocol, published reliability estimates will remain inconsistent.

Exercise Speed

The mean torque/body weight ratios at 60 degrees/sec were significantly higher than those achieved at 300 degrees/sec for both the preferred and non-preferred limb during both internal and external rotation of the shoulder. The effect of exercise speed on peak torque was also reported by Ivey (1984), and Connelly-Maddux, Kibler, & Uhl (1989).

DeVries, (1980) suggest that the limb's ability to produce torque is directly related to muscle's contractile efficiency. The efficiency of the contractile properties can be examined through means of the actin-myosin sliding filament theory at the microscopic level. As the velocity at which the muscle shortens increases, torque production decreases.

With initial muscular contraction, the cross bridges of the actin-myosin filaments within the muscle sarcomere are too far apart from each other to generate maximal muscular tension. As the angle at which maximal torque can be produced approaches, muscular tension increases, but because of the velocity at which limb is performing, this optimal angle is passed by too quickly to maintain a high level of tension and in turn fails to achieve a high level of torque production. To compound this biomechanical disadvantage, as the muscle continues toward the final stage of contraction the aforementioned cross bridges of the actin-myosin filament are too close to form an effective connection. Finally, the ability of the central nervous system to transmit neuromuscular messages in order to achieve maximal fiber recruitment was not as effective at the higher limb speed. Thus as a higher limb velocity was achieved, less torque was generated , and in turn, less resistance was placed upon the limb.

Limb Preference

A significant difference was found between the preferred and non-preferred limbs across the measure of PT/BW ratio at 60 and 300 degrees for both internal/external rotation. At 300 degrees/second, AVP was also significantly different between preferred and non-preferred limbs for both internal and external rotation. In addition, TAE during internal rotation was found to be significantly different.

Stone & O'Bryant (1983) suggest that at least three major factors of training could be responsible for the reported differences between the preferred and non-preferred limbs. These factors are total workload, movement specificity and neuromuscular facilitation.

Total work is based upon the duration and frequency of a particular exercise. Because a preferred limb has a higher degree of frequency of skill performance, it normally produces a higher level of volume of the total work. This effect is paramount in meeting one of the basic requirements of strength and power performance. The muscle group becomes stronger and more powerful than the non-preferred limb because it may be systematically overloaded.

Perhaps a more crucial factor in the effect of limb preference would be movement specificity of the exercise movement. The preferred limb has the advantage over the non-preferred limb. The preferred limb displays higher levels of strength and power because it has performed the specifically desired movement (i.e. internal and external rotation of the shoulder) more frequently. Because the preferred limb executed the movement more frequently, the specific muscle group (i.e. rotator cuff) of the preferred limb had been progressively overloaded beyond the point achieved by the non-preferred limb those muscles that were overloaded in turn responded to the increased workload by improving their ability to produce force (i.e. strength).

A greater level of neuromuscular facilitation could also be a factor in explaining the preferred limb's advantage in strength and power. As exercise frequency is increased, the neuromuscular pathway of the preferred limb becomes more efficient and in turn becomes a significant mechanism of strength and power production.

This efficiency can be traced to the improvement of several neuromuscular factors. First, a greater number of motor units are innervated by the preferred limb, and the frequency at which they fire is also increased. In addition to their higher frequency, the motor units' synchronicity is also improved, as well as their coordination between individual motor units and the entire muscular contraction. With neuromuscular training, the degree of neuromuscular inhibition is reduced. In each instance, the preferred limb has an advantage over the non-preferred limb.

In analyzing endurance ratio, there was no significant difference between the preferred and non-preferred limbs. While Ivey, Calhoun, Rusche, & Bierschenk (1984) and Connelly- Maddux, Kibler, & Uhl (1989) had reported that preferred limb was stronger and more powerful, neither reported conclusive results with respect to muscular endurance. An inconclusive result was reported for the specific study found herein as well. These indefinite results as supported by a reliability estimate range of r=.50-.34 may in part be explained by the operational definition of the endurance ratio. In addition, the absence of a training effect normally associated with a muscular endurance may be a factor. Endurance ratio for the specific study found herein was defined as the percent change between the initial eight repetitions and the final eight repetitions of a forty repetition exercise bout. By this operational definition, the greater the difference between initial and final production, the lower the endurance ratio.

By definition, endurance ratio is a function of relative endurance performance, not absolute performance. DeVries (1980) has suggested that the relationship between muscular strength and endurance is dependent upon the type of evaluation used. When the same workload is used for all subjects, as seen with absolute endurance evaluation, a clear relationship exists (r=.75-.97) between the initial strength level and the muscular endurance achieved. But, when the performance is evaluated by means of comparing a relative percentage of initial repetitions with a comparable number of final repetitions from the same exercise bout, as was done with this particular study, DeVries (1980) suggests that the relationship between strength level and muscular endurance is approximately zero, and Heyward (1975) even suggests the possibility of a negative relationship. This result was reflected in the close proximity of the endurance ratios for both the preferred and non-preferred limbs during internal and external rotation for this specific study.

This negligible effect of relative endurance with respect to limb preference may be explained in part by the following: theoretically, when evaluating relative muscular endurance by means of comparing the peak torque generated by the initial repetitions to that of the peak torque generated by the final repetitions, it is clear that muscular endurance will not be a product of a limb's level of strength because each endurance ratio which is reported will be relative to the same limb. Thus a preferred limb will show no more fatigue than that of the non-preferred limb because the basis of comparison, i.e. the initial repetitions to that of the final repetitions will always be compared using the same limb. The initial repetitions of the preferred limb will always be compared to the final repetitions of the preferred limb. thus, while limb preference may have a significant effect on absolute endurance, as it did with the strength and power parameters, it had no apparent effect upon relative endurance as seen with the isokinetic parameter of endurance ratio.

In addition, because the subjects had no prior training in the general area of isokinetics, and specifically with the exercise of internal and external rotation of the shoulder at 90 degrees abduction, they were not exposed to various benefits which accompany a training regime; i.e. increased motor unit activity, improved motor unit sychronicity, and a decreased degree of neuromuscular inhibition. Thus, the preferred limb could not show itself to be significantly different from the non-preferred limb with respect to muscular endurance (Stone & O'Bryant 1983).

SUMMARY

This study demonstrated that exercise speed and limb preference influence certain isokinetic variables measured when performing internal and external rotation of the shoulder. Peak torque/body weight ratio was significantly influenced by exercise speed for both the preferred and non-preferred limbs in both internal and external rotation. Average power was significantly effected by limb preference in both internal and external rotation.

Torque acceleration energy was significantly influenced by limb preference in only internal rotation. During external rotation, torque acceleration energy was not significantly effected by limb preference.

Endurance ratio was not significantly influenced by limb preference in either internal or external rotation. Average power, torque acceleration energy and endurance ratio are considered power measures and were therefore only measured at 300 degrees per second.

Table 2. provides the means and standard deviations of these isokinetic measures considering the potential influence of exercise speed and limb preference. These data provide the clinician with a normative profile that could be used to reference the

Table 2

Means and Standard Deviations for Internal and External Rotation of the Shoulder

	60 deg/sec.				300 deg/sec.			
	Internal Rotation		External Rotation		Internal Rotation		External Rotation	
	Pref.	Non-Pref.	Pref.	Non-Pref.	Pref.	Non-Pref.	Pref.	Non-Pref.
PT/BW								
Mean	.4554	.4090	.3104	.2982	.3078	.2836	.2129	.2036
S.D.	.1221	.1075	.0869	.0760	.0770	.0729	.0663	.0570
AVP								
Mean					123.51	114.98	77.93	71.89
S.D.					36.58	33.90	25.75	23.10
TAE								
Mean					13.50	12.27	10.09	9.78
S.D.					3.32	3.06	2.80	2.53
END								
Mean					.6599	.6810	.5524	.5562
S.D.					.2104	.1566	.1255	.1137

Legend:

PT/BW - PEAK TORQUE/BODY WEIGHT RATIO   S.D. - STANDARD DEVIATION
AVP - AVERAGE POWER
TAE - TORQUE ACCELERATION ENERGY
END - ENDURANCE RATIO

degree of limb impairment or rehabilitation progress of the shoulder during internal and external rotation.

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CHAPTER IV

SUMMARY

This study examined the effects of limb velocity and limb preference on the isokinetic measures of muscular strength, power, and endurance. Forty-five male subjects between the ages of 18 and 30 years voluntarily participated in this study.

This testing session required each subject to perform a standardized isokinetic shoulder internal/external rotation in 90 degrees abduction test on the Cybex dynomometer as stated in the Isolated Joint Testing and Exercise Manual (1983) on both limbs.

The test protocol consisted of 5 maximal repetitions at a velocity of 60 degrees per second. Upon the completion of a 60 second rest period, the subject then proceded to execute 40 maximal repetitions at a limb velocity of 300 degrees per second. Upon completion of a two minute rest period, each subject then repeated the same series of exercise repetitions with the other limb. Each subject was retested within 30 days using the same testing procedures.

The isokinetic measures measured in this investigation were peak torque to bodyweight ratio (PT/BW), average power (AVP), torque acceleration energy (TAE), and endurance ratio (END).

Research Implications

The results of this study revealed that all reliability estimates fell within the moderate level(r=.50 to .72) for all measures with the notable exception of endurance ratio of the non-preferred limb during external rotation. Higher r values were consistently observed at the lower limb velocity for both the preferred and non-preferred limbs. This result appears consistent with published data. A review of literature revealed that numerous studies have examined the test/retest reliability of isokinetic parameters for the lower extremity. Perrin (1986) investigated the reliability of peak torque, torque acceleration energy, average power, endurance ratio, and total work measures were examined using the test/retest protocol. The results of the Perrin (1986) study closely paralleled the findings of this particular study in that higher test/retest correlation coefficients were observed for peak torque, torque acceleration energy, and average power, while the lowest estimates were observed for endurance ratio. Similar results were reported by Burdett & Van Swearingan (1987). Higher estimates were observed for the strength and power parameters during lower extremity testing.ty testing. Burdett & Van Swearingan (1987) observed a generally higher level of reliability at the slower exercise velocities. These results were confirmed by Montgomery & Douglass, (1989). Prior research (Ivey, 1984, Conne-Maddux, Kibler, & Uhl, 1989) had established an inverse relationship between limb velocity and peak torque. As the limb velocity was increased, torque decreased. Thus, at the lower exercise velocity, a higher level of torque production paralleled a higher test/retest reliability.

