1988

The relationship between vertical jump ability and upper leg muscle strength in male collegiate basketball players

William J. Thomas
Ithaca College

THE RELATIONSHIP BETWEEN VERTICAL JUMP ABILITY AND UPPER LEG MUSCLE STRENGTH IN MALE COLLEGIATE BASKETBALL PLAYERS

by

William J. Thomas

An Abstract

of a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the Division of Health, Physical Education, and Recreation at Ithaca College

December 1988

Thesis Advisor: Dr. G. A. Sforzo

ABSTRACT

The purpose of this investigation was to examine the relationship between vertical jump (VJ) ability and upper leg muscle strength in male collegiate basketball players. Subjects were 43 males between the ages of 18 and 24 years from Ithaca College, SUNY at Cortland, and Cornell University. Each subject (a) performed three maximal effort VJs, (b) participated in a gravity correction procedure, and (c) performed five-repetition maximal effort strength tests at 180, 240, and 300°/s on the Cybex II isokinetic dynamometer. Pearson product-moment correlations were applied to (a) VJ distance (in.) with each of the gravity-corrected and with noncorrected H:Q ratios, (b) VJ work (kgm) with gravity-corrected and with noncorrected H:Q ratios, (c) VJ work (kgm) with gravity-corrected and with noncorrected peak quadriceps torque (PQT), and (d) multiple correlations. Results were not statistically significant at the .05 level for any of the three speeds of testing. It was concluded that there is no significant relationship between VJ ability and H:Q ratios or between VJ ability and PQT at 180, 240, or 300°/s.

THE RELATIONSHIP BETWEEN VERTICAL JUMP ABILITY AND UPPER LEG MUSCLE STRENGTH IN MALE COLLEGIATE BASKETBALL PLAYERS

A Thesis Presented to the Faculty of the
Division of Health, Physical Education,
and Recreation at Ithaca College

In Partial Fulfillment of the
Requirements for the Degree
Master of Science

by
William J. Thomas

December 1988

Ithaca College
Division of Health, Physical Education, and Recreation
Ithaca, New York

CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Master of Science Thesis of

William J. Thomas

submitted in partial fulfillment of the requirements for the degree of Master of Science in the Division of Health, Physical Education, and Recreation at Ithaca College has been approved.

Thesis Advisor:

Committee Member:

Candidate:

Chairman of Graduate Program in Physical Education:

Dean of Graduate Studies:

Date: October 19, 1988 10/21/88

ACKNOWLEDGMENTS

This thesis is dedicated to the glory of God according to Philippians 4:13, "I can do all things through Christ who strengthens me."

Special appreciation is given to:

1. My parents and family for their constant love, support, and encouragement throughout my life and education.

2. Dr. Gary A. Sforzo for his shared knowledge and diligent supervision in the investigation of this topic and the preparation of this manuscript.

3. Dr. Patricia A. Frye for her shared knowledge and supervision in the preparation of this manuscript.

4. Coaches Tom Baker, Bill Williams, and Mike Dement for their cooperation in recruiting subjects.

5. All the subjects who volunteered their time and effort for the purposes of this investigation.

TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	ii
LIST OF TABLES	vi
Chapter	
1. INTRODUCTION	1
Scope of the Problem	2
Statement of the Problem	3
Hypothesis	3
Assumptions	3
Definition of Terms	3
Delimitations	4
Limitations	5
2. REVIEW OF LITERATURE	6
Vertical Jump Tests	6
Vertical Jump as an Indicator of Power	7
Types of Vertical Jumps Used in Testing	8
Determinants of Vertical Jump Performance	12
The Effect of Muscle Fiber Types on Jumping Ability	12
The Use of Stored Elastic Energy	13
The Contribution of Body Segments	16
The Knee as a Determinant of Vertical Jump Ability	17
Physiological Characteristics of the Vertical Jump	18

TABLE OF CONTENTS (continued)

Chapter | Page

2. (continued)

Hamstring-to-quadriceps Strength Ratios 18

The Speed of Joint Movements in the Vertical Jump 20

Isokinetic Dynamometry. 22

Isokinetic and Isotonic Testing Instruments 23

Special Considerations When Using the Cybex II. 25

Summary 28

3. METHODS AND PROCEDURES. 30

Selection of Subjects 30

Methods of Data Collection. 30

The Vertical Jump Test 31

The Cybex II Strength Tests. 31

The Gravity Correction Procedure 33

Treatment of Data 36

Summary 37

4. RESULTS 38

Vertical Jump Scores. 38

Gravity-corrected H:Q Ratios. 41

Noncorrected H:Q Ratios 41

Correlations of Vertical Jump with H:Q Ratios 43

TABLE OF CONTENTS (continued)

Chapter Page

4. (continued)

Correlations of Vertical Jump Work with H:Q Ratios 43

Correlations of Vertical Jump Work with Peak Quadriceps Torque 46

Multiple Correlations 46

5. DISCUSSION. 47

Vertical Jump Scores. 47

Peak Torque and Vertical Jump 48

H:Q Ratios and Vertical Jump. 50

Practical Applications. 52

Summary 54

6. SUMMARY, CONCLUSIONS, RECOMMENDATIONS 56

Summary 56

Conclusions 57

Recommendations 57

APPENDIXES

A. INFORMED CONSENT. 59

B. VERTICAL JUMP INSTRUCTIONS. 61

C. GRAVITY CORRECTION FORMULA. 62

D. GRAVITY CORRECTION INSTRUCTIONS 63

E. STRENGTH TEST INSTRUCTIONS. 64

F. ADDRESSES 65

REFERENCES 66

LIST OF TABLES

Table Page

1. Vertical Jump Scores. 39

2. ANOVA of Vertical Jump Scores Among Three Schools. 40

3. H:Q Ratios. 42

4. Correlations of Vertical Jump with H:Q Ratios 44

5. Correlations of Work with H:Q Ratios and with PQT 45

Chapter 1

INTRODUCTION

For as long as the game of basketball has been played, participants and spectators have wondered why two individuals of similar height and muscular build vary so greatly in their ability to jump vertically. This quandary still exists today, as the shortest player in the National Basketball Association, Spud Webb, won a recent league dunking contest. This showed that there is room for the shorter athlete, even in a sport known as "the tall man's game." It has also caused some serious investigation into the question of why some people jump well and others do not.

For years, the standing jump test has been most commonly used in physical education as a test of leg power, coordination, and jumping ability. However, as the scientific community has been called upon for more detailed information, a variety of vertical jump test forms have been used to further investigate different components of the vertical jump.

The knee joint and surrounding musculature have been the areas of central focus in the research. Glencross (1966a) stated that shoulder flexion and leg extension were the major movements of the vertical jump. Bangerter (1968) stated that knee and hip extension were responsible for "almost all" of the vertical jump height attained. Because of their contributions to these movements, the hamstring and quadriceps muscle groups have been subjected to various forms of testing (e.g., fiber typing and strength testing).

Another characteristic examined has been the hamstring to quadriceps (H:Q) strength ratio. This is known to be a valuable indicator of readiness to participate and readiness to return to activity after injury rehabilitation. The most accurate assessment of the H:Q ratio has been obtained from the use of modern isokinetic devices, such as the Cybex II (see Appendix F).

The primary objective of this investigation was to further examine the relationship between vertical jump ability and upper leg muscle strength. The secondary objective was to contribute information valuable for the functional testing and development of vertical jump ability.

Scope of the Problem

A combined total of 43 male collegiate basketball players from Ithaca College, Cornell University, and the State University of New York (SUNY) at Cortland participated as volunteer subjects for research into the relationship between vertical jump ability and upper leg muscle strength. Each subject performed three maximal effort vertical jumps and was tested for strength ratios at three speeds of movement on the Cybex II isokinetic muscle testing and rehabilitation device. All testing occurred between October 15 and December 15, 1987.

Statement of the Problem

The purpose of this study was to examine the relationship between vertical jump ability and upper leg muscle strength in male collegiate basketball players.

Hypothesis

1. There will be no significant relationship between vertical jump ability and upper leg muscle strength at movement speeds of 180, 240, and 300°/s.

Assumptions

The following assumptions were considered necessary for the purposes of this study:

1. Subjects honestly verified their qualifications as "basketball players" as specified in the informed consent.

2. Subjects performed all testing procedures with maximal effort as requested in the testing instructions.

3. The Cybex II devices produced accurate and comparable results as calibrated prior to testing.

4. Gravity correction procedures used at each testing site produced accurate and comparable correction factors, and subjects adequately relaxed their leg musculature during these procedures.

5. The motor units of the hamstrings and quadriceps recruited during vertical jump testing were the same or similar to those recruited during Cybex II strength testing.

Definition of Terms

The following definitions are used for the purposes of this study:

1. Basketball players--Athletes with at least 1 year of varsity high school experience or 1 year of collegiate experience.

2. Countermovement--The preliminary bending of the knees prior to performance of the vertical jump.

3. Eccentric stretch--The stretch of associated musculature while performing an eccentric contraction.

4. Stored elastic energy--The energy temporarily stored within the musculature as a result of the eccentric stretch of the involved musculature. This occurs during the countermovement.

5. Vertical jump height--The height the athlete rises off the floor as determined by the difference between the maximum height touched on a scale and the original height touched with the athlete standing flat-footed on the ground. See chapter 3 for further description of the vertical jump form used.

Delimitations

The delimitations of this study are as follows:

1. Only male basketball players between the ages of 18 and 24 years participated as subjects.

2. Only qualified athletes from Ithaca College, SUNY at Cortland, and Cornell University participated as subjects.

3. Only those athletes not receiving treatment or rehabilitation for a hip, knee, or ankle injury on the day of testing participated as subjects.

4. Only the form of vertical jump eliminating the use

of the arms and the countermovement, as described in chapter 3, was used in this study.

5. Only H:Q ratios formed from Cybex II torque values were used in correlations with vertical jump scores.

6. Only the gravity correction procedure and formula of Nelson and Duncan (1983) was used at Ithaca College and SUNY at Cortland.

