

2008-01-01

Effect of Resistance Training in the Improvement of H:Q Ratio in Males and Females

Pradeep Edupuganti

University of Texas at El Paso, pedupuganti@miners.utep.edu

Follow this and additional works at: https://digitalcommons.utep.edu/open_etd



Part of the [Physical Therapy Commons](#)

Recommended Citation

Edupuganti, Pradeep, "Effect of Resistance Training in the Improvement of H:Q Ratio in Males and Females" (2008). *Open Access Theses & Dissertations*. 247.

https://digitalcommons.utep.edu/open_etd/247

EFFECT OF RESISTANCE TRAINING IN THE IMPROVEMENT OF HAMSTRINGS TO
QUADRICEPS (H:Q) STRENGTH RATIO IN MALES AND FEMALES

PRADEEP EDUPUGANTI

Department of Kinesiology

APPROVED:

Sandor, Dorgo, Ph.D., Chair

Darla R. Smith, Ph.D.

Melchor, Ortiz, Ph.D.

Patricia D. Witherspoon, Ph.D.
Dean of the Graduate School

EFFECT OF RESISTANCE TRAINING IN THE IMPROVEMENT OF HAMSTRINGS TO
QUADRICEPS (H:Q) STRENGTH RATIO IN MALES AND FEMALES

By

PRADEEP EDUPUGANTI, PT.

THESIS

Presented to the Faculty of Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Kinesiology

THE UNIVERSITY OF TEXAS AT EL PASO

December 2008

ACKNOWLEDGMENTS

This study was supported by a grant from Graduate enhancement fund, College of Health Sciences, University of Texas at El Paso. I would also like to thank the following thesis committee members for their continued advisement and assistance throughout this thesis project: Dr. Sandor Dorgo (Chairperson of the committee), Dr. Darla Smith and Dr. Melchor Ortiz. Additionally, I would like to express gratitude to Dr. Sandor Dorgo for special contributions as thesis advisor, committee chairperson, friend and mentor throughout the master's program. I would also thank the students who assisted during training program and data collection process.

Most importantly special thanks to my parents and my brother for their moral support and encouragement throughout this process.

ABSTRACT

Objective: The purpose of this study was to examine the change in hamstrings to quadriceps (H:Q) strength ratio between males and females following a 12-week resistance training program.

Design and Setting: We used a pretest-posttest experimental design to determine the amount of change produced by the training intervention in males and females. Isokinetic testing was performed on a Biodex System 3 isokinetic machine at 30°/sec, 60°/sec, 180°/sec and 240°/sec angular velocities, both before and after a 12-week training program.

Subjects: Twenty eight (14 male, 14 female) university recreationally active volunteers.

Variables: The dependent variables of interest were the conventional and functional hamstring to quadriceps (H:Q) strength ratios.

Results: Both males and females increased their isokinetic strength of hamstrings and quadriceps at all angular velocities following resistance training program. A comparison of percent increase in conventional H:Q ratio following training revealed significant statistical differences ($p < 0.05$) at 30°/sec with females increasing their ratio by 66% and males by 15%. Functionally, there was a significant difference ($p \leq 0.05$) in percent increase between males and females at 30°/sec, 60°/sec and 180°/sec angular velocities with females increasing their H:Q ratio at greater percentage than males

Conclusion: The findings of this study showed that with similar resistance training females increased their strength ratios at greater percent than males.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
ABSTRACT	iv
TABLE OF CONTENTS	v
LIST OF TABLES	vii
LIST OF FIGURES	viii
GLOSSARY	ix
CHAPTER ONE	
INTRODUCTION	1
LITERATURE REVIEW	2
CHAPTER TWO	
PURPOSE AND SIGNIFICANCE	16
AIMS AND HYPOTHESIS	17
CHAPTER THREE	
METHODS	18
SUBJECTS	18
ISOKINETIC TESTING PROCEDURES	19
POST-TEST	21
RESISTANCE TRAINING INTERVENTION	21
STATISTICAL DESIGN	23