The lowest reliability estimates were those generated by endurance ratio. The reliability estimate endurance ratio was r=.34. It is possible that two factors contributed to this low reliability estimate. First, this low correlation coefficient was produced by the non-preferred limb, and secondly, it was produced while doing an infrequent movement(i.e. external rotation). While internal rotation is a movement executed with a great deal of regularity (overhand throwing motion, serving motion in racquet sports, etc.,), external rotation of the shoulder(swimming backstroke, backhand volley in racquet sports) is not executed as often. As would be the case with most any physical skill, the greater the frequency of execution, the greater the proficiency of the performance, and in turn a greater probability of achieving statistical reproducibility.

A repeated measures ANOVA was utilized to determine if any statistically significant differences existed between subject performance of test one and two. It was determined that no significant difference existed; therefore, the two data sets were merged into one data set for all subsequent statistical analysis.

Exercise Velocity

A repeated measures ANOVA was used to determine if the peak torque/body weight ratio (PT/BW) which was generated at a limb velocity of 60 degrees per second would be significantly different from that measure at 300 degrees per second for both internal and external rotation of the shoulder. In each instance, the mean scores recorded at 60 degrees/second exceeded those values recorded at 300 degrees/second for both preferred and non-preferred limbs for during internal and external rotation. Analysis of variance for limb velocity demonstrated a significant difference between the peak torque/body weight ratio produced at 60 degrees per second and 300 degrees per second. This difference was observed for both internal (F=62.86) and external (F=53.22) rotation. Thus, limb velocity produced create a significant effect upon the peak torque generated during internal and external rotation of both the preferred and non-preferred limb. As the limb velocity increased, the torque production decreased (Ivey, 1984, Connelly-Maddux, Kibler, & Uhl, 1989).

DeVries (1980) suggests that a possible explananation for this force velocity relationship is related to the muscle's contractile efficiency. The efficiency of the contractile properties can be evaluated at the microscopic level. The actin-myosin sliding filament theory is clearly demonstrated by electromicrography. As the velocity of the limb increases the velocity at which the muscle shortens increases. This phenomenon is a detrement to torque production both biomechanically and neuromuscularly.

With initial muscular contraction, the cross bridges of the actin-myosin filaments within the muscle tissues' sarcomere, are too far apart from each other to generate maximal muscular tension. As the optimal torque production angle is approached, muscular tension increases, but because of the velocity at which limb is performing, this optimal angle is passed by too quickly to maintain a high level of tension and in turn fails to achieve a high level of torque production. To compound this biomechanical disadvantage, as the muscle continues toward the final stage of contraction the aforementioned cross bridges of the actin-myosin filament are too close to form an effective connection. Finally, the ability of the Central Nervous System to transmit neuromuscular messages in order to achieve maximal fiber recruitment was not as effective at the higher limb velocity. Thus as a higher limb velocity was achieved, less resistance was placed upon the limb, and in turn less force was needed to maintain that predescribed limb velocity.

Limb Preference

A significant difference was found between the preferred and non-preferred limbs in the variable of PT/BW ratio at 60 and 300 degrees for both internal/external rotation. At 300 degrees/second, AVP was also a function of limb preference for both internal and external rotation. In addition, TAE during internal rotation was found to be significantly different between the preferred and non-preferred limbs.

Stone & O'Bryant (1983) suggest that at least three major factors of training could be responsible for the reported differences between the preferred and non-preferred limbs; those being total workload, movement specificity and greater neuromuscular facilitation.

Total work is based upon the duration and frequency of a particular exercise. Because a preferred limb has a higher degree of frequency of skill performance, it normally produces a higher level of volume of the total work. This effect is paramount in meeting one of the basic requirements of strength and power performance. The muscle group becomes stronger and more powerful than the non-preferred limb because it may be systematically overloaded.

Perhaps a more crucial underlying factor in the effect of limb preference with respect to the total volume of work would be movement specificity of the exercise movement. The preferred limb has the advantage over the non-preferred limb. The preferred limb usually displays higher levels of strength and power because it has performed the specifically desired movement (i.e. internal and external rotation of the shoulder) more frequently. Because the preferred limb executed the specific movement more frequently, the specific muscle group (i.e. rotator cuff) of the preferred limb had been progressively overloaded beyond the point achieved by the non-preferred limb those muscles that were overloaded in turn responded to the increased workload by improving their ability to produce force (i.e. strength).

A greater level of neuromuscular facility could also be a key factor in explaining the preferred limbs' advantage in strength and power. As exercise frequency is increased, the neuromuscular pathway of the preferred limb becomes more efficient and in turn becomes a significant mechanism of strength and power production.

This efficiency can be traced to the improvement of several neuromuscular factors. First, a greater number of motor units are innervated by the preferred limb, and the frequency at which they fire is also increased. In addition to their higher frequency, the motor units' synchronicity is also improved, as well as their coordination between individual motor units and the entire muscular contraction. With improved neuromuscular training, the degree of neuromuscular inhibition is reduced. In each instance, the preferred limb has an advantage over the non-preferred limb with respect to isokinetic strength and power.

While both Ivey, Calhoun, Rusche, & Bierschenk (1984) and Connelly-Maddux, Kibler, & Uhl (1989) reported there to be a difference in isokinetic strength and power parameters, neither reported a significant difference in performance of the preferred limb over that of the non-preferred.

In analyzing endurance ratio, there was no significant difference between the preferred and non-preferred limbs. While Ivey, Calhoun, Rusche, & Bierschenk (1984) and Connelly- Maddux, Kibler, & Uhl (1989) had reported that preferred limb was stronger and more powerful, neither reported conclusive results with respect to muscular endurance.

Endurance ratio for this specific study was defined as the percent change between the initial eight repetitions and the final eight repetitions of a forty repetition exercise bout. By this operational definition, the greater the difference between initial and final production, the lower the endurance ratio.

By definition, endurance ratio is a function of relative endurance performance, not absolute performance. DeVries (1980) has suggested that the relationship between muscular strength and endurance is dependent upon the type of evaluation used. When the same workload is used for all subjects, as seen with absolute endurance evaluation, a clear relationship exists (r=.75-.97) between the initial strength level and the muscular endurance achieved, but when the performance is evaluated by means of comparing a relative percentage of initial repetitions with a comparable number of final repetitions from the same exercise bout, as was done with this particular study, the relationship between strength level and muscular endurance is practically nonexistant. Heyward (1975) even suggests the possibility of a negative relationship. This result was reflected in the close proximity of the endurance ratios for both the preferred and non-preferred limbs during internal and external rotation for this specific study.

The relationship between relative endurance and limb preference may be explained in part by the following: Theoretically, when evaluating relative muscular endurance by means of comparing the peak torque generated by the initial repetitions to that of the peak torque generated by the final repetitions, it is clear that muscular endurance will not be a product of a limb's level of strength because each endurance ratio percentage which is reported will be relative to the same limb. Thus a preferred limb will show no more fatigue than that of the non-preferred limb because the basis of comparison, i.e. the initial repetitions to that of the final repetitions will always be compared using the same limb. The initial repetitions of the preferred limb will always be compared to the final repetitions of the preferred limb. thus, while limb preference may have a significant effect on strength and power, it had no apparent effect upon relative endurance as seen with the isokinetic parameter of endurance ratio.

The results of this investigation do not confirm the results reported by Connelly-Maddux, Kibler, & Uhl (1989) with respect to the effect of limb preference. While strength and power parameters were a function of limb preference in this study, they were found not significantly related as reported by Connelly-Maddux, Kibler, & Uhl (1989), but interestingly, while this study revealed no significant difference with respect to the endurance ratio, the Connelly-Maddux, Kibler, & Uhl (1989) study did suggest that there existed a significant difference with respect to limb preference. But, regardless of these findings, the statistical evidence of this particular study would indicate that indeed both limb velocity and preference had significant effect upon isokinetic strength and power.

Recommendations for Future Research

The following recommendations are made for future research in this area:

1. A similar study is recommended using both male and female subjects. This would allow the researcher to determine the effects of gender upon isokinetic strength, power, and endurance parameters as recorded by Connelly-Maddux, Kibler, & Uhl (1989).
2. It is recommended that a similar study be conducted to investigate the effects of body composition on internal and external rotation of the shoulder.

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APPENDIX A

METHODOLOGY

METHODOLOGY

SELECTION OF SUBJECTS

Forty-five males between the ages of 18 and 30 years volunteered to serve as subjects in this study. Participants were recruited from physical education classes at Virginia Polytechnic Institute and State University. Criteria of selection for this study included the following stipulations: Each subject had no prior history of any wrist, elbow, or shoulder injury or cardiac disfunction. In addition, no subject had prior training on isokinetic exercise equipment. Upon meeting these criteria, each subject was given the opportunity to confirm their participation in the study by signing a written consent form. (Appendix B.)

EXPERIMENTAL PROCEDURES

Each subject was scheduled for two experimental sessions in the Muscular Function Laboratory. The initial session served a dual purpose. It provided an individualized subject orientation to the Cybex equipment, and was used to test the internal and external rotation of the shoulder at 90 degrees abduction as outlined in the Isolated Joint Testing and Exercise manual (Cybex II, Bayshore, N.Y.). The orientation session began with each subject being individually positioned on the Cybex and stabilized according to standard Cybex testing protocol. (Appendix C.) The subject was then allowed to perform a standard warm up set of 5 repetitions to familiarize himself with the Cybex equipment. The position of the Upper Body Exercise and Testing Table (UBXT), the offset input adapter with shoulder testing accessory, the horizontal handgrip, shoulder rotation support, the height and horizontal position of the dynomometer for each limb, and the limb preference for each subject was recorded during the orientation session, and remained constant for each subject during the test and retest. (Appendix D.) Limb preference was determined by asking the subject to select the limb they would use if throwing an object for distance, throwing an object for accuracy, and writing their name. The preferred limb was considered to be the one which was chosen in at least two of the three instances. The order of limb testing was randomized.