7. Only the gravity correction procedure programmed into the Cybex II Data Reduction Computer (see Appendix F) was used at Cornell University.

Limitations

1. Results are generalizable only to athletes of similar age, basketball ability, and college division level.

2. Results may apply only to vertical jump testing using the form described in chapter 3.

3. Results may apply only to H:Q ratios formed from Cybex II torque values.

4. Results may only apply to data corrected under the procedures of Nelson and Duncan (1983), or to data corrected under the procedures of the Cybex II data reduction program, as appropriate.

Chapter 2

REVIEW OF LITERATURE

The vertical jump is considered important to overall success in basketball performance. Therefore, it is an area of considerable attention on the practical and scientific level. It is believed that the ability to generate greater force at higher velocities of movement is an indicator of greater vertical jump ability and potential for greater basketball performance.

The vertical jump, the earliest published version of which was called Sargent's Physical Test of Man, has for many years been the generally accepted test to measure "explosive energy" or "power" of the legs. This standing jump test is one of the most common physical skills tests used in physical education and is purported to measure muscular power, leg power, dynamic strength, coordination, and jump ability (Genuario & Dolgener, 1980; Glencross, 1966a; Smith, 1961). Valuable information about vertical jump ability may be obtained from evaluation of the vertical jump and leg strength. A thorough understanding of (a) vertical jump tests, (b) determinants of vertical jump performance, (c) physiological characteristics of the vertical jump, and (d) isokinetic dynamometry are necessary for such an evaluation.

Vertical Jump Tests

The complex nature of the jump itself has provided a wide variety of characteristics to be examined. Because of this, no standard form of the vertical jump has been established for use in research or practical testing. At least seven different forms of the vertical jump have been employed in scientific investigation, depending on the purpose of the testing.

Vertical Jump as an Indicator of Power

Because it is claimed that vertical jump tests measure power, there has been considerable discussion in the literature as to whether or not these tests actually measure power or only indicate power. The mechanical principle of power is force times distance divided by the time over which that force is acting. A true measure of power would consider the time taken to produce the force in a given explosive movement (e.g., the time from first muscle contraction to the time the feet leave the floor in the vertical jump). This type of measurement is difficult and has been demonstrated by Gray, Start, and Glencross (1962b). Although most jump tests are measures of leg strength, none of the commonly used tests truly measure power, which is the maximal work output per unit of time (Costill, Miller, Myers, Kehoe, & Hoffman, 1968). Therefore, the common tests for muscle power do not actually measure power, but are only an indication of it (Adamson & Whitney, 1971; Glencross, 1966b). Because explosive movements are complex, it is difficult to measure the power produced. However, when muscular effort is applied against an external load, the power developed can be measured and used as an indicator of the power produced by the body

(Glencross, 1966b).

Because the mathematically validated "vertical power jump" of Gray et al. (1962b) and the jump and reach test traditionally used to measure muscular power are found to have limited application as practical measures of muscular power, a test of leg power is needed that is less time consuming to administer (Glencross, 1966a). Because actual measurements of power output are time consuming and not of practical use outside of the research setting, only an indicator of power is desired in most examinations of vertical jump ability or power.

Types of Vertical Jumps Used in Testing

Throughout the many years of investigation of the vertical jump, power, and leg strength, a wide variety of forms of the vertical jump have been used in testing. The original form, called Sargent's Physical Test of Man or the Sargent Jump was so identified in 1921 (Smith, 1961). This form, however, has rarely been used in recent scientific investigation, except by Glencross (1966a) in his comparison of the vertical jump test and the standing broad jump. The Sargent Jump allows for a natural countermovement as well as the use of both arms in rapid forward flexion to enhance the takeoff velocity and vertical height attained. At least seven forms or modifications of the Sargent Jump have been used for research purposes.

A modification of the Sargent Jump used by Smith (1961) and Gray et al. (1962b) eliminated the use of the arm swing, thus requiring less coordination and more isolation of the leg musculature. This elimination of the arm swing is consistent across all literature consulted except Glencross (1966a). The most common form required subjects either to place both hands on the hips as specified in Gregoire, Veeger, Huijing, and van Ingen Schenau (1984), or to place one hand behind the back while reaching overhead with the other (Gray, Start, & Glencross, 1962a; Gray et al., 1962b).

Another form of the vertical jump that is more concerned with the movement of the knees and the stretch of the involved musculature is called the countermovement jump (CMJ). The CMJ allows the subject to lower him/herself to any depth of knee bend desired, followed immediately by the upward movement of the vertical jump. This unquantified amount of knee bend was termed a "natural" countermovement. This technique was used by Cavagna, Komarek, Citterio, and Margaria (1971) as well as in several other studies (Asmussen & Bonde-Peterson, 1974; Bosco, Komi, & Ito, 1981; Bosco, Tihanyi, Komi, Fekete, & Apor, 1982; Gray et al., 1962b). Other studies utilizing the countermovement, yet not specifying the amount of countermovement, were Gregoire et al. (1984) and Hubley and Wells (1983).

In contrast to the CMJ is the stationary jump (SJ). This form requires the subject to lower his/her body to an unspecified angle of knee bend called a "full squat," pause in that position, and then perform the vertical jump. None of the literature consulted specified the angle of knee flexion in the "full squat" but it is implied to be 90°. Bosco et al. (1981) used the angle of the subject's own natural countermovement but did not specify the angle of either. Hudson (1986) was the only author who stated the length of the pause used in the SJ prior to the vertical jump. It was reported to be 2.25 to 4.25 s.

The SJ forms used by Gray et al. (1962b) are what they called the vertical power jump (VPJ) and the modified vertical power jump (MVPJ). The VPJ test is the most accurate, yet involved, test form and requires the location of the subject's center of gravity, measurement of its displacement during the jump, and measurement of the time over which the force was produced to cause that displacement. This test was used in comparison to the MVPJ, the original jump and reach test, and a squat jump. The MVPJ was a duplicate of the VPJ test in form, but without calculation of the center of gravity movements or the time of force production as in the VPJ. The MVPJ showed a .977 reliability coefficient and a .989 validity coefficient when correlated with the VPJ and also had the highest correlation with the mathematically validated VPJ of Gray et al. (1962b). Asmussen and Bonde-Peterson (1974) used a similar form of the SJ that began from a position called the "semi-squatting" position.

A less frequently used form of the vertical jump test involves jumping off boxes of different heights, landing on both feet, and immediately performing a vertical jump. This technique is sometimes used in training and referred to as plyometric testing. This unique test method was used by Asmussen and Bonde-Peterson (1974) in comparison with a CMJ and a semi-squatting position SJ. They used heights of 0.23 m, 0.40 m, and 0.69 m. It was found that subjects jumping off the first two heights had more stored energy available for tightening and stretching the elastic components of the muscles, thus storing more energy for the vertical jump. The third height (0.69 m) was found to be less efficient than the first two. It was suggested that the force required in breaking the fast downward movement of the jump from 0.69 m before the vertical jump may have impaired performance of the subsequent vertical jump.

A similar method was used by Fukushiro, Ohmichi, Kanehisa, and Miyashita (1981). One part of their study compared the SJ with jumping from 0- to 90-cm heights immediately prior to performing a vertical jump. The second part of the study used repetitive vertical jumps at five different heights for 1 min each. Results indicated that the usable amount of stored elastic energy depends on the negative work previously performed. Their study supports the work of Cavagna et al. (1971), who also used consecutive vertical jumps in comparison to the SJ and CMJ.

It is apparent from the wide variety of forms of the vertical jump used in research that not all vertical jump data are comparable. The complex nature of the movement requires that the form used is chosen to elicit certain information about the various determinants of vertical jump ability.

Determinants of Vertical Jump Performance

As with any complex movement, the list of determinants or factors affecting its execution and resultant performance varies with the sophistication of the testing device. Although many factors could be considered, only a few determinants need to be examined in any depth for the practical evaluation of vertical jump performance. Those of major concern are (a) the effect of muscle fiber types on jumping ability, (b) the use of stored elastic energy, (c) the contribution of body segments, and (d) the knee movement as a key determinant of vertical jump performance.

The Effect of Muscle Fiber Types on Jumping Ability

It is well established that muscle composition varies among individuals and within specific muscles of the same individual (Gollnick & Matoba, 1984). Roy, Baldwin, Martin, Chimarusti, and Edgerton (1985) showed that different muscles have different proportions of fast- and slow-twitch fibers as identified by their speed of contraction (e.g., the predominantly fast-twitch [FT] medial gastrocnemius and the predominantly slow-twitch [ST] soleus muscles). In addition, activities requiring muscular power or explosive contraction rely heavily on FT fibers, and ST fibers are primarily employed during endurance activities. Previous research holds that while both FT and ST motor units are recruited for any movement, FT units are recruited more heavily for high speed or short duration performance (e.g., vertical jumping). It would logically follow that those who excel at a certain activity would have a greater percentage of the appropriate fiber type or would have made exceptional use of their muscle fiber composition (e.g., sprinters would have a high percentage of FT fibers in the thigh and calf muscles or would have nearly 100% recruitment of his/her FT motor units available).

Bosco, Komi, Tihanyi, Fekete, and Apor (1983) attempted to assess the extent to which performance of consecutive jumping for 60 s was related to the percentages of FT and ST fibers distributed in the vastus medialis muscle. Results showed that the percentage of FT fibers best correlated with the power output calculated during the first 15 s of the 60-s test and became insignificant after 30 s. Therefore, the percentage of FT fibers was only a significant factor during the initial stages of repetitive jumping. The remainder of the 60-s test relied more heavily on the ST fibers as the FT fibers became fatigued.

The Use of Stored Elastic Energy

A common characteristic of skeletal muscle fibers is that they possess elastic properties and the ability to store mechanical work energy when stretched. The elastic properties of muscle have been identified and studied for over 100 years. Theories of muscle elasticity acting as a buffer and temporary storage site of mechanical energy have varied and developed as research has progressed (Asmussen &

Bonde-Peterson, 1974). The use of this elastic energy potential is common in all types of human locomotion (Bosco, Luhtanen, & Komi, 1983). This storage of mechanical work energy is thought to occur in sarcomere cross bridges by rotating myosin heads backwards against their natural tendency to a position of higher potential energy (Bosco, Tihanyi, et al., 1982; Fukushiro et al., 1983).