	Page
CHAPTER FOUR	
RESULTS	24
CHAPTER FIVE	
DISCUSSION	29
CHAPTER SIX	
CONCLUSION	34
LIST OF REFERENCES	36
APPENDIX 1	
INSTITUTIONAL REVIEW BOARD APPROVAL FORM	42
INFORMED CONCENT FORM	43
SOLICITATION QUESTIONNAIRE	45
QUESTIONNAIRE ABOUT TRAINING EXEPERIENCE	46
APPENDIX 2	
PROCEDURES FOR BIODEX SYSTEM 3.....	47
APPENDIX 3	
RESISTANCE TRAINING PROGRAM	50
CURRICULUM VITA	51

LIST OF TABLES

	Page
Table 1. Subjects anthropometric characteristics	18
Table 2. Peak isokinetic concentric strength of hamstring and quadriceps muscles.....	26
Table 3. Peak isokinetic eccentric strength of hamstring and quadriceps muscles.....	26
Table 4. Conventional H:Q ratios for males and females.....	27
Table 5. Functional H:Q ratios for males and females.....	27
Table 6. Percent increase in conventional H:Q ratio in males and females.....	28
Table 7. Percent increase in functional H:Q ratio in males and females.....	28

LIST OF FIGURES

	Page
Figure 1. Quadriceps muscle.....	3
Figure 2. Posterior aspect of knee joint.....	3
Figure 3. Ligaments of the knee joint.....	4
Figure 4. Quadriceps and hamstring strength for mature and immature boys and girls.....	8
Figure 5. Functional H:Q strength ratio	10
Figure 6. Age and gender comparisons of muscle quality levels	13

GLOSSARY

Agonist to antagonist ratio – The reciprocal muscle group ratio. Excessive imbalances predispose a joint to injury.

Concentric contraction – This contraction of muscle occurs when the muscle torque is greater than the torque produced by the resistive force and the muscle shortens.

Eccentric contraction – This contraction of muscle occurs when the muscle torque is less than the torque produced by the resistive force and the muscle lengthens.

Maximal strength – It is the peak force generated by a muscle during a single maximal voluntary contraction.

Torque – It is a force that is perpendicular to a lever arm which is rotating or tends to rotate about an axis of rotation. It is a measure of muscular output.

Peak torque – Highest muscular force output at any moment during a repetition. It is indicative of muscle's strength capabilities.

Angular velocity – The rate of change with respect to time of angular displacement, given in units of degrees per second.

Isokinetic testing – It is a mode of muscle strength test involving dynamic concentric or eccentric muscular activity performed at a constant angular velocity controlled by an external dynamometer.

Hamstring to quadriceps (H:Q) strength ratio – It is the peak torque ratio of knee flexors to knee extensors.

Conventional H:Q ratio – It is the peak torque ratio of concentric knee flexors to concentric knee extensors.

Functional H:Q ratio – It is the peak torque ratio of eccentric knee flexors to concentric knee extensors.

Resistance training - A systematic program of exercises involving the exertion of force against a load used to develop strength, endurance, and/or hypertrophy of the muscular system.

Periodization - This is a training regime divided into phases intended to bring about the best possible increase in muscular strength and hypertrophy.

CHAPTER 1

Introduction

Improvement in muscular strength does not only enhance athletic performance but contributes to the prevention of injuries by reducing the risk of muscular strains and by stabilizing the joints more effectively. In addition to the strength of individual muscles, another factor considered in injury prevention is the ratio of strength between agonist and antagonist muscles (Holcomb, Rubley, Lee, & Guadagnoli, 2007). The strength ratios between agonist and antagonist muscles have received attention in the literature. A particular area of interest has been the ratio between hamstring and quadriceps muscles due to the large discrepancies in injury rates between males and females at the knee joint (Arendt & Dick, 1995). The H:Q strength ratio is critical in providing the muscular stability of the knee in order to prevent injuries, especially anterior cruciate ligament (ACL) injuries which are common in a variety of athletic activities (Hewett, Lindenfeld, Riccobene, & Noyes, 1999).