The Cybex and Data Reduction Computer (CDRC) system was calibrated and placed on line prior to experimental testing. This testing session required each subject to perform a standardized isokinetic shoulder internal/external rotation in 90 degree abduction test on the Cybex dynomometer as stated in the Isolated Joint Testing and Exercise Manual (1983.) on both limbs. A standardized warm up protocol (Appendix C.) was performed by each subject prior to the testing of each limb. The previously recorded orientation values were used to establish test reproducibility during the experimental testing sessions. The subject, with the UBXT placed at its highest position, was placed upon his back. Belts were fastened around the subject's chest and hips to prevent muscle substitution. The limb involved in the test was secured to the offset input adapter by way of the Cybex shoulder rotation support at the elbow. The wrist remained in a fixed position while the subject maintained a grasp on the horizontal handgrip. The opposite hand gripped the stabilization handle. Standardized instructions for testing were administered to all subjects. (Appendix C.) The test protocol consisted of 5 maximal repetitions at a speed of 60 degrees per second. Upon completion of a 60 second rest period, the subject then proceded to execute 40 maximal repetitions at a limb speed of 300 degrees per second. In addition, the muscular parameters of average power (AVP), torque acceleration energy(TAE), and endurance ratio (END) were calculated at a limb speed of 300 degrees per second. Upon completion of a two minute rest period, each subject repeated the same series of exercise repetitions with the other limb. Each subject then returned within 30 days to perform a retest using the same procedures.

STATISTICAL ANALYSIS

RELIABILITY

Initial statistical strategy focused upon test/retest reliability for the four isokinetic measures of peak torque/body weight ratio, average power, torque acceleration energy, and endurance ratio. The reliability coefficient of all four measures were established using Pearson Product Moment Correlation. The alpha level was set at .05. In addition, a series of repeated measures two way analysis of variance statistical procedures (Anova) were used to determine the effect of limb speed and limb preference.

Peak torque/body weight ratios were analyzed at limb speeds of 60 and 300 degrees per second for the preferred and non-preferred limbs. The reliability estimates for PT/BW were well within the moderate range (r = .57-.70) on both the preferred and non-preferred limbs.

The power parameters of AVP and TAE, recorded at the limb speed of 300 degrees per second, followed a similar pattern of r values (r = .52-.66) to that of the peak torque values. The endurance ratio of the preferred limb produced a value of r= .68 while the non-preferred had a value of r= .50 at a limb speed of 300 degrees per second.

External rotation was performed across limb speeds of both 60 and 300 degrees per second for both the preferred and non-preferred limb. Again, moderate values (r = .59-.72) were observed for peak torque to body weight ratio.

The range of r values (r = .58-.70) for average power and torque acceleration energy for external rotation were consistent with results recorded during internal rotation.

The endurance ratio during external rotation, for the preferred limb was r=.56. The value of the non-preferred limb was r=.34.

TEST/RETEST ANOVA

A repeated measures ANOVA was conducted in order to determine if any statistically significant differences existed between the subjects' performance across testing sessions. Table 3 (Appendix E.) reveals that there existed no statistically significant difference between the performance of the subjects on day 1 and day 2 therefore, the two data sets were combined into one data set for all subsequent statistical analysis.

EXERCISE SPEED

Table 4 (Appendix E.) presents the results of a one-way repeated measures anova which reported that exercise speed had a significant effect on peak torque/body weight ratio of subjects as they performed isokinetic internal/external rotation of the shoulder joint at exercise speeds of 60 and 300 degrees per second. The exceptionally high F values for both internal (F=62.86) and external (F=53.22) rotation indicated that peak torque/ body weight ratio was a function of exercise speed.

The significant level of the respective F values was reflected in the descriptive statistics, more specifically in the mean scores.

In each instance, the mean scores were visably different, with the peak torque/body weight ratios at 60 degrees exceeding the mean at 300 degrees for both preferred and non-preferred limbs for both internal and external rotation.

Table 6 (Appendix F) clearly showed the consistent relationship which these scores reflected. There existed an inverse relationship between the torque produced and the limb speed at which the limb was allowed to exercise. As the limb speed increased, the torque production decreased (Wyatt & Edwards, 1983).

Limb Preference

This study's other major hypothesis focused upon the effect of limb preference on isokinetic performance. In addition to the strength parameter of peak torque, the question of limb preference and its effect focused upon the power parameters of average power and torque acceleration energy as well as endurance ratio. Limb preference had no clear indication as to its effect upon the isokinetic parameters in question. A repeated measures analysis of variance was used to determine that a significant statistical difference existed between the performances of the preferred and non-preferred limb for the strength and power parameters at an alpha level of .05.

As clearly seen in Table 5 (Appendix E), during internal rotation as 60 degrees, the statistically significant difference in performance of the preferred versus the non-preferred limb was reinforced by an F value of 29.67. At 300 degrees, the F ratio remained significant with a value of 22.47. Although not as high as internal rotation, the respective F values for external rotation were still statistically significant for both 60 (F=4.76) and 300 (F= 3.78) degrees. In each instance of the isokinetic movement, the preferred limb had higher values and the difference in performance of the limbs was deemed statistically significant.

The parameters of power which were addressed held a similar pattern of results. Power measures were taken at a limb speed of 300 degrees per second. As was seen with the peak torque ANOVA, there were statistically significant F values for both internal (F=12.46 AVP, F=40.29 TAE) and external (F=8.30 AVP, F=3.61 TAE) rotation. Although all F values indicated significant differences between the performance of the preferred and non-preferred limb, the most obvious advantage was found during internal rotation. There existed a great enough difference between the power achieved by the preferred and non-preferred limbs to draw the logical conclusion that the preferred limb was more powerful, i.e. 123.51 watts for the preferred limb versus 114.98 watts for the non-preferred. (Appendix E)

The endurance ratio was also evaluated by means of a repeated measures two way analysis of variance, but unlike the aforementioned strength, and power parameters, the F values revealed no statistically significant difference between preferred and non-preferred limbs for both internal (F=.52) and external (F=.02) rotation.

All statistical analysis followed an expected pattern with respect to limb speed and preference with the notable exception of endurance ratio. In each instance, the preferred limbs' mean performance was significantly different from the non-preferred for both isokinetic strength and power. Thus, from the results of this particular study, the evidence would indicate that indeed both limb speed and preference had significant effect upon the muscular function of each isokinetic performance with respect to muscular strength and power.

APPENDIX B

INFORMED CONSENT

LABORATORY FOR EXERCISE, SPORTS, AND WORK PHYSIOLOGY

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.

Title of Study: Isokinetic Strength and Power Measures of the Shoulder during Internal/External Rotation

The purposes of this study include: To evaluate the effects of Limb Speed(60 and 300 degrees/sec.) and Limb Preference on Isokinetic Strength and Power measures of the shoulder during internal/external rotation. In addition, a normalized data set will be created based upon the experimental 45 sample. I voluntarily agree to participate in this testing program. It is my understanding that my participation will include: Two isokinetic testing sessions. The first session will consist of two phases: First, I will be introduced to an isokinetic testing protocol for upper body function. Upon completion of this orientation period, the upper body test of internal and external rotation of the shoulder as outlined in the isolated Joint Testing and Exercise handbook as constructed by Cybex Inc. The second session will serve as a retest period for the purpose for statistical reliability.

I understand that participation in this study may produce certain discomforts and risks. These discomforts and risks include: Upper extremity muscle strain and/or delayed muscle soreness. These risks will be minimized by a screening session during the orientation period, as well as a flexibility and a sub-maximal isokinetic warm up prior to the beginning of the testing session.

Certain personal benefits may be expected from participation in this study. These include: Knowledge of isokinetic measures such as peak torque, peak torque/body weight ratio, torque acceleration energy, average power, and endurance ratio in the form of a bilateral comparison between preferred and non-preferred limb.

I understand that any data of a personal nature will be held confidential and will be used for research purposes only. I also understand that these data may only be used when not identifiable with me.

I understand that I may abstain from participation in any part of the study or withdraw from the study 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 problem that might arise in the course of this study 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 read the above statements and have had the opportunity to ask questions. I understand that the researchers will, at any time, answer my inquiries concerning the procedures used in this study.

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

If you would like to receive the results of this investigation, please indicate this choice by marking in the appropriate space provided below. A copy will then be distributed to you as soon as the results are made available by the investigator. Thank you for making this important contribution.

_____ I request a copy of the results of this study.

Date__________ Time___________a.m./p.m.

Participant Signature_________________________________

Witness_________________________________

HPL Personnel Project Director________________
Telephone_______________

HPER Human Subjects Chairman Dr. Charles Baffi

Telephone 961-6561.

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

APPENDIX C

ORIENTATION PROCEDURES

STANDARDIZED WARM-UP PROTOCOL

CYBEX TEST PROTOCOL

CYBEX TEST PROTOCOL

1. Position and secure subject.
2. Set up procedures for the dual channel recorder and Cybex computer.
3. When computer display reads Trial Repetitions at 60 or 300, administer the following warm-up.

WARM-UP

1. 5 submaximal trials at 180 degrees/second.
2. 2 maximal trials at 180 degrees/second.
3. 30 seconds rest.
4. 3 submaximal trials at 60 degrees/second.
5. Turn recorder on to 25 mm/sec.
6. 2 maximal trials at 60 degrees/second.
7. Observe torque curves. If consistent curves are present, go on to step 9.
8. If curves are not consistent, repeat steps 1-7.
9. Enter (return) on Cybex computer and begin test.

TEST PROTOCOL

1. Turn recorder speed on (25 mm/sec). Place limb speed at 60 degrees/second.
2. Tell subject to "give me 5 repetitions, each as hard and as fast as possible".
3. Make sure the subject is in the correct starting position (humerus in 90 degrees abduction and in full external rotation). Give the command "Ready...Begin".
4. When "End of Test" is displayed on the computer, tell subject to "relax".
5. 60 seconds rest.
6. Place limb speed at 300 degrees/second.
7. Tell subject to "give me 40 repetitions, each as hard and as fast as possible".
8. Make sure the subject is in the correct starting position (humerus in 90 degrees abduction and in full external rotation). Give the command "Ready...Begin".
9. When "End of Test" is displayed on the computer, tell subject to "relax". Turn dual channel recorder off. Check with the data acquisition technician if the data were recorded by the CDRC.