An important factor in the use of stored elastic energy is the speed of the stretch prior to concentric muscle contraction. The ability to store this energy may vary according to the speed of the stretch, final muscle length, and the force developed at the end of the stretch (Bosco et al., 1981; Bosco, Ito, et al., 1982). In a later study, Bosco, Tihanyi, et al. (1982) showed that FT fibers were able to store greater amounts of mechanical energy during small, fast stretches, but ST fibers were more efficient at using energy from larger, slower stretches. The slower coupling times of ST fibers allowed them to retain energy longer that FT fibers with shorter coupling times. It was also shown that the speed of force development and final force developed prior to the positive work phase was greater in FT fibers.

The improvements resulting from muscle stretch prior to concentric muscle contraction were shown to be a 66% force increase and an 81% power increase (Bosco et al., 1981). In a similar study, Cavagna et al. (1971) found a 70% power increase, a 10% work increase, and a 6% maximal speed of movement increase with a stretch prior to concentric muscle contraction in vertical jump testing. This 11% difference in observed power increases may be attributed to a lack of standardization of knee flexion prior to jumping in these and other studies of vertical jump ability. These increases in power, force, work, and maximal speed of movement demonstrate the importance of optimal stretch prior to vertical jump performance. Minimizing the effect of such a variable is crucial to isolating other characteristics of superior vertical jump performers.

Many authors agree that the speed of shortening and the degree of stretch prior to concentric muscle contraction are the limiting factors of maximal upward speed and power (Asmussen & Bonde-Peterson, 1974; Bosco et al., 1981; Bosco, Ito, et al., 1982; Bosco, Tihanyi, et al., 1982; Cavagna et al., 1971; Fukushiro et al., 1983). As in the work of Bosco, Luhtanen, et al. (1983), a 90^{0} knee bend prior to vertical jumping seems to be best for standardizing the degree of muscle stretch prior to concentric muscle contraction. Bosco et al. (1981) and Bosco, Tihanyi, et al. (1982) state that the elastic energy is reused if the muscle is allowed to shorten immediately after the stretch. Therefore, the use of a pause prior to the vertical jump in testing may serve to decrease the effect of fiber type advantages and decrease the use of stored elastic energy. This will serve to cause the muscles to obtain most of their energy from chemical energy transformation within the muscles themselves (Bosco, Luhtanen, et al., 1983).

The Contribution of Body Segments

Glencross (1966a) identified shoulder flexion and leg extension (i.e., the combination of hip extension, knee extension, and ankle plantar flexion) as the major movements of the vertical jump. The timing and sequencing of the segmental movements (i.e., the coordination and order in which the muscles contract to produce movement of a multiple jointed limb) seem to be the keys to optimal performance in the vertical jump (Hudson, 1986). Hudson explained that such movement is either simultaneous or sequential. Any task in which the object to be thrown or the mass to be moved is heavy and/or the distal end of the linkage is closed (e.g., the squat in weightlifting or the vertical jump) is expected to be produced by simultaneous joint movements. Any task in which the object to be thrown is light is expected to be produced by sequential joint movements. In that study on 20 lean adult track athletes, Hudson found the simultaneous pattern of coordination to be more representative of vertical jump movement than the sequential pattern. However, both patterns were observed among the subjects tested.

In a study on eight male subjects performing the CMJ with their hands on their hips, Gregoire et al. (1984) found the timing of hip, knee, and ankle extension to be sequential. The disagreement between Hudson (1986) and Gregoire et al. (1984) as to whether the vertical jump is a simultaneous or a sequential pattern of movement lends support to the idea of a modified simultaneous pattern suggested by Hopper (cited in Hudson, 1986). He suggested that although simultaneous extension is attempted, the rapid trunk acceleration actually increases the knee and ankle flexion before the three movements can become simultaneous. This idea allows for both sequential and simultaneous patterns of coordination, which may better represent some of the variance between skilled and unskilled jumpers.

The Knee as a Determinant of Vertical Jump Ability

Many studies have been done to identify the musculature most responsible for the action of a specific joint, but little has been done to establish the importance of specific joints in a complex movement. Hubley and Wells (1983) used a work-energy approach to determine which joints in the lower limb contribute the most work during the vertical jump. By calculating the net mechanical work done by the agonists and antagonists, it was shown that the knee contributed an average of 49% of the total work done in both the CMJ and SJ. The hips and ankles contributed 28% and 23%, respectively. This supports the work of Luhtanen and Komi (1978), who analyzed the contribution of different body segments to the forces acting on the body's center of gravity. Data showed that 56% of the takeoff velocity was caused by knee extension, 23% by ankle plantar flexion, 10% by trunk extension, 10% by arm swing, and 2% by head swing or neck extension.

In a rare study on the angular velocity and range of motion of the hips, knees, and ankles during the vertical jump and standing broad jump, Eckert (1968) stated that the greatest probability of finding some relationship between maximal strength and maximal angular velocity in the vertical jump would be in the action of the knee or ankle. In looking at the contributions of hip extensors, knee extensors, and ankle plantar flexors, Bangerter (1968) found that the knee and hip extensors are responsible for almost all of the height attained in the vertical jump. Subsequently, the knee joint and surrounding musculature have been the areas of central focus of the majority of research on vertical jump performance.

Physiological Characteristics of the Vertical Jump

As the knee joint and the surrounding musculature have been shown to be central to the examination of vertical jump ability, two physiological characteristics need to be considered prior to its examination. These characteristics are hamstring-to-quadriceps (H:Q) strength ratios and the speed of joint movements in the vertical jump.

Hamstring-to-quadriceps Strength Ratios

The importance of muscular strength for optimal performance is well documented in the literature. However, as sport programs become increasingly competitive, the need for more extensive evaluation of muscular strength characteristics has emerged. Two such characteristics under investigation are balance of strength between bilateral muscle groups (e.g., left and right hamstring groups) and balance between agonists and antagonists of the same limb (e.g., hamstring and quadriceps groups of the left leg). This latter relationship is called the H:Q ratio and refers to the ratio of the maximum torque produced by the hamstring group during knee flexion divided by the maximum torque produced by the quadriceps group during knee extension.

Klafs and Arnheim (1981) stated that a 10% or greater imbalance between bilateral muscle groups produces a high incidence of strain to the weaker group and that strains occur most frequently in individuals with some deficiency in the reciprocal or complementary action of opposing muscle groups. However, Stafford and Grana (1984) stated that, although bilateral torques may be within that 10% safety zone between muscle groups, bilateral H:Q ratios may not be within that 10% safety zone. This comparison of H:Q ratios, as compared to only looking at the H:Q ratio of each leg separately, is thought to be a more sensitive indicator of readiness to participate or readiness to return to competition after injury rehabilitation.

Normally, the hamstring muscle group is 50% to 60% as strong as the quadriceps muscle group (Appen & Duncan, 1986; Klafs & Arnheim, 1981). Imwold, Rider, Haymes, and Green (1983) reported that a 0.60 H:Q ratio is the accepted value for college athletes, and Laird (1981) reported that a 0.60 H:Q ratio is optimal for injury prevention. The work of Holmes and Alderink (1984) on high school student athletes reports the same values.

Due to the selective nature of competitive sport, individuals competing in a certain sport usually share similar physical characteristics (e.g., sprinters generally demonstrate greater strength and less endurance than marathon runners). In their study of the related literature, Stafford and Grana (1984) reported that optimal H:Q ratios differ between males and females, from sport to sport, and at different testing speeds, depending on the requirements of each athlete's position and sport.

In general, as testing speed increases from 180 to 300°/s, torque values decrease and the H:Q ratio increases (Stafford & Grana, 1984). Because the quadriceps torque value decreases more than the hamstring torque value with increasing speed of contraction, the H:Q ratio increases toward 1.0 or "unity" (Appen & Duncan, 1986; Holmes & Alderink, 1984; Imwold et al., 1983; Stafford & Grana, 1984). This indicates a need for muscular balance unilaterally as well as bilaterally for injury prevention, especially for sports activities performed at high speeds (Imwold et al., 1983). However, little research has been done using the higher speeds of 180 to 300°/s.

The Speed of Joint Movements in the Vertical Jump

Although past research has shown little, if any, significant relationship between vertical jump ability and H:Q strength ratios, it is crucial to note that the speeds used in previous research were far from approximating the actual speed of movement in the vertical jump. This speed factor seems to have been overlooked in establishing test protocols that will best isolate the characteristic of study and therefore differentiate between skilled and unskilled jumpers.

In a study on the angular velocity and ROM in the vertical jump and standing broad jump in men, Eckert (1968) found that the maximal angular velocity of the knee during the vertical jump was 902.8 $\pm$ 128.5°/s. Additionally, the ankle was recorded to plantar flex at a speed of 1,079.7 $\pm$ 126.2°/s. This work is given support by the work of Gregoire et al. (1984) on the role of mono- and biarticular muscles in explosive movements, in which they stated that the ankle moves at over 1,000°/s in plantar flexion during the vertical jump. These velocities are much faster than any objective and verifiable muscle testing device, other than high speed film analysis.

Testing speeds used in research to examine H:Q ratios ranged from 30 to 300°/s. Most of these studies merely examined the increase in H:Q ratio with increasing test speed. In their study on the relationship between isokinetic torque at two speeds and vertical jump ability, Genuario and Dolgener (1980) tested 29 female athletes at 30 and 180°/s on the Cybex and correlated peak torques with the vertical jump scores. Results showed low, yet positive, relationships of .513, $p < .01$, between vertical jump expressed in ft-lb and the torque produced by the quadriceps muscles at 180°/s, and .369, $p < .05$, for vertical jump scores with the torque produced by the hamstrings at 180°/s. This positive relationship indicates that strength is related to vertical jump ability and should be examined further at speeds closer to the actual speed of movement.