Optimal training for increasing athletic performance and for prevention of injuries requires multiple training modalities including traditional resistance training programs (Wilmore, 1974). Previous studies have shown that regular resistance training will strengthen and tone muscles and increase bone density (Wilmore, 1974; Cureton, Collins, Hill, & McElhannon, 1988). Only few studies in the past focused on the change in the H:Q ratio after a systematic resistance training program (Holcomb et al., 2007; Hewett, 2006; Aagard, Simonsen, Trolle, Bangsbo, & Klausen, 1996) . However, no known studies to date have compared the changes in the H:Q ratio in males and females after a systematic strength training program.

Gender differences, especially differences in response to resistance training between males and females further complicate our understanding on how this type of training affects the

H:Q ratio. Therefore, these issues are to be further understood in order to prevent muscle strains, ligament injuries and to develop best athletic ability during sports participation.

The literature review examines the background information that focused on the importance of H:Q ratio and ACL in knee joint stability and gender responses to systematic resistance training. Other topics reviewed are the functional anatomy of knee joint, gender differences in the H:Q ratio and current research in isokinetic testing of hamstring and quadriceps muscle groups. Reviewing these topics can offer insights into the role of H:Q ratio in knee joint stability and the effect of different training programs in improvement of H:Q ratio in males and females.

Literature Review

Functional anatomy of knee

The knee joint is a complex synovial hinge type of joint with two major articulations: the patello-femoral joint and the tibio-femoral joint, both of which are located within the capsule (Kisner & Colby, 1990). The patello-femoral joint is a part of the extensor mechanism. The patella is a sesamoid bone contained in the tendon of the quadriceps. The tibio-femoral joint is a modified hinge joint with flexion and extension in the sagittal plane and rotation in the transverse plane at the knee joint.

Musculature around the knee joint

Quadriceps femoris (Figure 1) is the primary muscle involved in knee extension which consists of four distinct parts: rectus femoris, vastus medialis, vastus intermedius and the vastus lateralis. All four parts of this muscle group together insert on the proximal edge of the patella, which then transfers their action, by way of the patellar tendon to the tibia (Kisner & Colby, 1990). The knee flexor group consists of hamstrings, sartorius, gracilis, popliteus and

gastrocnemius muscles. The hamstring group (Figure 2) is comprised of biceps femoris, semitendinosus and the semimembranosus muscles which are inserted on the proximal tibia and head of the fibula. The primary function of semimembranosus, semitendinosus, popliteus and gracilis is to flex the knee and extend the hip and also they medially rotate the tibia on a fixed femur. The biceps femoris muscle also acts to laterally rotate the tibia on a fixed femur (Kisner & Colby, 1990).

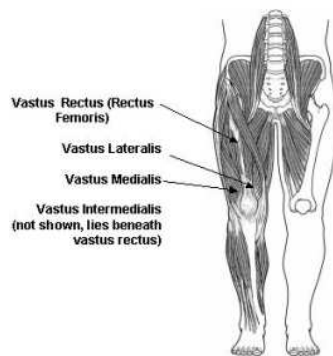


Figure 1. Quadriceps Muscle

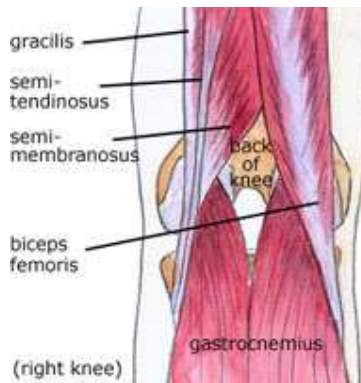


Figure 2. Posterior aspect of knee joint

Ligaments of the knee joint

Medial and lateral collateral ligaments prevent excessive movement in the frontal plane and provide medial-lateral stability of the knee. Anterior and posterior cruciate ligaments are responsible for providing anterior-posterior and rotatory stability throughout the range of motion

of the knee joint. The ACL functions to prevent anterior displacement of the tibia on the femur (Kisner & Colby, 1990). Other ligaments of the knee joint include the transverse ligament, coronary ligaments, arcuate ligaments, popliteal ligament, meniscomfemoral and meniscotibial ligaments.