10. 120 seconds rest.
11. Follow the same procedures for testing the remaining limb.

APPENDIX D

BASIC DATA FORM/CYBEX SETUP POSITION

CYBEX SET UP FORM

SHOULDER: INTERNAL/EXTERNAL ROTATION(90 DEG. ABDUCTION)

NAME:____________________ BODY WEIGHT:__________

A. U.B.X.T. BACKREST FLAT. _____

B. U.B.X.T. SEAT TO HIGHEST POSITION. _____

C. HEIGHT OF DYNOMOMETER. _____

D. FOOTREST ADJUSTED TO PATIENT COMFORT. _____

E. UNIVERSAL ADAPTER(J) W/ LONG STABILIZATION. _____

F. PELVIC AND STABILIZATION STRAPS. _____

G. START TEST IN MAXIMAL EXTERNAL ROTATION. _____

H. OFFSET INPUT ADAPTER(K) WITH SHOULDER TESTING ACCESSORY(C) (HOLE #_____). _____

I. HORIZONTAL HANDGRIP(Q)(DISTAL PLACEMENT LENGTH _____)._____

J. SHOULDER ROTATION SUPPORT(F) (DISTAL PLACEMENT LENGTH_____). _____

K. RANGE LIMITER SETTINGS: EXTERNAL ROTATION_______

APPENDIX E

ANALYSIS OF VARIANCE

Table 3

TEST/RETEST REPEATED MEASURES ANALYSIS OF VARIANCE FOR TEST 1 AND TEST 2.

MOVEMENT	INTERNAL		EXTERNAL	
Speed	60	300	60	300
Variable	F Values		F Values	
Peak Torque	.36	.75	.09	1.29
Average Power		.83		1.22
Torque Acceleration Energy		.98		.05
Endurance Ratio		.27		.00

Table 4

ANALYSIS OF VARIANCE FOR LIMB SPEED

MOVEMENT	INTERNAL	EXTERNAL
	F VALUE	F VALUE
VARIABLE		
PEAK TORQUE	62.86*	53.22*

* SIGNIFICANT AT .01

Table 5

Analysis of Variance for Limb Preference

MOVEMENT	INTERNAL		EXTERNAL	
EXERCISE SPEED	60	300	60	300
VARIABLE	F Value		F Value	
PT/BW	29.67*	22.47*	4.76*	3.78*
AVP		12.46*		8.30*
TAE		40.29*		3.61
END		.52		.02

* SIGNIFICANT AT .05

Legend:

PT/BW = PEAK TORQUE/BODY WEIGHT RATIO
AVP = AVERAGE POWER
TAE = TORQUE ACCELERATION ENERGY
END = ENDURANCE RATIO

APPENDIX F

DESCRIPTIVE STATISTICS

Table 7

Descriptive Statistics For Isokinetic Muscular Parameters

VARIABLE	LIMB PREF.	EXERCISE SPEED	MEAN	STANDARD DEVIATION	STANDARD ERROR
PT/BW	P(I)	60	45.54	12.21	1.83
PT/BW	P(I)	300	30.78	7.70	1.15
PT/BW	N(I)	60	40.90	10.75	1.61
PT/BW	N(I)	300	28.36	7.29	1.09
PT/BW	P(E)	60	30.94	8.69	1.30
PT/BW	P(E)	300	21.29	6.63	.99
PT/BW	N(E)	60	29.86	7.60	1.13
PT/BW	N(E)	300	20.36	5.70	.85
AVP	P(I)	300	123.51	36.58	5.48
AVP	N(I)	300	114.98	33.90	5.08
AVP	P(E)	300	77.93	25.75	3.86
AVP	N(E)	300	71.89	23.10	3.44
TAE	P(I)	300	13.50	3.32	.50
TAE	N(I)	300	12.27	3.06	.46
TAE	P(E)	300	10.09	2.80	.42
TAE	N(E)	300	9.78	2.53	.38
END	P(I)	300	65.99	21.04	2.61
END	N(I)	300	68.10	15.66	2.01
END	P(E)	300	55.24	12.55	1.93
END	N(E)	300	55.62	11.37	1.76

Legend:

PT/BW = PEAK TORQUE/BODY WEIGHT RATIO
AVP = AVERAGE POWER
TAE = TORQUE ACCELERATION ENERGY
END = ENDURANCE RATIO
P(I) = PREFERRED LIMB (INTERNAL ROTATION)
P(E) = PREFERRED LIMB (EXTERNAL ROTATION)
N(I) = NON-PREFERRED LIMB (INTERNAL ROTATION)
N(E) = NON-PREFERRED LIMB (EXTERNAL ROTATION)

APPENDIX G

RAW DATA

Raw Data- Peak Torque Internal Rotation

OBS	SUBJ	AGE	HT	WT	LBM	FAT	PREF	PT6RI1	PT6RI2	PT6LI1	PT6LI2
27	35	24	71	87.10	20.48	19.52	R	38	34	38	32
28	36	21	75	83.30	91.89	8.11	R	32	68	28	50
29	37	22	68	71.67	83.71	16.29	R	34	30	28	26
30	38	22	73	78.50	89.09	10.91	R	48	48	50	40
31	39	30	72	73.20	91.21	8.79	R	38	30	42	28
32	40	22	71	80.50	89.75	10.25	R	60	50	52	50
33	41	22	74	80.20	88.05	11.95	R	38	38	38	34
34	42	21	72	76.60	92.77	7.23	R	33	36	38	34
35	43	25	71	74.84	83.02	16.98	R	42	44	40	36
36	44	23	70	72.30	92.81	7.19	R	63	52	53	44
37	46	22	75	83.00	85.33	14.67	R	36	36	32	39
38	47	24	74	88.70	87.11	12.89	R	68	63	61	82
39	48	22	73	74.20	89.47	10.53	R	48	44	42	38
40	49	22	69	84.60	83.89	16.11	R	52	61	46	47
41	50	24	70	63.30	85.09	14.91	R	34	34	30	32
42	51	27	75	97.00	85.02	14.98	R	44	66	34	59
43	52	22	72	81.20	82.82	17.18	R	34	52	46	50
44	53	22	66	83.10	79.38	20.62	R	64	60	54	52
45	54	23	71	85.70	84.43	15.57	R	79	68	61	62

OBS	PT3RI1	PT3RI2	PT3LI1	PT3LI2	PTR6	PTL6	PTR3	PTL3	PT6	PT3
27	26	26	26	26	36.0	35.0	26.0	26.0	35.50	26.00
28	18	38	20	32	50.0	39.0	28.0	26.0	44.50	27.00
29	20	22	23	18	32.0	27.0	21.0	20.5	29.50	20.75
30	32	36	30	28	48.0	45.0	34.0	29.0	46.50	31.50
31	24	20	22	18	34.0	35.0	22.0	20.0	34.50	21.00
32	22	36	24	33	55.0	51.0	29.0	28.5	53.00	28.75
33	26	26	28	24	38.0	36.0	26.0	26.0	37.00	26.00
34	22	30	26	28	34.5	36.0	26.0	27.0	35.25	26.50
35	28	32	30	28	43.0	38.0	30.0	29.0	40.50	29.50
36	26	28	26	18	57.5	48.5	27.0	22.0	53.00	24.50
37	28	28	22	26	36.0	35.5	28.0	24.0	35.75	26.00
38	36	44	38	54	65.5	71.5	40.0	46.0	68.50	43.00
39	20	36	22	24	46.0	40.0	28.0	23.0	43.00	25.50
40	31	44	28	32	56.5	46.5	37.5	30.0	51.50	33.75
41	18	28	10	23	34.0	31.0	23.0	16.5	32.50	19.75
42	32	50	20	42	55.0	46.5	41.0	31.0	50.75	36.00
43	29	36	31	32	43.0	48.0	32.5	31.5	45.50	32.00
44	38	40	36	36	62.0	53.0	39.0	36.0	57.50	37.50
45	55	52	48	48	73.5	61.5	53.5	48.0	67.50	50.75

Raw Data- Peak Torque Internal Rotation

OBS	SUBJ	AGE	HT	WT	LBM	FAT	PREF	PT6RI1	PT6RI2	PT6LI1	PT6LI2
1	1	22	73	71.40	95.07	4.93	R	34	34	32	33
2	3	21	67	67.15	91.70	8.30	R	42	24	52	22
3	4	25	68	78.10	80.45	19.55	R	62	60	55	58
4	5	21	70	66.75	94.24	5.76	R	42	34	38	30
5	6	24	74	80.00	91.54	8.46	R	47	54	39	44
6	7	20	67	72.80	86.49	13.51	R	57	45	46	50
7	9	22	70	67.50	87.24	12.76	R	63	50	46	52
8	10	22	74	103.70	86.01	13.99	R	76	89	60	66
9	11	22	73	77.60	87.63	12.37	R	38	39	40	36
10	12	21	68	88.30	90.84	9.16	R	51	52	48	59
11	13	23	69	63.80	80.18	19.82	R	34	38	29	30
12	14	22	70	78.64	83.53	16.47	R	52	44	44	30
13	15	22	69	64.80	90.20	9.80	R	32	20	32	28
14	16	22	67	65.30	94.67	5.33	R	50	56	50	48
15	17	25	75	85.10	79.80	20.21	R	38	26	30	27
16	20	29	71	71.75	88.56	11.44	R	34	38	36	38
17	21	22	70	77.80	75.80	24.20	R	29	32	14	16
18	22	22	73	78.18	92.36	7.64	R	54	54	50	39
19	23	23	71	77.70	79.10	20.90	R	61	56	46	40
20	24	21	64	76.75	82.83	17.17	R	39	36	40	32
21	25	22	72	76.00	81.25	18.75	R	52	26	32	22
22	26	22	65	64.20	85.88	14.12	R	42	38	32	30
23	27	21	70	60.80	94.05	5.95	R	44	42	45	40
24	29	22	70	80.40	87.79	12.21	R	50	46	53	44
25	31	22	67	66.60	79.51	20.49	R	34	26	32	24
26	32	21	72	75.50	91.04	8.96	R	46	38	38	36