The Cybex and Cybex II (see Appendix F) isokinetic muscle testing machines have been the ones most commonly used in such research, but their capacity does not allow work at speeds greater than 300°/s. The only study using a testing speed greater than 300°/s was that of Osternig, Hamill, Sawhill, and Bates (1983), who used a modified Orthotron machine to test subjects at eight speeds ranging from 50 to 400°/s. Recently, however, the Universal Gym Equipment, Inc. (see Appendix F) has produced an isokinetic muscle testing machine, called the Merrac, that works at speeds up to 500°/s. However, it is relatively unavailable in most research settings. In summary, although it is evident that available modern isokinetic muscle testing devices do not even approach functional speeds of joint motion in the vertical jump, they are the closest and most reliable approximation available.

Isokinetic Dynamometry

The concept of isokinetic exercise was developed by James Perrine in the late 1960s (Davies, 1984). Over the past 20 years, the use of isokinetic exercise has steadily expanded to include training, diagnostic testing, and rehabilitation (Holmes & Alderink, 1984). The requirements of high intensity competition have revealed the need for testing and training equipment that better simulates the speed and intensity of actual sport performance. While most athletic movements occur at speeds from 90 to over 200^{o}/s, isotonic exercise rarely exceeds 60^{o}/s (Fox & Matthews, 1981; Halling & Dooley, 1979; Stafford & Grana, 1984). In light of this difference, a comparison of isokinetic and isotonic testing instruments and special considerations when using the Cybex II will be discussed in the following sections.

<u>Isokinetic and Isotonic Testing Instruments</u>

The main difference between isokinetic and isotonic exercise is that in isokinetic exercise the speed of movement is constant and limited, the resistance accommodates to the force applied, and the amount of force required to move the apparatus is maximum throughout the movement as long as the preset speed is met (Halling & Dooley, 1979). In isotonic movement, these characteristics are not evident. In isotonic muscle loading, weights or weight machines used to measure a one-repetition maximum are limited in that the maximum amount of weight to be lifted is determined by the weakest point in the range of motion (ROM) (Elliot, 1978). This results in less than full resistance throughout the ROM, which is unacceptable for testing maximum muscular strength. Therefore, the differences between isokinetics and isotonics are readily apparent.

Davies (1984) defined isokinetic movement as movement at a fixed speed (e.g., 1 to 500^{o}/s) against an accommodating resistance and defines isotonic movement as movement at a variable speed against a fixed resistance. Machines such as the Nautilus (see Appendix F), sometimes mislabeled as isokinetic, Eagle (see Appendix F), or Universal gym equipment are a cross between isokinetic and isotonic exercise and thus may be labeled as pseudoisokinetic (Davies, 1984). They are isokinetic in that the resistance varies throughout the ROM according to the joint position and the design of the apparatus (e.g., the cam in the Nautilus machine functions as an efficient fulcrum at the point that the joint and surrounding musculature are inefficient). They are isotonic in that the resistance is a fixed weight and the speed of movement is variable, not controlled or constant.

Although there are many advantages and some disadvantages to using isokinetic exercise, Davies (1984) listed the following as unique advantages: (a) efficiency, (b) safety, (c) decreased joint compressive forces, (d) minimal postexercise muscle soreness, (e) high validity, and (f) high reliability. Davies also listed the following disadvantages: (a) cost of some equipment, (b) lack of eccentric muscle loading, (c) decreased sensitivity in testing large muscled joint motions, (d) time-consuming equipment changes, and (e) lack of resistance until preset speed is met.

Overall, because modern isokinetic devices can function at speeds from 1 to 500°/s, they have proven useful for simulating speeds of actual sport performance. Therefore, true isokinetic contractions and training programs are considered by many to be superior to isotonic and pseudoisokinetic programs (e.g., Nautilus) for improving muscular strength, power, and endurance for athletic performance (Fox & Matthews, 1981).

The most commonly used isokinetic device on the market is the Cybex II. This device was developed by Cybex in 1970 as an isokinetic muscle testing device used for diagnostic testing, rehabilitation, and training of all major joints of the body (Elliot, 1978). The Cybex II has been shown to be highly reliable and valid in recording maximum force generation throughout the ROM (Imwold et al., 1983). It is adaptable to any of the major joints of the body and is adjustable to the size of the subject. The Cybex II provides full accommodating resistance throughout the ROM, provided that the preset speed of the machine is met by the applied force. Speeds may be set at 1 to 300°/s. Extra effort is registered as torque displayed in ft-lb, and insufficient speed (effort) will register as 0 torque. Because the system provides accommodating resistance for pain and fatigue, it is safe for postinjury diagnostic testing and rehabilitation (Elliot, 1978). A dual channel recorder, a dynamometer, and an electrogoniometer provide accurate simultaneous recording of torque curves and ROM throughout the concentric joint motion. However, the Cybex II does not assess eccentric strength characteristics, which are also important for joint stabilization and injury prevention (Elliot, 1978).

<u>Special Considerations When Using the Cybex II</u>

In the use of such a highly sophisticated and versatile machine as the Cybex II, there are special considerations and procedures to be used in testing, depending on the desired information and purpose of its use. Three such considerations are (a) correction for the effect of gravity, (b) torque overshoot, and (c) machine damping.

One area of considerable debate is the importance of correcting torque values for the effect of gravity. Nelson and Duncan (1983) stated that maximum torque values, as recorded on the Cybex II isokinetic dynamometer, are significantly affected by gravitational forces. Due to the nature of the machine, knee extension works against gravitational forces and knee flexion works with gravitational forces. When these forces are not accounted for, the result is an underestimation of quadriceps muscle group torque and an overestimation of hamstring muscle group torque, thereby significantly altering the H:Q ratios at all testing speeds (Appen & Duncan, 1986). During both endurance and high-velocity testing, the effect of gravity becomes more pronounced as active torque generation decreases (Nelson & Duncan, 1983).

Nelson and Duncan (1983) believed that the correction for gravity technique of Winter, Wills, and Orr (1981) required equipment that was too sophisticated for practical usage. They also found two difficulties with the formula provided by the Cybex II manufacturer (Lumex, Inc.). First, they were unable to obtain the anticipated zero effect of gravity when the input arm was vertical. Second, they believed the mathematical derivation of the formula was unclear. Therefore, Nelson and Duncan developed their own technique and formula, which seemed accurate and clinically feasible for practical usage.

A second area of consideration and a major problem with the Cybex II is that of torque overshoot. Until the accelerating limb-lever system meets the preset speed of the machine, there is little or no resistance other than the weight of the limb and the input arm of the machine. The accelerating limb matching the preset speed causes prominent initial torque spikes and secondary oscillations that falsely appear on the readout as intermittent surges of contractile force (Sapega, Nicholas, Sokolow, & Saraniti, 1982). These torque spikes, called overshoot and undershoot, are associated with the deceleration and subsequent velocity fluctuations of the accelerating limb-lever system moving faster than the preset speed of the machine during the initial part of the ROM (Sapega et al., 1982). One cause is identified as a time lag of 0.0035 $\pm$ 0.0005 s between actual resistance of the machine and actual movement of the recording stylus away from the baseline recording. A second cause is identified as elastic deformation of the system itself when rapidly loaded under testing (Sapega et al., 1982). It was concluded, however, that there is less overshoot at higher speeds of testing.

A third consideration is the effect of damping of the machine. This refers to an adjustment of the machine to reduce the effects of overshoot. However, the damping inadvertently suppresses some of the actual muscular forces produced as well as the overshoot (Sapega et al., 1982). Undamped readouts tend to merge the overshoot with the true torque produced, making it difficult to differentiate between the two. Although damping suppresses actual muscular forces, the damped curve does "lie within the general region of the calculated mean level of true muscular torque" (Sapega et al.). Therefore, when specific torque values are desired for some purpose, a damping of 0 should be used. When specific torque values are used only to form ratios (e.g., H:Q ratios), the damping setting is not a major concern.

Summary

As the need and desire to obtain more objective and practical knowledge about the skill and physical requirements of the vertical jump have increased over the past century, so has the amount of research in the area of exercise physiology and biomechanics. As exemplified in the literature, a variety of forms of the vertical jump have been used, depending on the type of information that was desired from that examination of the skill. Although there have been some misconceptions as to what the "vertical jump test" actually measures, the standard form of the test has been accepted as an indicator of muscular power rather than a pure measure of power itself. The complex nature of the skill provides numerous areas for investigation and analysis in order to find the source of the desired characteristic (e.g., power, fiber types, or H:Q ratios). The means of obtaining this information are as varied as the characteristics themselves, ranging from a simple jump test to a more complex analysis, using a modern isokinetic device such as the Cybex II isokinetic muscle testing and rehabilitation device. As of yet, no single determinant of vertical jump ability has been isolated and substantially verified. Thus, the scientific community continues to investigate this common, yet complex motor skill.

Chapter 3

METHODS AND PROCEDURES

The methods and procedures used in this study are recorded in this chapter. They were carefully developed and selected based on previous research in the field and generally accepted protocols for similar testing. The areas described are (a) selection of subjects, (b) methods of data collection, (c) treatment of data, and (d) summary.

Selection of Subjects

The subjects for this study were 43 male basketball players, between the ages of 18 and 24 years, recruited as volunteers from Ithaca College, SUNY at Cortland, and Cornell University. Subjects were recruited by verbal request at the end of a team practice or by personal request to those not present at practice that day. Subjects were tested between October 15 and December 15, 1987. Only those not receiving treatment or rehabilitation for a hip, knee, or ankle injury on the day of testing were allowed to participate. The informed consent (see Appendix A) was approved by the Ithaca College All-college Review Board on Human Subjects Research and signed by each subject prior to participation.

Methods of Data Collection

Data collection was divided into three phases, described as (a) the vertical jump test, (b) the gravity correction procedure, and (c) the Cybex II strength tests.

The Vertical Jump Test

The vertical jump test used was similar to the modified vertical power jump of Gray et al. (1962b). A written explanation of the test was given to the subject to read (see Appendix B) and read to the subject, and then the test was demonstrated prior to data collection. The testing proceeded as follows:

1. The subject stood sideways, approximately 6 in. from the jump scale, with his dominant arm extended overhead and closest to the jump scale, and the other hand grasping the back of his waistband.