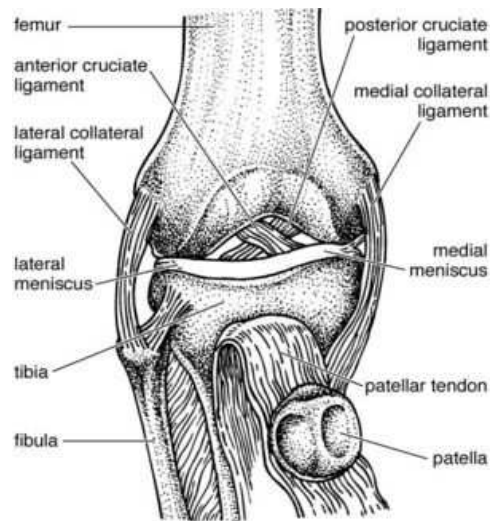


Figure 3. Ligaments of the knee joint

Importance of H:Q ratio in knee joint stability

To measure and analyze the strength of the thigh muscles and thus the imbalance that may cause ACL injury, the hamstring to quadriceps ratio is often used. Hamstring muscle activation aids in stabilization of the knee joint. A muscular strength imbalance due to weaker hamstrings or due to stronger quadriceps hinders the knee joint stabilization, requiring the ACL to play a major role in joint stabilization. This increases the susceptibility of hamstring strains and ACL injuries (Holcomb et al., 2007). The co-activation of the hamstring muscle group along with the quadriceps is necessary to aid the knee joint ligaments in maintaining joint stability, equalizing the articular surface pressure distribution and regulating the joint's mechanical impedance (Baratta et al., 1988). Solomonow, Baratta, Zhou, and D'Ambrosia (1988) also demonstrated that well balanced antagonistic musculature surrounding the joint is necessary to

distribute even pressure across the articular surfaces of the joint to avoid a focal stress point that would lead to joint degeneration.

The H:Q strength ratio can be evaluated in both conventional and functional methods (Aagard, Simonsen, Magnusson, Larsson, & Poulsen, 1998). The conventional H:Q strength ratio is estimated by dividing maximal concentric knee flexor moment by the maximal concentric knee extensor moment obtained at a given angular velocity . However, co-activation of hamstring and quadriceps muscle groups was known to occur and takes place through opposing contraction modes (Solomonow et al., 1988). During knee joint flexion hamstring contract concentrically (Hcon) and quadriceps contract eccentrically (Qecc). Conversely, hamstrings contract eccentrically (Hecc) and quadriceps contract concentrically (Qcon) during knee joint extension. Therefore, a functional ratio of Hecc/Qcon representing knee extension or Hcon/Qecc ratio representing knee flexion is more accurate to evaluate hamstring and quadriceps muscle strength balance at knee joint (Aagard et al., 1998).

White, Lee, and Cutuk (2003) emphasized the importance of the relationship between the quadriceps and hamstrings, and their interaction with the knee joint during dynamic movements. They concluded that increased quadriceps co-activation in females may increase anterior tibial loads under dynamic conditions, thus placing the ACL at higher risk for injury in female athletes. Che Tin, Maffulli, Hsu, and Chan (1996) found that increasing the functional H:Q ratio to 100% or 1.0 resulted in an increased functional ability of ACL deficient knees. Dunnam, Hunter, Williams, and Dremsa (1988) suggested that a conventional H:Q ratio of more than 0.60 or 60% and functional H:Q ratio of more than 1.0 or 100% is appropriate to prevent ACL and hamstring injuries. Clanton and Coupe (1998) in their study on hamstrings strains in athletes reported that a

conventional H:Q strength ratio of at least 0.5 to 0.6 is recommended to decrease the chances of hamstring injuries.

Athletes with stronger inhibitory effects on hamstring co-activation and increased anterior tibial translation has been shown to increase as a function of strong quadriceps forces (Kvist, Karlberg, Gerdle, & Gillquist, 2001). Therefore inappropriate training of quadriceps and hamstrings results in diminished antagonist capacity and reduced joint stability for preventing anterior tibial translation in response to strong quadriceps forces (Hewitt et al., 1999). Tensile stress on the ACL is significantly reduced when the hamstrings and the quadriceps co-activate during extension, compared to quadriceps activation alone (More et al., 1993). Therefore, it is important to have a balance in strength of the thigh muscle groups in order to provide the necessary stabilization during sport specific activities.