OBS	PT3RI1	PT3RI2	PT3LI1	PT3LI2	PTR6	PTL6	PTR3	PTL3	PT6	PT3
1	30	26	30	28	34.0	32.5	28.0	29.0	33.25	28.50
2	32	18	38	14	33.0	37.0	25.0	26.0	35.00	25.50
3	42	34	38	38	61.0	56.5	38.0	38.0	58.75	38.00
4	26	22	28	16	38.0	34.0	24.0	22.0	36.00	23.00
5	34	40	29	34	50.5	41.5	37.0	31.5	46.00	34.25
6	43	32	34	34	51.0	48.0	37.5	34.0	49.50	35.75
7	32	30	31	32	56.5	49.0	31.0	31.5	52.75	31.25
8	50	53	40	46	82.5	63.0	51.5	43.0	72.75	47.25
9	30	36	38	28	38.5	38.0	33.0	33.0	38.25	33.00
10	38	36	33	40	51.5	53.5	37.0	36.5	52.50	36.75
11	22	26	15	26	36.0	29.5	24.0	20.5	32.75	22.25
12	32	28	26	17	48.0	37.0	30.0	21.5	42.50	25.75
13	28	16	24	15	26.0	30.0	22.0	19.5	28.00	20.75
14	36	33	32	34	53.0	49.0	34.5	33.0	51.00	33.75
15	26	18	24	21	32.0	28.5	22.0	22.5	30.25	22.25
16	30	30	26	32	36.0	37.0	30.0	29.0	36.50	29.50
17	21	24	18	18	30.5	15.0	22.5	18.0	22.75	20.25
18	36	38	34	32	54.0	44.5	37.0	33.0	49.25	35.00
19	46	38	36	33	58.5	43.0	42.0	34.5	50.75	38.25
20	28	24	26	23	37.5	36.0	26.0	24.5	36.75	25.25
21	34	20	26	18	39.0	27.0	27.0	22.0	33.00	24.50
22	26	25	20	18	40.0	31.0	25.5	19.0	35.50	22.25
23	30	30	28	32	43.0	42.5	30.0	30.0	42.75	30.00
24	32	30	36	34	48.0	48.5	31.0	35.0	48.25	33.00
25	12	18	20	16	30.0	28.0	15.0	18.0	29.00	16.50
26	34	32	33	30	42.0	37.0	33.0	31.5	39.50	32.25

Raw Data-Peak Torque External Rotation

OBS	SUBJ	AGE	HT	WT	LBM	FAT	PREF	PT6RE1	PT6RE2	PT6LE1	PT6LE2
1	1	22	73	71.40	95.07	4.93	R	26	28	28	23
2	3	21	67	67.15	91.70	8.30	R	24	42	28	38
3	4	25	68	78.10	80.45	19.55	R	33	34	34	38
4	5	21	70	66.75	94.24	5.76	R	26	24	28	22
5	6	24	74	80.00	91.54	8.46	R	34	36	30	33
6	7	20	67	72.80	86.49	13.51	R	24	24	24	26
7	9	22	70	67.50	87.24	12.76	R	30	26	28	28
8	10	22	74	103.70	86.01	13.99	R	50	56	47	54
9	11	22	73	77.60	87.63	12.37	R	26	26	26	26
10	12	21	68	88.30	90.84	9.16	R	40	44	36	40
11	13	23	69	63.80	80.18	19.82	R	22	22	22	20
12	14	22	70	78.64	88.15	11.85	R	20	20	24	20
13	15	22	69	64.80	90.20	9.80	R	20	6	22	22
14	16	22	67	65.30	94.67	5.33	R	32	30	28	28
15	17	25	75	85.10	79.80	20.21	R	26	34	24	37
16	20	29	71	71.75	88.56	11.44	R	22	26	26	24
17	21	22	70	77.80	75.80	24.20	R	37	35	22	25
18	22	22	73	78.18	92.36	7.64	R	34	32	32	34
19	23	23	71	77.70	79.10	20.90	R	36	36	30	36
20	24	21	64	76.75	82.83	17.17	R	26	29	24	22
21	25	22	72	76.00	81.25	18.75	R	34	32	26	32
22	26	22	65	64.20	85.88	14.12	R	22	24	22	23
23	27	21	70	60.80	94.05	5.95	R	28	26	23	26
24	29	22	70	80.40	87.79	12.21	R	32	32	32	30
25	31	22	67	66.60	79.51	20.49	R	17	18	22	22
26	32	21	72	75.50	91.04	8.96	R	28	28	26	28

OBS	PT3RE1	PT3RE2	PT3LE1	PT3LE2	PTR6	PTL6	PTR3	PTL3	PT6	PT3
1	20	20	22	23	27.0	25.5	20.0	22.5	26.25	21.25
2	15	38	18	32	33.0	33.0	26.5	25.0	33.00	25.75
3	26	18	24	22	33.5	36.0	22.0	23.0	34.75	22.50
4	18	15	17	14	25.0	25.0	16.5	15.5	25.00	16.00
5	23	26	20	20	35.0	31.5	24.5	20.0	33.25	22.25
6	16	15	20	20	24.0	25.0	15.5	20.0	24.50	17.75
7	22	20	18	18	28.0	28.0	21.0	18.0	28.00	19.50
8	34	40	28	34	53.0	50.5	37.0	31.0	51.75	34.00
9	18	20	22	22	26.0	26.0	19.0	22.0	26.00	20.50
10	28	30	20	28	42.0	38.0	29.0	24.0	40.00	26.50
11	12	14	10	14	22.0	21.0	13.0	12.0	21.50	12.50
12	14	12	14	10	20.0	22.0	13.0	12.0	21.00	12.50
13	17	12	17	14	13.0	22.0	14.5	15.5	17.50	15.00
14	20	18	16	18	31.0	28.0	19.0	17.0	29.50	18.00
15	16	28	15	27	30.0	30.5	22.0	21.0	30.25	21.50
16	18	18	20	18	24.0	25.0	18.0	19.0	24.50	18.50
17	31	35	28	26	36.0	23.5	33.0	27.0	29.75	30.00
18	22	22	22	22	33.0	33.0	22.0	22.0	33.00	22.00
19	28	24	23	22	36.0	33.0	26.0	22.5	34.50	24.25
20	18	21	16	14	27.5	23.0	19.5	15.0	25.25	17.25
21	22	23	20	28	33.0	29.0	22.5	24.0	31.00	23.25
22	12	12	12	14	23.0	22.5	12.0	13.0	22.75	12.50
23	15	14	14	15	27.0	24.5	14.5	14.5	25.75	14.50
24	23	23	24	22	32.0	31.0	23.0	23.0	31.50	23.00
25	7	12	14	12	17.5	22.0	9.5	13.0	19.75	11.25
26	20	20	18	18	28.0	27.0	20.0	18.0	27.50	19.00

Raw Data-Peak Torque External Rotation

OBS	SUBJ	AGE	HT	WT	LBM	FAT	PREF	PT6RE1	PT6RE2	PT6LE1	PT6LE2
27	35	24	71	87.10	20.48	19.52	R	30	28	28	24
28	36	21	75	83.30	91.89	8.11	R	54	36	56	38
29	37	22	68	71.67	83.71	16.29	R	22	26	22	23
30	38	22	73	78.50	89.09	10.91	R	32	30	30	26
31	39	30	72	73.20	91.21	8.79	R	32	28	30	26
32	40	22	71	80.50	89.75	10.25	R	40	36	32	32
33	41	22	74	80.20	88.05	11.95	R	23	22	20	26
34	42	21	72	76.60	92.77	7.23	R	24	24	28	26
35	43	25	71	74.84	83.02	16.98	R	28	32	32	26
36	44	23	70	72.30	92.81	7.19	R	38	33	34	30
37	46	22	75	83.00	85.33	14.67	R	26	28	22	24
38	47	24	74	88.70	87.11	12.89	R	47	50	42	54
39	48	22	73	74.20	89.47	10.53	R	32	30	34	36
40	49	22	69	84.60	83.89	16.11	R	32	32	28	28
41	50	24	70	63.30	85.09	14.91	R	20	22	22	23
42	51	27	75	97.00	85.02	14.98	R	76	36	60	40
43	52	22	72	81.20	82.82	17.18	R	32	32	30	34
44	53	22	66	83.10	79.38	20.62	R	33	34	34	36
45	54	23	71	85.70	84.43	15.57	R	46	40	42	40

OBS	PT3RE1	PT3RE2	PT3LE1	PT3LE2	PTR6	PTL6	PTR3	PTL3	PT6	PT3
27	12	14	16	14	29.0	26.0	13.0	15.0	27.50	14.00
28	30	20	39	18	45.0	46.0	25.0	28.5	45.50	26.75
29	14	26	14	14	24.0	22.5	20.0	14.0	23.25	17.00
30	18	22	22	18	31.0	28.0	20.0	20.0	29.50	20.00
31	18	15	16	14	30.0	28.0	16.5	15.0	29.00	15.75
32	22	24	22	18	38.0	32.0	23.0	20.0	35.00	21.50
33	18	18	18	16	22.5	23.0	18.0	17.0	22.75	17.50
34	17	18	20	20	24.0	27.0	17.5	20.0	25.50	18.75
35	18	20	20	16	30.0	29.0	19.0	18.0	29.50	18.50
36	26	22	22	14	35.5	32.0	24.0	18.0	33.75	21.00
37	20	20	14	18	27.0	23.0	20.0	16.0	25.00	18.00
38	30	36	26	40	48.5	48.0	33.0	33.0	48.25	33.00
39	15	24	22	23	31.0	35.0	19.5	22.5	33.00	21.00
40	18	26	18	22	32.0	28.0	22.0	20.0	30.00	21.00
41	12	18	8	16	21.0	22.5	15.0	12.0	21.75	13.50
42	54	30	34	30	56.0	50.0	42.0	32.0	53.00	37.00
43	22	26	24	28	32.0	32.0	24.0	26.0	32.00	25.00
44	22	22	26	26	33.5	35.0	22.0	26.0	34.25	24.00
45	34	30	34	33	43.0	41.0	32.0	33.5	42.00	32.75