2. While standing with his feet approximately 6 in. apart and flat on the ground, the subject's initial maximum reach height was recorded where he touched the scale with the chalked middle fingertip.

3. With the back straight and the arms overhead and behind the back as mentioned above, the subject squatted to a knee bend of approximately 90°.

4. When instructed to stop, the subject paused in that position for 3 s and then jumped on cue.

5. The subject was given three trials.

6. The maximum jump height of the three trials was measured to the nearest 0.5 in. and determined by subtracting the standing reach height from the jump height as touched on the scale with the chalked fingertip.

The Cybex II Strength Tests

The procedures and protocols used in the Cybex strength testing phase of this study were carefully selected based on the previous research in the field and the standard protocols for Cybex testing as described in the Cybex II instruction manual. Procedures used in this study were as follows:

1. The Cybex was calibrated according to the Cybex manual. The frequency of calibration was (a) before every subject at Ithaca College, (b) before every subject (except two) at SUNY at Cortland, and (c) on October 16 and November 21 at Cornell University. Only negligible adjustment was ever needed at any of the testing sites during calibration procedures.

2. Cybex II settings used were (a) a damping of 2, (b) the 180-ft-lb scale, and (c) the 150° scale.

3. The subject was positioned in a seated, upright position and securely strapped in place at the chest, hips, thigh, and ankle.

4. The dynamometer was adjusted so that the axis of the input arm was in alignment with the condyles of the femur and so that the ankle pad allowed full ankle dorsiflexion.

5. The subject's descriptive data were entered into the computer prior to beginning the appropriate protocol.

6. Each subject was given a copy of the Cybex test instructions outlined in Appendix E, which were read aloud to the subject.

7. The subject was allowed 10-15 repetitions of extension and flexion as a warm-up prior to testing at each speed.

8. When the subject indicated readiness, he was instructed to perform five maximal effort repetitions on the cue to begin.

9. Peak hamstring torque (PHT), peak quadriceps torque (PQT), and the angles of peak torque were recorded from the computer before each test to allow adequate rest and recovery between tests.

10. The sequence of steps 7 to 9 were repeated for each of three test speeds. These speeds were 180, 240, and 300°/s.

11. The testing speed sequence was altered to negate the order effect of subjects experiencing the same sequence of test speeds. When one subject's appointment did not immediately follow that of another subject, the speed sequence was not altered. As a result, 27 subjects were tested in the sequence 180, 240, and 300°/s, 11 were tested in the sequence 240, 300, and 180°/s, 4 were tested in the sequence 300, 240, and 180°/s, and 1 subject was tested in the sequence of 300, 180, and 240°/s. Data were considered comparable, as the warm-up trials at each test speed were considered adequate to familiarize the subject with the apparatus and test speed, regardless of the testing sequence.

<u>The Gravity Correction Procedure</u>

The gravity correction procedure is a measurement taken on each subject to make specific adjustment of his torque values according the weight of the limb being tested. Although there is some disagreement as to whether or not it is necessary to make correction for the effect of gravity when using the Cybex, without such correction, torque values are not thought to be true measures of absolute strength. Therefore, gravity correction was believed to be necessary to obtain the most accurate data possible.

The computer interface at each testing location utilized a different computer program. However, despite this difference, it was believed that comparable data would be obtained at each testing site.

The gravity correction procedure of the Isoscan program (see Appendix F) at Ithaca College was not functioning properly. Therefore, the procedure of Nelson and Duncan (1983) was adopted for use. Administration of this procedure in conjunction with the Isoscan program was relatively quick, and results were easily calculated (see Appendix C).

The Humac program (see Appendix F) used at SUNY at Cortland, however, did not contain a gravity correction procedure. Through phone consultation with Computer Sports Medicine, Inc. (personal communication, October 1987), it was stated that their "research at Massachusetts General Hospital showed subjects were unable to consistently relax their leg musculature to obtain accurate gravity correction, and therefore, a gravity correction procedure was not included in the Humac program." However, for the purpose of consistency, the procedure of Nelson and Duncan (1983) was used on the data collected at this location.

Each subject was given a copy of the correction instructions outlined in Appendix D, and the instructions were read to each subject prior to participating in the gravity correction procedure. The correction procedures of Nelson and Duncan (1983) are described as follows:

1. The Cybex II dynamometer and channel recorder must be calibrated according to the instructions supplied by with the Cybex unit.

2. The torque resulting from the weight of the leg and input accessories is determined by (a) the tester instructing the subject to completely relax the musculature while the tester raises the leg and input accessories to full extension, and (b) then allowing the leg to fall passively against the resistance of the machine set at 30 /s.

3. Simultaneous recordings of the torque generated by the passive flexion of the knee and the angle at which this torque was maximum are taken.

4. Steps 2 and 3 are repeated three to five times as necessary to obtain accurate measurements, and the largest torque measure is used for correction calculations (see Appendix C for correction formulas).

The gravity correction procedure used at Cornell was that which was already programmed into the Cybex II computer and described fully in the Cybex II instruction manual. This procedure was repeated until the correction factor appeared proportional to the subject's body weight (e.g., when a heavy subject produced a smaller correction factor than other athletes of similar or lighter body weight, the correction procedure was repeated).

Treatment of Data

The data collected were as follows:

1. The largest of three vertical jump scores was recorded to the nearest 0.5 in. and labeled as maximum vertical jump height.

2. The largest measure of the combined weight of the leg and the input accessories and the coinciding angle recorded during gravity correction procedures were recorded to the nearest ft-lb and the nearest degree, respectively. These values were used in calculating the gravity-corrected values for peak torque and H:Q ratios for each subject. These H:Q ratios were recorded as decimals to the nearest 0.01.

3. The largest torque value for each test of the hamstring and quadriceps muscle groups was recorded as peak torque. Those peak torque values and the coinciding angles for peak torque were recorded for each test speed and used in calculating gravity-corrected torque. The torque values were recorded to the nearest ft-lb and the angles to the nearest degree.

The data collected were entered into an Ithaca College VAX superminicomputer for a total of 43 subjects. A Pearson product-moment correlation was applied to relate vertical jump scores with gravity-corrected H:Q ratios at each test speed. Vertical jump scores were related with noncorrected H:Q ratios for 29 of the subjects. Multiple correlations between vertical jump scores, PHT, and PQT were also employed. Resulting _r_ values were tested for significance at the .05 level.

Summary

For the purposes of examining the relationship between vertical jump ability and upper leg muscle strength in male collegiate basketball players, 43 male basketball players from Ithaca College, Cornell University, and SUNY at Cortland were recruited as volunteer subjects for this study. Testing procedures included (a) three trials of a maximal vertical jump test, (b) a gravity correction procedure, and (c) a five-repetition maximal effort strength test at each of three speeds performed on the Cybex II isokinetic dynamometer.

The data collected were vertical jump height, vertical jump work, limb weight, PHT, PQT, and H:Q ratios. Pearson product-moment correlations were applied to relate vertical jump measures with gravity-corrected PHT and with PQT. Vertical jump measures were also related with noncorrected PHT and with PQT. Multiple correlations among vertical jump measures, PHT, and PQT were also examined.

Chapter 4

RESULTS

The data obtained from this investigation are presented as (a) vertical jump scores, (b) gravity-corrected hamstring-to-quadriceps (H:Q) ratios, (c) noncorrected H:Q ratios, (d) correlations of vertical jump with H:Q ratios, (e) correlations of work with H:Q ratios, (f) correlations of work with peak quadriceps torque (PQT), and (g) multiple correlations.

Vertical Jump Scores

The first data collected for each subject was his vertical jump score. As shown in Table 1, whether expressed as a distance measure (in.) or a work measure (kgm), the mean vertical jump scores for Cornell University subjects were considerably higher than the total group means. The mean scores for Ithaca College and SUNY at Cortland do not appear to be significantly different.

As shown in Table 2, analysis of variance (ANOVA) demonstrates a significant difference among the three schools tested at $F(2,40) = 9.26$, $p < .05$. Use of the Tukey test shows that vertical jump scores of Cornell University subjects are significantly different from those of Ithaca College and from those of SUNY at Cortland. However, scores of Ithaca College and SUNY at Cortland subjects were not significantly different from each other.

Table 1

Vertical Jump Scores

School	N	M ± SD (in.)	Mode (in.)	Range (in.)
Ithaca	20	16.0 ± 1.5	15.5	7.0
Cortland	9	17.0 ± 2.5	15.0,17.0	5.5
Cornell	14	18.5 ± 2.5	17.0	8.5
Total	43	17.0 ± 2.5	16.5	10.0

School	N	M ± SD (kgm)	Mode (kgm)	Range (kgm)
Ithaca	20	34.2 ± 4.1	32.0,35.0	17.7
Cortland	9	35.0 ± 6.7	--	23.1
Cornell	14	44.7 ± 10.5	--	37.4
Total	43	37.8 ± 8.6	35.0	36.2

Note. All vertical jump scores are reported to the nearest 0.5 in. and the nearest 0.1 kgm.

Table 2

ANOVA of Vertical Jump Scores Among Three Schools

Source of Variation	SS	df	MS	F
Among	986.53	2	493.27	9.26*
Within	2129.70	40	53.24	
Total	3116.24	42		

*$p < .05$.

Gravity-corrected H:Q Ratios

The second part of the data collection was to obtain gravity-corrected H:Q ratios at three test speeds. As shown in Table 3, the mean scores for gravity-corrected H:Q ratios at Ithaca College and Cornell University remained consistent across test speeds from 180 to 300°/s, but the scores at SUNY at Cortland did not. Mean scores for Ithaca subjects were considerably higher than the total group means, and those of Cortland subjects were considerably lower. The mean scores of Cornell subjects were very similar to the total group means. In addition, the standard deviation at Ithaca was noticeably larger than that of the total group and larger than that at the other schools.