H:Q ratio and gender comparison

The incidence of female ACL tears in sports such as soccer and basketball is much higher than in male athletes competing in the same sports (Arendt et al., 1995). The role that the ACL plays in the stability of the knee joint is particularly important in sports involving the jump-landing, such as basketball, soccer, and volleyball (White et al., 2003). It has been suggested that female athletes are two to eight times more likely to tear the ACL than their male counterparts participating in the same sports (Arendt et al, 1995). The differences in the H:Q strength ratio between males and females may play an important role to determine females at greater risk for ACL sprains than males. Nagano, Akai, and Fukubayashi (2007) concluded that increased internal tibial rotation combined with greater quadriceps activity and a lower H:Q ratio would be the reason for higher incidence of non-contact ACL injuries in female athletes. They found that

H:Q ratio for the 50 ms time period before foot contact during a drop jump during electromyography testing was greater in male athletes (n=18) than in female (n=19) athletes.

Youdas, Hollman, Hitchcock, Hoyme, and Johnsen (2007) in their study of performing a single-leg squat (SLS) on both stable and liable (balance mat) surfaces, found that the H:Q ratio of males was approximately 3.5 times larger than their female counterparts suggesting that men activate their hamstrings more effectively than women during an SLS. Carcia, Schultz, Granata, Perrin, and Martin (2005) studied the neuromuscular recruitment patterns and the response of hamstring and quadriceps muscles during a perturbation of single leg stance in ten males and ten females. They reported that females demonstrated a more sensitive reflex and responded to the perturbation with increased quadriceps activation relative to hamstring activation. Gender differences in peak torque values across velocities have been reported (Evetovich, Housh, & Johnson, 1998). Males demonstrated greater concentric and eccentric mechanomyographic responses during isokinetic exercise than females.

Wojtys, Huston, Schock, Boylan, and Miller (2003) studied the internal rotation loading patterns of knee using a weighted pendulum in 24 National Collegiate Athletic Association (NCAA) Division-I athletes and 28 collegiate athletes competing in sports associated with a high risk of injury to the ACL and low risk to ACL injury respectively. They concluded that females involved in high-risk sports exhibited less muscular protection of the knee ligaments during external loading of the knee than did size and sport-matched male athletes. Westin, Noyes and Galloway (2006) measured the isokinetic hamstrings and quadriceps strength ratio at 300°/s in 1140 athletes of 9-17 years-old and found that female athletes (11 years old) had maximum hamstring strength greater than males athletes (14 years old).

Holmes and Alderink (1984) studied the differences between male and female high-school students in isokinetic strength characteristics of quadriceps and hamstring muscles. They found significant sex differences in isokinetic strength as males demonstrated greater average hamstring to quadriceps ratios. In specific at 60°/sec the difference in hamstring to quadriceps ratio between males and females was 0.57 and at 180°/sec a difference of 0.7 was observed.

Ahmad, Clark, Heilman, Schoeb, and Levine (2006) examined the effect of age and gender differences on H:Q strength ratio and anterior cruciate ligament laxity in 53 female and 70 male recreational soccer players of 10 to 18 years of age. They found that ligament laxity was significantly less for the mature boys than for the immature boys, mature girls and immature girls. Boys demonstrated a greater percentage increase in hamstring-quadriceps strength with maturity compared with girls (Figure 4). The authors further suggested that strengthening programs that emphasize hamstring activation in a closed-chain fashion would be beneficial in injury-prevention programs for females.