Raw data-Average Power-Internal Rotation

OBS	SUBJ	AGE	HT	WT	LBM	FAT	PREF	AVPRI1	AVPRI2	AVPLI1	AVPLI2	AVPR	AVPL
1	1	22	73	71.40	95.07	4.93	R	109	113	126	101	111.0	113.5
2	3	21	67	67.15	91.70	8.30	R	135	62	168	57	98.5	112.5
3	4	25	68	78.10	80.45	19.55	R	149	110	168	142	129.5	155.0
4	5	21	70	66.75	94.24	5.76	R	98	71	115	53	84.5	84.0
5	6	24	74	80.00	91.54	8.46	R	94	171	71	119	132.5	95.0
6	7	20	67	72.80	86.49	13.51	R	206	113	198	143	159.5	170.5
7	9	22	70	67.50	87.24	12.76	R	128	121	123	102	124.5	112.5
8	10	22	74	103.70	86.01	13.99	R	177	242	145	186	209.5	165.5
9	11	22	73	77.60	87.63	12.37	R	128	137	116	113	132.5	114.5
10	12	21	68	88.30	90.84	9.16	R	144	137	117	139	140.5	128.0
11	13	23	69	63.80	80.18	19.82	R	81	119	73	85	100.0	79.0
12	14	22	70	78.64	88.15	11.85	R	127	104	112	75	115.5	93.5
13	15	22	69	64.80	90.20	9.80	R	99	82	93	81	90.5	87.0
14	16	22	67	65.30	94.67	5.33	R	138	120	113	104	129.0	108.5
15	17	25	75	85.10	79.80	20.21	R	89	60	99	57	74.5	78.0
16	20	29	71	71.75	88.56	11.44	R	147	152	131	127	149.5	129.0
17	21	22	70	77.80	75.80	24.20	R	52	55	60	63	53.5	61.5
18	22	22	73	78.18	92.36	7.64	R	167	162	161	149	164.5	155.0
19	23	23	71	77.70	79.10	20.90	R	214	166	157	139	190.0	148.0
20	24	21	64	76.75	82.83	17.17	R	131	100	122	90	115.5	106.0
21	25	22	72	76.00	81.25	18.75	R	135	56	94	60	95.5	77.0
22	26	22	65	64.20	85.88	14.12	R	106	100	92	85	103.0	88.5
23	27	21	70	60.80	94.05	5.95	R	122	108	124	133	115.0	128.5
24	29	22	70	80.40	87.79	12.21	R	142	143	148	117	142.5	132.5
25	31	22	67	66.60	79.51	20.49	R	42	73	84	59	57.5	71.5
26	32	21	72	75.50	91.04	8.96	R	148	154	148	132	151.0	140.0
27	35	24	71	87.10	20.48	19.52	R	129	106	101	99	117.5	100.0
28	36	21	75	83.30	91.89	8.11	R	68	153	87	111	110.5	99.0
29	37	22	68	71.67	83.71	16.29	R	72	73	75	84	72.5	79.5
30	38	22	73	78.50	89.09	10.91	R	137	171	127	130	154.0	128.5
31	39	30	72	73.20	91.21	8.79	R	109	87	98	87	98.0	92.5
32	40	22	71	80.50	89.75	10.25	R	125	125	94	119	125.0	106.5
33	41	22	74	80.20	88.05	11.95	R	99	81	109	87	90.0	98.0
34	42	21	72	76.60	92.77	7.23	R	75	93	82	94	84.0	88.0
35	43	25	71	74.84	83.02	16.98	R	115	129	146	104	122.0	125.0
36	44	23	70	72.30	92.81	7.19	R	137	103	119	79	120.0	99.0
37	46	22	75	83.00	85.33	14.67	R	91	94	82	84	92.5	83.0
38	47	24	74	88.70	87.11	12.89	R	171	214	173	229	192.5	201.0
39	48	22	73	74.20	89.47	10.53	R	97	159	100	101	128.0	100.5
40	49	22	69	84.60	83.89	16.11	R	121	204	117	129	162.5	123.0
41	50	24	70	63.30	85.09	14.91	R	58	119	120	68	88.5	94.0
42	51	27	75	97.00	85.02	14.98	R	98	164	81	147	131.0	114.0
43	52	22	72	81.20	82.82	17.18	R	124	139	120	135	131.5	127.5
44	53	22	66	83.10	79.38	20.62	R	151	149	157	147	150.0	152.0
45	54	23	71	85.70	84.43	15.57	R	241	196	232	225	218.5	228.5

Raw Data--Average power extension

OBS	SUBJ	AGE	HT	WT	LBM	FAT	PREF	AVPRE1	AVPRE2	AVPLE1	AVPLE2	AVPR	AVPL
1	1	22	73	71.40	95.07	4.93	p	69	77	68	79	73.0	73.5
2	3	21	67	67.15	91.70	8.30	p	58	158	74	125	108.0	99.5
3	4	25	68	78.10	80.45	19.55	p	85	55	77	65	70.0	71.0
4	5	21	70	66.75	94.24	5.76	p	67	46	67	39	56.5	53.0
5	6	24	74	80.00	91.54	8.46	p	58	77	55	71	67.5	63.0
6	7	20	67	72.80	86.49	13.51	p	71	58	94	74	64.5	84.0
7	9	22	70	67.50	87.24	12.76	p	70	64	57	50	67.0	53.5
8	10	22	74	103.70	86.01	13.99	p	117	169	90	111	143.0	100.5
9	11	22	73	77.60	87.63	12.37	p	73	67	75	59	70.0	67.0
10	12	21	68	88.30	90.84	9.16	p	101	95	71	87	98.0	79.0
11	13	23	69	63.80	80.18	19.82	p	30	59	29	36	44.5	32.5
12	14	22	70	78.64	88.15	11.85	p	53	44	49	36	48.5	42.5
13	15	22	69	64.80	90.20	9.80	p	63	49	69	69	56.0	69.0
14	16	22	67	65.30	94.67	5.33	p	69	47	43	51	58.0	47.0
15	17	25	75	85.10	79.80	20.21	p	59	103	56	111	81.0	83.5
16	20	29	71	71.75	88.56	11.44	p	70	76	83	70	73.0	76.5
17	21	22	70	77.80	75.80	24.20	p	132	111	114	102	121.5	108.0
18	22	22	73	78.18	92.36	7.64	p	95	83	89	88	89.0	88.5
19	23	23	71	77.70	79.10	20.90	p	119	102	76	82	110.5	79.0
20	24	21	64	76.75	82.83	17.17	p	72	87	69	72	79.5	70.5
21	25	22	72	76.00	81.25	18.75	p	88	88	64	47	88.0	55.5
22	26	22	65	64.20	85.88	14.12	p	55	49	41	37	52.0	39.0
23	27	21	70	60.80	94.05	5.95	p	47	37	38	48	42.0	43.0
24	29	22	70	80.40	87.79	12.21	p	98	93	90	72	95.5	81.0
25	31	22	67	66.60	79.51	20.49	p	16	35	54	51	25.5	52.5
26	32	21	72	75.50	91.04	8.96	p	89	89	67	74	89.0	70.5
27	35	24	71	87.10	20.48	19.52	p	69	64	61	53	66.5	57.0
28	36	21	75	83.30	91.89	8.11	p	101	82	147	73	91.5	110.0
29	37	22	68	71.67	83.71	16.29	p	46	43	38	40	44.5	39.0
30	38	22	73	78.50	89.09	10.91	p	69	81	82	59	75.0	70.5
31	39	30	72	73.20	91.21	8.79	p	62	46	53	40	54.0	46.5
32	40	22	71	80.50	89.75	10.25	p	97	87	68	53	92.0	60.5
33	41	22	74	80.20	88.05	11.95	p	64	62	70	57	63.0	63.5
34	42	21	72	76.60	92.77	7.23	p	56	60	64	66	58.0	65.0
35	43	25	71	74.84	83.02	16.98	p	52	61	61	39	56.5	50.0
36	44	23	70	72.30	92.81	7.19	p	95	69	77	52	82.0	64.5
37	46	22	75	83.00	85.33	14.67	p	68	70	57	60	69.0	58.5
38	47	24	74	88.70	87.11	12.89	p	118	127	103	135	122.5	119.0
39	48	22	73	74.20	89.47	10.53	p	76	105	81	94	90.5	87.5
40	49	22	69	84.60	83.89	16.11	p	65	115	67	81	90.0	74.0
41	50	24	70	63.30	85.09	14.91	p	32	67	42	70	49.5	56.0
42	51	27	75	97.00	85.02	14.98	p	165	111	127	103	138.0	115.0
43	52	22	72	81.20	82.82	17.18	p	84	98	88	88	91.0	88.0
44	53	22	66	83.10	79.38	20.62	p	98	77	103	88	87.5	95.5
45	54	23	71	85.70	84.43	15.57	p	136	94	144	121	115.0	132.5