Noncorrected H:Q Ratios

Although unavailable at Cornell University, non-gravity-corrected scores were obtained at Ithaca College and SUNY at Cortland. As shown in Table 3, athletes at both schools produced scores whose means only slightly differed from each other. However, as with the gravity-corrected H:Q ratios, the standard deviation at Ithaca College was considerably larger than at SUNY at Cortland. It is important to note that the noncorrected scores of Table 3 are much higher than the gravity-corrected scores and that a noncorrected H:Q ratio of 0.60 is considered a normal ratio for college athletes (Imwold et al., 1983) and optimal for injury prevention (Laird, 1981). Therefore, the H:Q ratio closer to the accepted value is the better score.

Table 3

H:Q Ratios

School	Test Speed (^{o}/s)	*N*	Gravity-corrected *M* ± *SD*	Noncorrected *M* ± *SD*
Ithaca	180	20	0.73 ± 0.14	0.87 ± 0.16
	240	20	0.75 ± 0.17	0.90 ± 0.19
	300	20	0.74 ± 0.19	0.90 ± 0.20
Cortland	180	9	0.55 ± 0.04	0.81 ± 0.14
	240	9	0.60 ± 0.09	0.89 ± 0.16
	300	9	0.61 ± 0.10	0.93 ± 0.18
Cornell	180	14	0.66 ± 0.08	--[a]
	240	14	0.68 ± 0.09	--
	300	14	0.66 ± 0.11	--
			N = 43	*N* = 29
Total	180		0.67 ± 0.13	0.85 ± 0.14
	240		0.70 ± 0.15	0.90 ± 0.16
	300		0.69 ± 0.16	0.91 ± 0.18

Note. All H:Q ratios are reported to the nearest 0.01.

[a]Noncorrected scores were not available at Cornell University.

Correlations of Vertical Jump with H:Q Ratios

The null hypothesis for this investigation stated that there would be no significant relationship between vertical jump ability and upper leg strength at movement speeds of 180, 240, and 300°/s. As shown in Table 4, the Pearson product-moment correlations for gravity-corrected H:Q ratios at each test speed showed extremely small negative relationships of -.161, -.048, and -.021, respectively. Correlations with noncorrected H:Q ratios also showed small negative relationships of -.134 and -.005 at speeds of 180 and 240°/s, respectively. A small positive relationship of .043 was seen at 300°/s. However, whether negative or positive, these correlations are not statistically significant at the .05 level. Therefore, the null hypothesis is supported, indicating no relationship between jumping ability and H:Q ratios.

Correlations of Vertical Jump Work with H:Q Ratios

Vertical jump scores were converted from a distance measure (in.) to a work measure (kgm) to account for the effect of body weight on vertical jump performance. As shown in Table 5, the Pearson product-moment correlations for gravity-corrected H:Q ratios with work at each test speed also showed extremely small relationships. This also supports the null hypothesis.

Table 4

Correlations of Vertical Jump With H:Q Ratios

Speed (°/s)	With Gravity-corrected H:Q (N = 43)	With Noncorrected H:Q (N = 29)
180	-.161	-.134
240	-.048	-.005
300	-.021	+.043

Note. Noncorrected scores were not available at Cornell University.

Table 5

Correlations of Work with H:Q Ratios and with PQT

Speed (°/s)	With Gravity-corrected H:Q (N = 43)	With Noncorrected H:Q (N = 29)
180	-.074	.108
240	-.025	.047
300	.052	.190

Speed (°/s)	With Gravity-corrected PQT (N = 43)	With Noncorrected PQT (N = 29)
180	.203	.271
240	.063	.303
300	-.077	.279

Note. Noncorrected scores were not available at Cornell University.

Correlations of Vertical Jump Work with Peak Quadriceps Torque

Vertical jump scores expressed as work were also correlated with gravity-corrected and noncorrected PQT values. As shown in Table 5, most of the Pearson product-moment correlations were much higher than the correlations of jump scores with H:Q ratios. Statistical significance for 43 subjects at the .05 level requires *r* = .296. The largest correlation achieved with gravity-corrected peak torques was .203, occurring at 180°/s. For 29 subjects, *r* = .367 is required for significance at the .05 level. The largest *r* values achieved were .271, .303, and .279 at 180, 240, and 300°/s, respectively. Therefore, no correlations between work and PQT indicate any significant relationships.

Multiple Correlations

In an attempt to identify the actual value of each component of the H:Q ratio and to explain why both high and low H:Q ratios were found in skilled and unskilled jumpers, multiple correlations were also used. Vertical jump work scores were regressed on gravity-corrected and noncorrected PHT and PQT at each speed of testing. Such regressions showed that no more than 11.3% of the variance in vertical jump ability can be explained by PHT and PQT.

Chapter 5

DISCUSSION

The purpose of this chapter is to discuss and interpret selected parts of this investigation. Critical to this discussion are the topics of vertical jump scores, peak torque and vertical jump, H:Q ratios and vertical jump, and practical applications.

Vertical Jump Scores

Vertical jump scores were expressed as distance (in.) and in total work (kgm) to take each subject's body weight into consideration. Gray et al. (1962b) stated that correlations of the broad jump, squat jump, jump and reach, and modified vertical power jump individually with the vertical power jump were larger for the work performed than the distance covered during the jump. The modified vertical power jump used by Gray et al. is almost identical to that used in the present study.

Although not all three schools compete at the same division level, it was expected that subjects at each school would be comparable in jumping ability. However, results of ANOVA showed a significant difference between the scores of subjects at Cornell University (Division I), and those at Ithaca College and SUNY at Cortland (Division III). Although one might quickly conclude that the differences between subject performance at each school may be attributed to the division level of the athletic program, these differences may also be attributed to insufficient warm-up prior to vertical jump testing.

Although each subject was given the option and the opportunity to warm-up as desired prior to vertical jump testing, very few subjects at Ithaca and Cortland performed any type of warm-up that would substantially contribute to their performance. Due to time constraints at the close of the school semester and the availability of the subjects, approximately 10 out of the 14 Cornell subjects were tested during a warm-up drill at the start of a practice. Therefore, their scores would be expected to be closer to maximal than those of subjects who chose not to warm-up prior to testing.

Peak Torque and Vertical Jump

After the collection of peak torque values and the examination of H:Q ratios, vertical jump work scores were related to gravity-corrected and noncorrected PQT values. Correlations with gravity-corrected PQT values were not significant at any speed. Correlations run with the 29 noncorrected PQT values available were larger but still did not reach significance at the .05 level.

Additionally, multiple correlations were run between vertical jump scores, PHT, and PQT for gravity-corrected and noncorrected torque values at all three speeds of testing. Results showed that even the combined variables of PHT and PQT did not account for any more than 11.3% of the variance in vertical jump ability, which was not significant at the

.05 level.

In contrast, Considine and Sullivan (1973) found a small, yet statistically significant relationship of r = .35, p < .05, between vertical jump ability and cable tensiometer strength of the nondominant knee. The work of Genuario and Dolgener (1980), on 29 female athletes, showed a moderate relationship of r = .513, p < .01, between vertical jump work and noncorrected PQT values on the Cybex at 180°/s. An even larger relationship of r = .64, p < .01, was found by Berger and Henderson (1966) in their examination of static leg strength and a modification of the leg power test of Gray et al. (1962a).

The differing results between these studies and the present study may be explained by certain methodological considerations. It is important to note that Considine and Sullivan (1973) and Berger and Henderson (1966) used a cable tensiometer and a squat-like leg dynamometer, respectively. Both movements are considerably different from those performed on the Cybex. Also, Genuario and Dolgener (1980) did not use a standard Cybex protocol and performed their study on women.

Smith (1961), however, found no significant relationship between static strength and physical performance tests such as the vertical jump. Smith suggested that force exerted against a dynamometer required a different neuromotor pattern than would be required in the performance of a dynamic movement, such as the vertical jump. Therefore, as the

Cybex II test and the vertical jump are both considered to be tests of dynamic strength, a positive relationship may be found to the degree that both movements are produced by similar neuromotor patterns. However, even though the same muscle groups contract in both movements, the two movements may not recruit all of the same motor units. In such a case, the fewer the number of similar motor units recruited during the two movements, the less the two movements may be considered to be related. It was an assumption of the present investigation that the two tests utilized would stress similar neuromuscular structures. However, results of this study do not support that assumption.

H:Q Ratios and Vertical Jump

Although the primary focus of this investigation was on vertical jump ability, the secondary focus was on the physiological characteristics of H:Q ratios and general strength measures at each of three speeds of movement. In consideration of the data and subsequent correlations, there appears to be no significant relationship between vertical jump ability and the specific leg strength characteristics investigated in this study. It is apparent, therefore, that the primary consideration should have been upon absolute strength, not H:Q ratios.

One possible reason for this lack of significance is that the hamstrings may not really be a key factor in vertical jump ability. Although the hamstrings do act as hip extensors, their contribution to hip extension during the vertical jump movement may be less than anticipated. Their function as decelerators of knee extension may be their main function during the vertical jump, leaving the production of hip extension mainly to the gluteal muscles. This would explain why hamstring strength and subsequent H:Q ratios seem to be inconsequential to optimal vertical jump performance.

Comparison of mean gravity-corrected and noncorrected H:Q ratios show that peak torque values and subsequent H:Q ratios are significantly affected by gravitational forces. Consistent with the work of Nelson and Duncan (1983) and Appen and Duncan (1986), the present study confirms that torque values obtained on the Cybex overestimate the strength of the hamstrings and underestimate that of the quadriceps, thus causing the H:Q ratios to be lower than those corrected for gravitational forces.

It was believed that the better jumpers would begin with, and maintain, H:Q ratios similar to the normal ratio of 0.60, even as speed of movement increased to 300°/s. To do so, the subject would have to continue to produce similar quadriceps torque levels at all three speeds of movement, whereas the expected pattern is for the quadriceps torque to decrease more than the hamstring torque decreases (Appen & Duncan, 1986; Holmes & Alderink, 1984; Imwold et al., 1983; Stafford & Grana, 1984). Although some of the better jumpers from each school maintained a "normal" H:Q ratio across test speeds, the majority of the subjects at each school followed the expected pattern, increasing toward 1.0 as test speed increased.