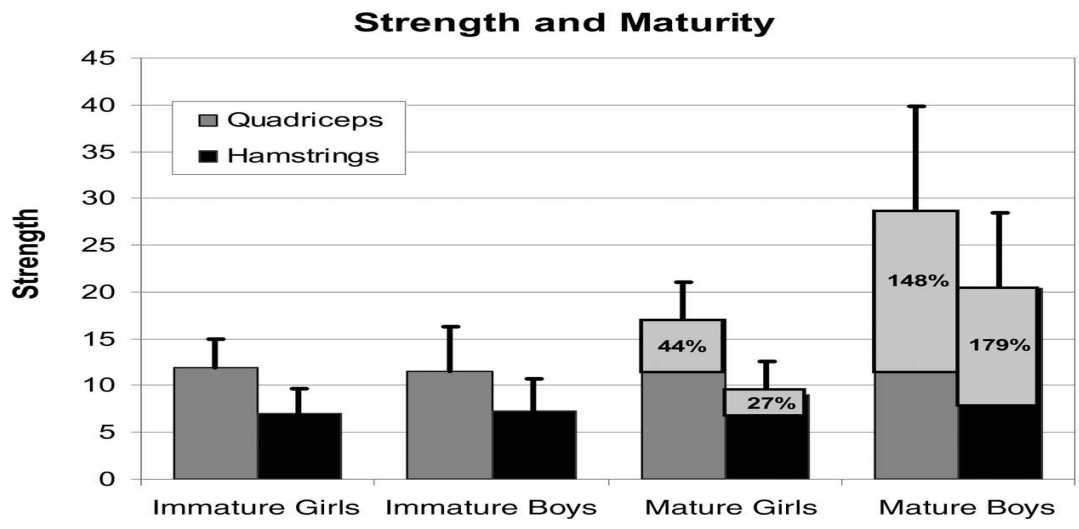


Figure 4: Quadriceps and Hamstrings strength for immature and mature boys and girls. Percentage increase in strength for quadriceps and hamstrings for the mature subjects compared with the immature subjects of the same gender are indicated (Ahmad et al, 2006).

Effect of different training regimens on H:Q strength ratio

Implementation of training programs to improve H:Q strength ratio as a preventative measure of ACL injury has also been considered. Holcomb et al. (2007) evaluated the effects of a 6-week strength training program on H:Q strength ratio in 12 female NCAA soccer players. They found an increase in functional H:Q ratio (>1.0) after training, which is recommended for prevention of ACL injuries (Figure 5). The authors concluded that 6 weeks of strength training with an emphasis on the development of hamstrings is sufficient to increase the functional ratio. Clark, Bryant, Culgan, and Hartley (2005) analyzed the effect of nordic eccentric hamstring training on vertical jump height and isokinetic peak torque between quadriceps and hamstrings in nine untrained male subjects. They found a significant increase in vertical jump height and a significant reduction in quadriceps peak torque in posttest following the training program. They suggested that eccentric hamstring training can produce favorable neuromuscular adaptations to prevent hamstring injuries. Wilkerson et al. (2004) studied a specific plyometric-based prevention program and its effect on the neuromuscular performance of female collegiate basketball players. Plyometric exercise allowed athletes to improve isokinetic hamstring performance in open chain activity, though closed chain activity produced no significant result.

Hewett (1996) observed a significant difference between hamstring and quadriceps muscle strength in female athletes before training. In addition, male athletes had three times higher knee flexor momentum than female athletes during a vertical jump. The training program included stretching, plyometrics and strength training which were demonstrated to decrease peak landing forces by decreasing abduction/adduction movements at the knee. The results of this study revealed a significant increase in hamstring muscle power and strength, H:Q strength ratio and a decrease in side-to-side hamstring muscle strength imbalances. The peak torque ratios of

male athletes were similar to those of trained females. Aagard, Simonsen, Trotle, Bangsbo, and Klausen (1996) examined the effects of three different training regimens on the isokinetic strength profile of quadriceps and hamstrings in twenty-two male soccer players. All subjects were randomly assigned to either heavy resistance training group (4 sets of 8 reps), low resistance training group (4 sets of 24 reps), loaded kick movements (4 sets of 16 reps) or control group. The results indicated a significant increase in the functional H:Q ratio in the subjects who were under heavy resistance training program, while the other training regimens failed to produce significant gains in isokinetic muscle strength and H:Q ratio from pre to post-test..