Raw Data-TAE internal rotation

OBS	SUBJ	AGE	HT	WT	LBM	FAT	PREF	TAERI1	TAERI2	TAELI1	TAELI2	TAER	TAEL
1	1	22	73	71.40	95.07	4.93	R	11.69	12.89	12.61	12.80	12.290	12.705
2	3	21	67	67.15	91.70	8.30	R	13.99	8.62	16.26	7.29	11.305	11.775
3	4	25	68	78.10	80.45	19.55	R	16.28	14.04	14.78	15.63	15.160	15.205
4	5	21	70	66.75	94.24	5.76	R	12.05	9.05	12.02	7.52	10.550	9.770
5	6	24	74	80.00	91.54	8.46	R	11.91	17.95	10.05	13.01	14.930	11.530
6	7	20	67	72.80	86.49	13.51	R	17.54	13.47	13.61	13.90	15.505	13.755
7	9	22	70	67.50	87.24	12.76	R	14.51	13.62	12.37	13.19	14.065	12.780
8	10	22	74	103.70	86.01	13.99	R	20.34	22.59	19.16	19.91	21.465	19.535
9	11	22	73	77.60	87.63	12.37	R	12.98	12.91	11.16	12.18	12.945	11.670
10	12	21	68	88.30	90.84	9.16	R	16.24	17.22	16.12	17.24	16.730	16.680
11	13	23	69	63.80	80.18	19.82	R	9.94	12.37	7.90	12.37	11.155	10.135
12	14	22	70	78.64	88.15	11.85	R	12.04	12.56	11.53	7.93	12.300	9.730
13	15	22	69	64.80	90.20	9.80	R	10.13	7.22	9.40	6.63	8.675	8.015
14	16	22	67	65.30	94.67	5.33	R	15.40	14.90	14.25	14.22	15.150	14.235
15	17	25	75	85.10	79.80	20.21	R	11.44	9.99	10.38	9.75	10.715	10.065
16	20	29	71	71.75	88.56	11.44	R	12.98	15.89	11.41	13.38	14.435	12.395
17	21	22	70	77.80	75.80	24.20	R	8.97	9.56	9.54	10.17	9.265	9.855
18	22	22	73	78.18	92.36	7.64	R	16.10	15.56	14.88	13.08	15.830	13.980
19	23	23	71	77.70	79.10	20.90	R	18.77	17.08	14.60	12.42	17.925	13.510
20	24	21	64	76.75	82.83	17.17	R	12.51	12.37	11.46	10.82	12.440	11.140
21	25	22	72	76.00	81.25	18.75	R	11.55	8.98	10.19	9.26	10.265	9.725
22	26	22	65	64.20	85.88	14.12	R	10.85	10.55	6.94	7.17	10.700	7.055
23	27	21	70	60.80	94.05	5.95	R	12.72	15.26	12.80	14.58	13.990	13.690
24	29	22	70	80.40	87.79	12.21	R	16.31	15.09	17.29	14.74	15.700	16.015
25	31	22	67	66.60	79.51	20.49	R	8.60	7.95	9.28	9.19	8.275	9.235
26	32	21	72	75.50	91.04	8.96	R	14.58	13.15	14.25	12.24	13.865	13.245
27	35	24	71	87.10	20.48	19.52	R	10.85	10.92	9.10	9.24	10.885	9.170
28	36	21	75	83.30	91.89	8.11	R	9.78	16.78	9.89	14.36	13.280	12.125
29	37	22	68	71.67	83.71	16.29	R	8.74	7.13	7.10	7.60	7.935	7.350
30	38	22	73	78.50	89.09	10.91	R	14.41	16.57	13.73	13.15	15.490	13.440
31	39	30	72	73.20	91.21	8.79	R	11.29	7.80	9.75	8.28	9.545	9.015
32	40	22	71	80.50	89.75	10.25	R	8.86	13.82	9.94	10.52	11.340	10.230
33	41	22	74	80.20	88.05	11.95	R	11.76	11.34	10.92	9.85	11.550	10.385
34	42	21	72	76.60	92.77	7.23	R	9.85	13.10	9.78	10.67	11.475	10.225
35	43	25	71	74.84	83.02	16.98	R	11.04	13.12	11.58	10.99	12.080	11.285
36	44	23	70	72.30	92.81	7.19	R	17.03	12.56	13.64	9.66	14.795	11.650
37	46	22	75	83.00	85.33	14.67	R	11.58	10.50	9.45	11.27	11.040	10.360
38	47	24	74	88.70	87.11	12.89	R	17.36	22.31	16.69	23.69	19.835	20.190
39	48	22	73	74.20	89.47	10.53	R	9.98	14.95	12.63	11.25	12.465	11.940
40	49	22	69	84.60	83.89	16.11	R	14.32	19.05	12.80	16.19	16.685	14.495
41	50	24	70	63.30	85.09	14.91	R	9.14	14.25	6.29	10.52	11.695	8.405
42	51	27	75	97.00	85.02	14.98	R	15.56	21.16	11.08	19.03	18.360	15.055
43	52	22	72	81.20	82.82	17.18	R	13.29	14.65	15.18	14.74	13.970	14.960
44	53	22	66	83.10	79.38	20.62	R	15.65	17.71	14.32	15.65	16.680	14.985
45	54	23	71	85.70	84.43	15.57	R	24.27	21.30	18.81	19.80	22.785	19.305

Raw Data--TAE extension

OBS	SUBJ	AGE	HT	WT	LBM	FAT	PREF	TAER1	TAER2	TAEL1	TAEL2	TAER	TAEL
1	1	22	73	71.40	95.07	4.93	R	9.63	10.29	10.45	11.01	9.960	10.730
2	3	21	67	67.15	91.70	8.30	R	6.52	16.19	8.77	14.27	11.355	11.520
3	4	25	68	78.10	80.45	19.55	R	11.60	9.96	11.49	10.53	10.780	11.010
4	5	21	70	66.75	94.24	5.76	R	8.49	7.04	8.67	6.36	7.765	7.515
5	6	24	74	80.00	91.54	8.46	R	9.35	13.69	8.53	9.38	11.520	8.955
6	7	20	67	72.80	86.49	13.51	R	9.22	8.55	9.80	9.89	8.885	9.845
7	9	22	70	67.50	87.24	12.76	R	11.02	9.26	7.80	9.26	10.140	8.530
8	10	22	74	103.70	86.01	13.99	R	15.39	15.56	12.54	14.48	15.475	13.510
9	11	22	73	77.60	87.63	12.37	R	9.21	10.60	9.98	10.34	9.905	10.160
10	12	21	68	88.30	90.84	9.16	R	13.97	14.71	9.82	13.34	14.340	11.580
11	13	23	69	63.80	80.18	19.82	R	6.21	7.45	5.54	5.98	6.830	5.760
12	14	22	70	78.64	88.15	11.85	R	6.45	6.05	7.67	5.95	6.250	6.810
13	15	22	69	64.80	90.20	9.80	R	7.41	5.26	7.20	6.82	6.335	7.010
14	16	22	67	65.30	94.67	5.33	R	10.31	8.62	8.27	9.17	9.465	8.720
15	17	25	75	85.10	79.80	20.21	R	9.00	11.53	8.04	12.44	10.285	10.240
16	20	29	71	71.75	88.56	11.44	R	7.74	7.62	8.60	8.27	7.680	8.435
17	21	22	70	77.80	75.80	24.20	R	12.42	11.83	12.33	11.94	12.125	12.135
18	22	22	73	78.18	92.36	7.64	R	10.85	10.83	11.20	12.11	10.840	11.655
19	23	23	71	77.70	79.10	20.90	R	13.45	11.83	10.26	11.18	12.640	10.720
20	24	21	64	76.75	82.83	17.17	R	9.68	11.21	7.67	8.05	10.445	7.860
21	25	22	72	76.00	81.25	18.75	R	9.40	8.89	9.12	10.88	9.145	10.000
22	26	22	65	64.20	85.88	14.12	R	5.88	6.23	5.74	5.72	6.055	5.730
23	27	21	70	60.80	94.05	5.95	R	8.02	7.74	7.78	8.55	7.880	8.165
24	29	22	70	80.40	87.79	12.21	R	13.83	12.44	12.45	11.83	13.135	12.140
25	31	22	67	66.60	79.51	20.49	R	4.22	4.55	6.26	5.51	4.385	5.885
26	32	21	72	75.50	91.04	8.96	R	9.31	8.35	8.34	8.67	8.830	8.505
27	35	24	71	87.10	20.48	19.52	R	7.43	7.06	8.11	7.06	7.245	7.585
28	36	21	75	83.30	91.89	8.11	R	12.51	10.78	16.57	9.07	11.645	12.820
29	37	22	68	71.67	83.71	16.29	R	6.49	8.72	7.04	6.28	7.605	6.660
30	38	22	73	78.50	89.09	10.91	R	9.17	10.66	10.64	8.98	9.915	9.810
31	39	30	72	73.20	91.21	8.79	R	9.63	8.18	8.70	7.15	8.905	7.925
32	40	22	71	80.50	89.75	10.25	R	9.38	11.01	10.64	9.42	10.195	10.030
33	41	22	74	80.20	88.05	11.95	R	7.50	7.86	8.79	8.30	7.680	8.545
34	42	21	72	76.60	92.77	7.23	R	7.25	8.39	8.81	8.58	7.820	8.695
35	43	25	71	74.84	83.02	16.98	R	8.51	8.63	9.26	7.83	8.570	8.545
36	44	23	70	72.30	92.81	7.19	R	11.83	10.10	10.24	7.71	10.965	8.975
37	46	22	75	83.00	85.33	14.67	R	10.17	9.28	7.32	7.85	9.725	7.585
38	47	24	74	88.70	87.11	12.89	R	13.89	16.12	13.29	16.96	15.005	15.125
39	48	22	73	74.20	89.47	10.53	R	9.00	12.31	10.64	11.91	10.655	11.275
40	49	22	69	84.60	83.89	16.11	R	9.68	13.68	9.85	12.31	11.680	11.080
41	50	24	70	63.30	85.09	14.91	R	5.47	8.91	5.79	8.06	7.190	6.925
42	51	27	75	97.00	85.02	14.98	R	22.63	13.97	18.53	14.97	18.300	16.750
43	52	22	72	81.20	82.82	17.18	R	11.49	13.80	11.29	11.86	12.645	11.575
44	53	22	66	83.10	79.38	20.62	R	10.52	11.01	11.08	12.24	10.765	11.660
45	54	23	71	85.70	84.43	15.57	R	16.73	13.89	16.17	14.50	15.310	15.335