Correlations of vertical jump scores, expressed in in. and in kgm, with gravity-corrected and noncorrected H:Q ratios did not show statistically significant relationships at any speed of testing. Though numerous studies have examined the vertical jump skill and others have examined H:Q ratios produced by athletes on the Cybex II, the present investigation is apparently the first to examine the relationship between the two. It is concluded that both skilled and unskilled jumpers may have the same H:Q ratios, and there appears to be no relationship between vertical jump ability and H:Q ratios.

Practical Applications

As discussed in the review of literature, the vertical jump movement is complex, requiring coordination and timing of the involved structures. The test form selected for this investigation was designed to isolate the strength characteristics of the quadriceps and hamstrings as much as possible. Therefore, other factors that significantly contribute to the height attained in the vertical jump, such as the use of stored elastic energy and the arm swing, were reduced as much as possible.

Due to the unique form of the vertical jump required for the test (i.e., one arm behind the back, one arm overhead, no step prior to the jump, and a pause before jumping), some subjects commented that they felt somewhat awkward. Other subjects commented that they jumped better from one foot and considered themselves "leapers," as opposed to being able to "jump" from two feet. These comments concerning the two movements seem accurate and quite pertinent to the evaluation of vertical jump ability.

This difference between "leapers" and "jumpers" was confirmed by personal observation of the subjects in this investigation and by observing the general population of collegiate basketball players. Those who played an "inside" position, requiring them to "jump" for rebounds and to dunk the ball, performed well in the jump test of this investigation. Those known to be exceptional on the running or "leaping" dunk did not perform in a comparable manner when measured on their "jumping" skill.

It is also concluded that different athletes jump well for different physiological reasons. One athlete may jump well because of powerful quadriceps muscles, while a second athlete, having average quadriceps power, may jump well because of exceptionally powerful gluteal muscles. A third athlete may obtain his vertical jump height from exceptionally powerful gastrocnemius and soleus muscles. The importance of all three muscle groups to performance of the vertical jump is demonstrated in the literature. The best performer, therefore, would be the athlete who optimally combines the use of all three major contributors to the vertical jump.

The works of Eckert (1968) and Gregoire et al. (1984) support the idea that the speed of knee extension in the vertical jump is approximately 800 to 1,000°/s. In response to their work and the low correlations of studies on vertical jump and Cybex strength at lower speeds, the present investigation sought to test at faster speeds (up to 300°/s) and expected more significant correlations than found in past research. However, the results at 300°/s did not show significance. Therefore, testing speeds that more closely approximate the actual speed of movement in the vertical jump may be required to obtain stronger correlations between that and peak torque. Therefore, testing at speeds such as 300°/s may still be too slow to determine the true nature of this relationship.

As mentioned in chapter 3, the testing speed sequence varied from subject to subject to negate the order effect of consecutive subjects experiencing the same speed sequence. A problem directly related to test speeds and sequence used was that a subject unfamiliar with the apparatus or type and speed of movement may not have performed maximally on one or more of the test speeds, especially the first speed. This would especially be true of subjects starting at 300°/s, the fastest and most difficult speed to perform. Because of this, while still trying to avoid the order effect, as many subjects as possible were tested in the sequence 180, 240, and 300°/s.

Summary

In view of the present investigation, it does not seem possible to isolate any single variable that best explains individual differences in vertical jump ability. Due to the complexity of the movement and coordination required, exercises more similar to the vertical jump, such as the weightlifting squat, may be more beneficial for improving vertical jump performance. Training movements more closely approximating the actual speed of movement in the jump may also be more beneficial for improving needed power. Although the Cybex II is one of the fastest machines on the market, it is still not fast enough to emulate the speed of movement in the vertical jump.

In view of the data collected, the limitations of this study, and the possible errors encountered within the methodology of this investigation, it is concluded that no significant relationship exists between vertical jump ability and upper leg strength at any of three fast speeds of movement tested on the Cybex II isokinetic dynamometer. Although it is still important to maintain a H:Q ratio of approximately 0.60 to help prevent injury (Laird, 1981), this ratio does not seem to be a significant factor in determining vertical jump ability.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The ability to jump vertically is usually considered to be an extremely important characteristic in evaluating the skills and abilities of a basketball player. Coaches and spectators alike are impressed with this ability, the former trying to enhance that ability and the latter marveling at its demonstration on the court.

It was the purpose of this investigation to examine the relationship between vertical jump ability and upper leg strength. Strength testing was conducted on the Cybex II isokinetic dynamometer because of its ability to test at speeds up to 300°/s. The underlying objective of this investigation was to obtain and contribute information valuable for the development of training programs to enhance vertical jump ability.

For the purposes of this investigation, 43 male collegiate basketball players were recruited as subjects from Ithaca College, SUNY at Cortland, and Cornell University. Testing procedures on each subject included (a) three maximal effort vertical jumps, (b) a gravity correction procedure, and (c) five-repetition maximal effort strength tests at 180, 240, and 300°/s on the Cybex II isokinetic dynamometer.

Data analysis consisted of Pearson product-moment correlations to relate vertical jump scores, expressed in in., with gravity-corrected and noncorrected H:Q ratios at each speed. Additional analysis examined the correlations between vertical jump work (kgm) and H:Q ratios, and vertical jump work and PQT, and multiple correlations of vertical jump work with PQT and PHT. Subsequent correlation values were small and not statistically significant at any speed of testing.

Conclusions

In view of the data collected and the limitations of this study, the following conclusions are drawn.

1. There is no significant relationship between vertical jump ability and gravity-corrected or noncorrected H:Q strength ratios at 180, 240, or 300°/s.

2. There is no significant relationship between vertical jump ability and gravity-corrected or noncorrected PQT values at 180, 240, or 300°/s.

3. There is no significant relationship between vertical jump ability and combined measures of PQT and PHT at 180, 240, or 300°/s.

Recommendations

As a result of the present investigation, and for the purposes of further investigation in the areas of vertical jump ability and isokinetic strength, the following recommendations are made.

1. A larger number of subjects should be used to improve generalizability.

2. A standardized warm-up should be used prior to

vertical jump testing to improve test performance.

3. All vertical jump testing should be done on the same day as the strength testing.

4. Further investigation of the necessity and accuracy of gravity correction procedures should be done before being applied to Cybex data.

5. Subjects should receive more practice on the Cybex apparatus prior to testing to familiarize themselves with the type and speed of movement required.

6. More investigation should be made into the physiological differences between "jumpers" and "leapers," as discussed in chapter 5.

7. More investigation should be made into the activity of the hamstrings and the gluteal muscles in hip extension during the vertical jump.

8. Testing should be done at higher speeds of movement that more closely approximate the actual speed of joint movement in the vertical jump.

9. Further investigation of the vertical jump should use a composite score that includes measurement of as many of the contributory variables as possible.

Appendix A

INFORMED CONSENT

1) a) Purpose of this study--To examine the relationship between vertical jump ability and hamstring-to-quadriceps strength ratios in male collegiate basketball players

   b) Benefits--You will be provided with an accurate assessment of your vertical jump ability and hamstring-to-quadriceps strength ratios as determined on the Cybex II isokinetic muscle testing machine. Additionally, this information may prove valuable for designing programs to improve vertical jump performance

2) Method--Part I of this study will require you to perform three maximal vertical jumps from a stationary position to be measured for the height you get off the floor. Part I will take approximately 5 minutes to complete. Part II of this study will require you to be tested for maximum hamstring and quadriceps strength of your kicking leg at three speeds of movement. Strength will be measured on the Cybex II isokinetic muscle testing machine. This is an electronic machine that will provide resistance to your leg as you extend and flex your knee. Appropriate warm-up and rest between tests will be provided. Part II will take approximately 15 minutes to complete.

3) Will this hurt?--Participation in this study does not involve any major risks. Physical discomfort, pain, or injury are not expected. However, possibility of muscular strain is always present when performing explosive or maximal effort movements. Mild muscle soreness is also possible the following day. Adequate warm-up and carefully selected testing procedures are designed to minimize the chance of injury or muscle soreness.

4) Need more information?--Additional information may be obtained either from William Thomas at 272-7187 or from Dr. G. A. Sforzo at 274-3359. All questions are welcomed and will be answered.

5) Withdrawal from this study--Participation in this study is completely voluntary. You are free to withdraw your consent and participation at any time without penalty. If you withdraw, it would be appreciated, but not mandatory, that you give advance notice to the researchers.

***** After reading this page, initial here ___________

6) Will the data be maintained confidential?--All data will be confidential. Once data are collected, all names will be coded into numbers and referred to by that number only. Your personal data will be available only to you and not to your coach or anyone else. Published material will not contain the names of the subjects.

7) Exclusion from this study--If you are between the ages of 18 and 24 with at least 1 year of high school varsity basketball experience or at least 1 year of collegiate varsity or junior varsity basketball experience, you are eligible. If you are receiving treatment or rehabilitation for a hip, knee, or ankle injury at the time of testing, you must report this to the researchers. A decision to reschedule your test time or to exclude you from the study will be made at that time.

8) By signing below, I acknowledge that I have read the entire INFORMED CONSENT FORM, understand its contents, and agree to participate in this study. I acknowledge that I am 18 years of age or older and meet the eligibility requirements of this study.