Hewett, Lindenfeld, Riccobene, and Noyes (1999) studied the effects of neuromuscular training on knee injury in female athletes involved in high-risk sports. They found that the incidence of knee injuries during entire season was 2.4 -3.6 times higher in the untrained group than trained group and increases were seen in hamstring muscle power and strength, H:Q peak torque ratios and decreased side-to-side hamstring muscle strength imbalances in the trained group. They also reported that high landing forces and imbalances in hamstring and quadriceps muscle strength and firing patterns may be the reason for the predisposition of the knee injury in female athletes.

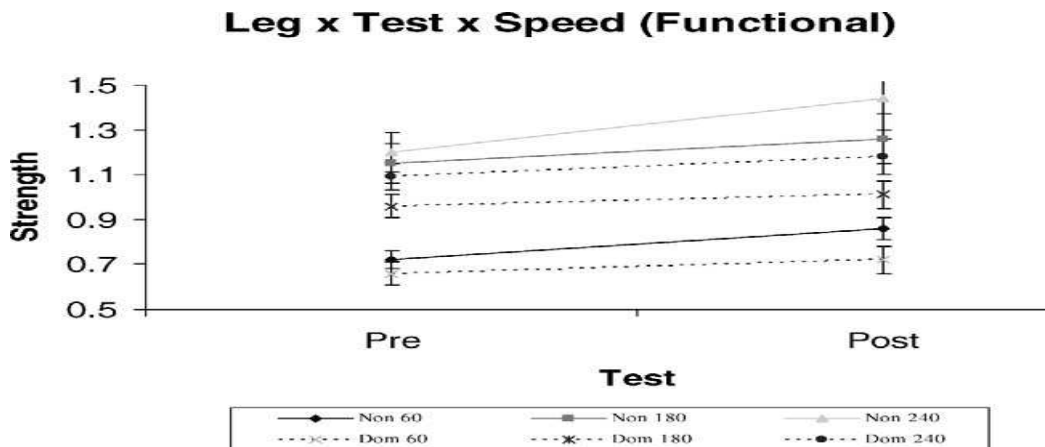


Figure 5. Functional H: Q strength ratio results for leg x test x angular velocity interaction (Holcomb et al., 2007).

Gender comparison of strength gains following a resistance training program

The main assumption behind the intervention in the present study is to focus on resistance training exercises that increase the hamstring and quadriceps co-activation and H:Q strength ratio after training in males and females. Literature review to date supports the assertion that males and females respond similarly to a resistance training based program and in some cases with prolonged and intense training women demonstrated faster strength gain than men. However, some gender differences exist in muscle cross sectional area and strength, when adjusted for body mass, as well as muscle activation patterns.

Gender differences in strength

A study by Miller, MacDougall, Tarnopolsky, and Salel (1993) examined strength and muscle characteristics of biceps brachii and vastus lateralis in males ($n = 8$) and females ($n = 8$). They found that females were 52% and 66% as strong as males in upper and lower body respectively with males having larger number of type I and type II muscle fibers in biceps brachii and vastus lateralis respectively than females. In another study Always, Grumbt, Gonyea, and Gunderson (1989) examined muscle cross-sectional area (CSA), fiber area and fiber number in biceps brachii of eight elite male body builders and five elite female body builders. They found that biceps CSA was twofold greater in males than in females. They also suggested that adaptations to resistance training may be complex and involve muscle fiber hypertrophy and fiber number proliferation. Wilkinson and Meyers (1993) examined isokinetic leg strength, power and hand grip strength in thirty male and female rodeo athletes. The results of their study showed that male athletes had significantly greater grip strength and knee extension/flexion strength and power at 30°/s and 180°/s compared to female athletes. Leyk et al. (2007) assessed maximum handgrip strength of young males and females and trained female athletes. The results

showed greater grip strength in men (541 N) than women (329 N). The female athletes were significantly stronger (444 N) than their untrained female counterparts, but they were not as strong as untrained male subjects.