Raw Data Endurance Ratio Internal Rotation

OBS	SUBJ	AGE	HT	WT	LBM	FAT	PREF	ENDRI1	ENDRI2	ENDLI1	ENDLI2	ENDR	ENDL
1	1	22	73	71.40	95.07	4.93	R	62	72	72	56	67.0	64.0
2	2	22	67	75.50	88.99	11.01	L	74	56	78	53	65.0	65.5
3	3	21	67	67.15	91.70	8.30	R	60	47	65	57	53.5	61.0
4	4	25	68	78.10	80.45	19.55	R	41	54	59	53	47.5	56.0
5	5	21	70	66.75	94.24	5.76	R	65	66	64	42	65.5	53.0
6	6	24	74	80.00	91.54	8.46	R	95	60	58	64	77.5	61.0
7	7	20	67	72.80	86.49	13.51	R	86	61	70	66	73.5	68.0
8	8	21	76	77.90	81.81	18.19	L	52	52	45	54	52.0	49.5
9	9	22	70	67.50	87.24	12.76	R	58	55	64	67	56.5	65.5
10	10	22	74	103.70	86.01	13.99	R	54	64	63	58	59.0	60.5
11	11	22	73	77.60	87.63	12.37	R	59	40	71	53	49.5	62.0
12	12	21	68	88.30	90.84	9.16	R	67	59	56	52	63.0	54.0
13	13	23	69	63.80	80.18	19.82	R	55	60	60	57	57.5	58.5
14	14	22	70	78.64	88.15	11.85	R	69	77	84	120	73.0	102.0
15	15	22	69	64.80	90.20	9.80	R	65	100	62	101	82.5	81.5
16	16	22	67	65.30	94.67	5.33	R	52	47	51	55	49.5	53.0
17	17	25	75	85.10	79.80	20.21	R	60	37	79	38	48.5	58.5
18	18	20	71	71.20	78.24	21.76	L	76	72	77	71	74.0	74.0
19	19	25	72	89.40	75.94	24.06	L	57	60	52	46	58.5	49.0
20	20	29	71	71.75	88.56	11.44	R	89	69	93	73	79.0	83.0
21	21	22	70	77.80	75.80	24.20	R	18	23	33	35	20.5	34.0
22	22	22	73	78.18	92.36	7.64	R	67	59	55	63	63.0	59.0
23	23	23	71	77.70	79.10	20.90	R	56	57	50	52	56.5	51.0
24	24	21	64	76.75	82.83	17.17	R	79	75	76	71	77.0	73.5
25	25	22	72	76.00	81.25	18.75	R	49	46	42	41	47.5	41.5
26	26	22	65	64.20	85.88	14.12	R	73	70	94	82	71.5	88.0
27	27	21	70	60.80	94.05	5.95	R	53	52	63	49	52.5	56.0
28	28	23	72	74.60	92.47	7.53	L	86	49	67	56	67.5	61.5
29	29	22	70	80.40	87.79	12.21	R	65	74	76	67	69.5	71.5
30	30	21	71	85.91	91.87	8.13	L	63	61	53	65	62.0	59.0
31	31	22	67	66.60	79.51	20.49	R	136	71	50	57	103.5	53.5
32	32	21	72	75.50	91.04	8.96	R	56	73	68	64	64.5	66.0
33	33	22	67	72.10	86.93	13.07	L	64	59	70	87	61.5	78.5
34	34	20	72	70.50	88.35	11.65	L	61	72	63	62	66.5	62.5
35	35	24	71	87.10	20.48	19.52	R	63	72	63	65	67.5	64.0
36	36	21	75	83.30	91.89	8.11	R	49	75	81	62	62.0	71.5
37	37	22	68	71.67	83.71	16.29	R	47	59	61	45	53.0	53.0
38	38	22	73	78.50	89.09	10.91	R	71	79	64	94	75.0	79.0
39	39	30	72	73.20	91.21	8.79	R	66	87	61	103	76.5	82.0
40	40	22	71	80.50	89.75	10.25	R	100	55	69	58	77.5	63.5
41	41	22	74	80.20	88.05	11.95	R	79	61	65	80	70.0	72.5
42	42	21	72	76.60	92.77	7.23	R	65	50	50	56	57.5	53.0
43	43	25	71	74.84	83.02	16.98	R	67	61	81	65	64.0	73.0
44	44	23	70	72.30	92.81	7.19	R	56	43	87	90	49.5	88.5
45	45	22	74	106.70	72.82	27.18	L	51	40	55	54	45.5	54.5
46	46	22	75	83.00	85.33	14.67	R	59	63	99	67	61.0	83.0
47	47	24	74	88.70	87.11	12.89	R	83	86	88	71	84.5	79.5
48	48	22	73	74.20	89.47	10.53	R	170	176	103	95	173.0	99.0
49	49	22	69	84.60	83.89	16.11	R	64	65	67	77	64.5	72.0
50	50	24	70	63.30	85.09	14.91	R	57	78	136	93	67.5	114.5
51	51	27	75	97.00	85.02	14.98	R	48	59	78	72	53.5	75.0
52	52	22	72	81.20	82.82	17.18	R	77	58	67	53	67.5	60.0
53	53	22	66	83.10	79.38	20.62	R	56	60	56	78	58.0	67.0
54	54	23	71	85.70	84.43	15.57	R	64	54	81	77	59.0	79.0
55	55	22	73	73.30	95.56	4.44	L	65	55	66	48	60.0	57.0

Raw Data Endurance Ratio External Rotation

OBS	SUBJ	AGE	HT	WT	LBM	FAT	PREF	ENDRE1	ENDRE2	ENDLE1	ENDLE2	ENDR	ENDL
1	1	22	73	71.40	95.07	4.93	R	37	47	37	53	42.0	45.0
2	3	21	67	67.15	91.70	8.30	R	51	65	51	60	58.0	55.5
3	4	25	68	78.10	80.45	19.55	R	40	43	35	45	41.5	40.0
4	5	21	70	66.75	94.24	5.76	R	65	33	60	33	49.0	46.5
5	6	24	74	80.00	91.54	8.46	R	54	.	81	46	.	63.5
6	7	20	67	72.80	86.49	13.51	R	56	43	71	66	49.5	68.5
7	9	22	70	67.50	87.24	12.76	R	47	51	47	59	49.0	53.0
8	10	22	74	103.70	86.01	13.99	R	49	59	63	43	54.0	53.0
9	11	22	73	77.60	87.63	12.37	R	59	34	49	29	46.5	39.0
10	12	21	68	88.30	90.84	9.16	R	48	50	63	37	49.0	50.0
11	13	23	69	63.80	80.18	19.82	R	27	44	31	41	35.5	36.0
12	14	22	70	78.64	88.15	11.85	R	61	60	61	.	60.5	.
13	15	22	69	64.80	90.20	9.80	R	59	75	53	92	67.0	72.5
14	16	22	67	65.30	94.67	5.33	R	37	40	38	37	38.5	37.5
15	17	25	75	85.10	79.80	20.21	R	58	40	48	54	49.0	51.0
16	20	29	71	71.75	88.56	11.44	R	71	67	84	51	69.0	67.5
17	21	22	70	77.80	75.80	24.20	R	59	52	58	56	55.5	57.0
18	22	22	73	78.18	92.36	7.64	R	64	52	46	54	58.0	50.0
19	23	23	71	77.70	79.10	20.90	R	50	57	46	47	53.5	46.5
20	24	21	64	76.75	82.83	17.17	R	72	71	72	60	71.5	66.0
21	25	22	72	76.00	81.25	18.75	R	51	32	26	41	41.5	33.5
22	26	22	65	64.20	85.88	14.12	R	91	84	80	76	87.5	78.0
23	27	21	70	60.80	94.05	5.95	R	26	43	70	31	34.5	50.5
24	29	22	70	80.40	87.79	12.21	R	59	65	61	61	62.0	61.0
25	31	22	67	66.60	79.51	20.49	R	68	64	68	61	66.0	64.5
26	32	21	72	75.50	91.04	8.96	R	58	63	63	60	60.5	61.5
27	35	24	71	87.10	20.48	19.52	R	85	80	48	68	82.5	58.0
28	36	21	75	83.30	91.89	8.11	R	56	82	61	72	69.0	66.5
29	37	22	68	71.67	83.71	16.29	R	34	30	35	32	32.0	33.5
30	38	22	73	78.50	89.09	10.91	R	58	52	58	58	55.0	58.0
31	39	30	72	73.20	91.21	8.79	R	51	50	54	62	50.5	58.0
32	40	22	71	80.50	89.75	10.25	R	65	45	51	46	55.0	48.5
33	41	22	74	80.20	88.05	11.95	R	60	61	58	49	60.5	53.5
34	42	21	72	76.60	92.77	7.23	R	55	44	51	52	49.5	51.5
35	43	25	71	74.84	83.02	16.98	R	33	54	40	39	43.5	39.5
36	44	23	70	72.30	92.81	7.19	R	50	33	57	.	41.5	.
37	46	22	75	83.00	85.33	14.67	R	49	56	76	63	52.5	69.5
38	47	24	74	88.70	87.11	12.89	R	82	89	83	54	85.5	68.5
39	48	22	73	74.20	89.47	10.53	R	.	59	52	63	.	57.5
40	49	22	69	84.60	83.89	16.11	R	59	58	62	68	58.5	65.0
41	50	24	70	63.30	85.09	14.91	R	43	62	.	68	52.5	.
42	51	27	75	97.00	85.02	14.98	R	54	64	77	64	59.0	70.5
43	52	22	72	81.20	82.82	17.18	R	68	52	55	50	60.0	52.5
44	53	22	66	83.10	79.38	20.62	R	70	53	59	65	61.5	62.0
45	54	23	71	85.70	84.43	15.57	R	68	49	75	61	58.5	68.0

VITA

Robert Shawn Maynard was born on the 26th of March, 1962, in Roanoke, Va., to Robert and Lena Maynard.

Bob grew up in Roanoke, and graduated from Patrick Henry High School in 1980. In 1985, after the completion of his undergraduate degree in Physical Education and Secondary Mathematics from Emory and Henry College, Bob began in the Master of Science Program at Virginia Polytechnic Institute and State University in the area of Exercise Science with the specialization in Muscular function.

In 1987 he began a teaching and coaching career in secondary education. Today, Bob is a teacher and coach at Salem High School, in Salem, Virginia.

Robert S. Maynard