------------------------------ --------------------

Signature Date

Appendix B

VERTICAL JUMP INSTRUCTIONS

"Read these instructions with me as I demonstrate and explain:

1. Stand 6 in. away from wall with feet 6 in. apart
2. One arm behind back and grasp your waistband
3. Other arm extended over head with middle fingertip chalked
4. Reach arm over head as far as possible and make first mark for a starting measurement
5. Bend knees until told to 'stop' at 90°, pause 3 s and jump on cue 'ready...set...jump'
6. Do NOT bend knees lower than 90° or bend further at the waist
7. I will record the maximum height reached during the 3 jumps

Remember, this is a max jump, so jump as high as you can"

Appendix C

GRAVITY CORRECTION FORMULA

Variables and Terms

$\theta 1$	= angle of passive knee flexion caused by gravity
Tg	= torque
$Tg\theta 1$	= maximum torque of passive knee flexion caused by gravity
Cos $\theta 1$	= cosine of the angle of passive knee flexion
$\theta 2$	= angle at which peak torque occurred
Cos $\theta 2$	= cosine of the angle at which peak torque occurred in that motion being corrected (e.g., $\theta 2$ for the peak hamstring torque will be different from $\theta 2$ for the peak quadriceps torque to be corrected)

Therefore, the gravity correction factor ($Tg\theta 2$) is obtained by multiplying the torque of passive knee flexion caused by gravity ($Tg\theta 1$) times the cosine of the angle at which peak torque occurred (Cos $\theta 2$) and divide that product by the cosine of the angle at which passive knee flexion caused by gravity was maximum (Cos $\theta 1$).

$$Tg\theta 2 = \frac{Tg\theta 1 \, (\cos \theta 2)}{\cos \theta 1}$$

The value obtained through the use of the $\theta 2$ of the peak hamstring torque is subtracted from that peak hamstring torque value recorded BEFORE gravity correction.

The value obtained through the use of the $\theta 2$ of the peak quadriceps torque is added to that peak quadriceps torque value recorded BEFORE gravity correction.

Note. See Nelson and Duncan (1983) for further explanation and derivation of this formula.

Appendix D

GRAVITY CORRECTION INSTRUCTIONS

"Read these instructions with me:

During the strength test, I need to account for the effect of gravity. To do this, I will measure the force of your leg falling with gravity. Please keep your leg completely relaxed. This will cause you no discomfort. I will raise and release your leg 3 times. Do not pull down or resist while I do this. Remember, keep your leg completely relaxed."

Appendix E

STRENGTH TEST INSTRUCTIONS

"Read these instructions with me:

During this part of the test, you will be performing five maximum effort repetitions at each of three speeds. You will be given 5 to 10 warm-up repetitions at each speed before you are tested at that speed. During the test, you will hear a beep at the end of each movement direction. You must hear that beep before you change directions. You will start and stop on my cues 'start' and 'stop.' Please do your best. This is a max test."

Appendix F

ADDRESSES

Cybex/Eagle	Cybex, Division of Lumex, Inc. 2100 Smithtown Ave. Ronkonkoma, NY 11779
Humac	Computer Sports Medicine, Inc. 21 Erie St. Suite 24 Cambridge, MA 02139
Isoscan	Isotechnologies PO Box 1239 Elizabeth Brady Rd. Hillsborough, CA 27278
Nautilus	Nautilus Sports/Medical Industries PO Box 178 Deland, FL 32721
Universal	Universal PO Box 1270 Cedar Rapids, IA 52406

REFERENCES

Adamson, G. T., & Whitney, R. J. (1971). Critical appraisal of jumping as a measure of human power. In J. Vredenbregt & J. Wartenweiler (Eds.), Medicine and sport: Vol. 6. Biomechanics II (pp. 208-211). Baltimore: University Park.

Appen, L., & Duncan, P. W. (1986). Strength relationship of the knee musculature: Effects of gravity and sport. The Journal of Orthopedic and Sports Physical Therapy, 7, 232-235.

Asmussen, E., & Bonde-Peterson, F. (1974). Storage of elastic energy in skeletal muscles in man. Acta Physiologica Scandinavica, 91, 385-392.

Bangerter, B. L. (1968). Contributive components of the vertical jump. Research Quarterly, 39, 432-436.

Berger, R. A., & Henderson, J. M. (1966). Relationship of power to static and dynamic strength. Research Quarterly, 37, 9-13.

Bosco, C., Ito, A., Komi, P. V., Luhtanen, P., Rahkila, P., Rusko, H., & Viitasalo, J. T. (1982). Neuromuscular function and mechanical efficiency of human leg extensor muscles during jumping exercises. Acta Physiologica Scandinavica, 114, 543-550.

Bosco, C., Komi, P. V., & Ito, A. (1981). Prestretch potentiation of human skeletal muscle during ballistic movement. Acta Physiologica Scandinavica, 111, 135-140.

Bosco, C., Komi, P. V., Tihanyi, J., Fekete, G., & Apor, P. (1983). Mechanical power test and fiber composition of human leg extensor muscles. European Journal of Applied Physiology and Occupational Physiology, 51, 129-135.

Bosco, C., Luhtanen, P., & Komi, P. V. (1983). A simple method for measurement of mechanical power in jumping. European Journal of Applied Physiology and Occupational Physiology, 50, 273-282.

Bosco, C., Tihanyi, J., Komi, P. V., Fekete, G., & Apor, P. (1982). Store and recoil of elastic energy in slow and fast types of human skeletal muscles. Acta Physiologica Scandinavica, 116, 343-349.

Cavagna, G. A., Komarek, L., Citterio, G., & Margaria, R. (1971). Power output of the previously stretched muscle. In J. Vredenbregt & J. Wartenweiler (Eds.), Medicine and sport: Vol. 6. Biomechanics II (pp. 159-167). Baltimore: University Park.

Considine, W. J., & Sullivan, W. J. (1973). Relationship of selected tests of leg strength and leg power on college men. Research Quarterly, 44, 404-416.

Costill, D. L., Miller, S. J., Myers, W. C., Kehoe, F. M., & Hoffman, W. M. (1968). Relationship among selected tests of explosive leg strength and power. Research Quarterly, 39, 785-787.

Davies, G. J. (1984). A compendium of isokinetics in clinical usage. La Crosse, WI: S & S.

Eckert, H. M. (1968). Angular velocity and range of motion in the vertical and standing broad jumps. Research Quarterly, 39, 937-942.

Elliot, I. (1978). Assessing muscle strength isokinetically. Journal of the American Medical Association, 240, 2408-2410.

Fox, E. L., & Matthews, D. K. (1981). The physiological basis of physical education and athletics (3rd ed.). Philadelphia: Saunders.

Fukushiro, S., Ohmichi, H., Kanehisa, H., & Miyashita, M. Utilization of stored elastic energy in leg extensors. (1981). In H. Matsui & K. Kobayushi (Eds.), Biomechanics VIII-A: Proceedings of the Eighth International Congress of Biomechanics, Nagoya, Japan (pp. 258-263). Champaign, IL: Human Kinetics.

Genuario, S. E., & Dolgener, F. A. (1980). The relationship of isokinetic torque at two speeds to the vertical jump. Research Quarterly for Exercise and Sport, 51, 593-598.

Glencross, D. J. (1966a). The nature of the vertical jump test and the standing broad jump. Research Quarterly, 37, 353-359.

Glencross, D. J. (1966b). The power lever: An instrument for measuring muscle power. Research Quarterly, 37, 202-210.

Gollnick, P. D., & Matoba, H. (1984). The muscle fiber composition of skeletal muscle as a predictor of athletic success: An overview. The American Journal of Sports

Medicine, 12, 212-217.

Gray, R. K., Start, K. B., & Glencross, D. J. (1962a). A test of leg power. Research Quarterly, 33, 44-50.

Gray, R. K., Start, K. B., & Glencross, D. J. (1962b). A useful modification of the vertical power jump. Research Quarterly, 33, 230-235.

Gregoire, L., Veeger, H. E., Huijing, P. A., & van Ingen Shenau, G. J. (1984). Role of mono- and biarticular muscles in explosive movements. International Journal of Sports Medicine, 5, 301-305.

Halling, A. H., & Dooley, J. N. (1979). The importance of isokinetic power and its specificity to athletic conditions. Athletic Training, 14, 83-86.

Holmes, J. R., & Alderink, G. J. (1984). Isokinetic strength characteristics of the quadriceps femoris and hamstring muscles in high school students. Physical Therapy, 64, 914-918.

Hubley, C. L., & Wells, R. P. (1983). A work-energy approach to determine individual joint contributions to vertical jump performance. European Journal of Applied Physiology and Occupational Physiology, 50, 247-254.

Hudson, J. L. (1986). Coordination of segments in the vertical jump. Medicine and Science in Sports and Exercise, 18, 242-251.

Imwold, C. H., Rider, R. A., Haymes, E. M., & Green, K. D. (1983). Isokinetic torque differences between college female varsity basketball and track athletes. Journal of

Sports Medicine, 23, 67-73.

Klafs, E. E., & Arnheim, D. D. (1981). Modern principles of athletic training. St. Louis: Mosby.

Laird, D. E. (1981). Comparison of quad to ham strength ratios of an intercollegiate soccer team. Athletic Training, 16, 66-67.

Luhtanen, P., & Komi, P. V. (1978). Sequential contribution to forces in vertical jump. European Journal of Applied Physiology and Occupational Physiology, 38, 181-188.

Nelson, S. G., & Duncan, P. W. (1983). Correction of isokinetic and isometric torque readings for the effects of gravity. Physical Therapy, 63, 674-676.

Osternig, L. R., Hamill, J., Sawhill, J. A., & Bates, B. T. (1983). Influence of torque and limb speed on power production in isokinetic exercise. American Journal of Physical Medicine, 62, 163-171.

Roy, R. R., Baldwin, K. M., Martin, T. P., Chimarusti, S. P., & Edgerton, V. R. (1985). Biomechanical and physiological changes in overloaded fast-twitch and slow-twitch ankle extensors. Journal of Applied Physiology, 59, 639-646.

Sapega, A. A., Nicholas, J. A., Sokolow, D., & Saraniti, A. (1982). The nature of torque "overshoot" in Cybex isokinetic dynamometry. Medicine and Science in Sport and Exercise, 14, 368-375.

Smith, L. E. (1961). Relationship between explosive leg strength and performance in vertical jump. Research

Quarterly, 32, 405-408.

Stafford, M. G., & Grana, W. A. (1984). Hamstring/ quadriceps ratios in college football players: A high velocity evaluation. The American Journal of Sports Medicine, 12, 209-211.

Winter, D. A., Wills, R. P., & Orr, G. W. (1981). Errors in the use of isokinetic dynamometers. European Journal of Applied Physiology, 46, 397-408.