Gender differences in strength gains following resistance training

Previous studies have suggested that males and females share some similarities in response to resistance training program. A study by Cureton, Collins, Hill, and McElhannon (1988) examined muscle hypertrophy changes in 7 males and 8 females following a 16-week weight training program. Though the bone-plus-muscle cross-sectional area is higher in males, the relative changes in elbow flexion, extension and in knee flexion and extension strength following the training period was similar in males and females. Another study by Wilmore (1974) also indicated that after a 10-week weight training program, males and females demonstrated similar relative gains in strength and absolute gains in body composition. However, females demonstrated greater relative increase in leg and bench press strength than male subjects. A study by Ivey et al. (2000) found that young females demonstrated greater increase in one repetition maximum (RM) strength and muscle volume of quadriceps than young and older males and older females following a 9-week strength training program (Figure 6).

Staron et al. (1994) investigated the time course for skeletal muscle adaptations in males and females for the lower extremity (vastus lateralis muscle) following an 8-week progressive resistance training program. The results of their study suggested that males and females responded to similar changes in skeletal muscle fiber composition and muscle cross-sectional area during the early phase of resistance training period. Weiss, Clark, and Howard (1988) compared the hypertrophy and strength of triceps surae muscle in males and females following an 8-week training program. They found that both males and females demonstrated similar

significant increase in isotonic muscle strength of triceps surae muscle. Another study by O'Hagan, Sale, MacDougall, and Garner (1995) compared the upper limb strength between males and females following a 20-week resistance training program on an eccentric/concentric weight training device. They found that females demonstrated greater increase in relative strength of elbow flexors (biceps & brachialis) than males.

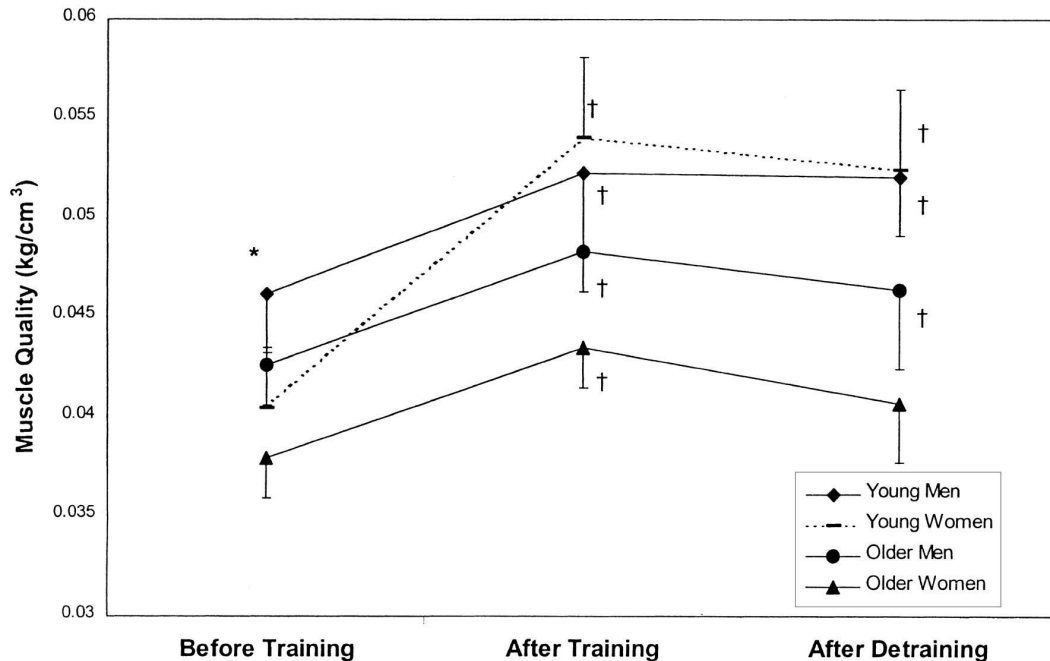


Figure 6. Age and gender comparisons of Muscle quality levels before and after training and detraining (Ivey et al., 2000)

Isokinetic testing

Isokinetic exercises are performed at a fixed speed with accommodating resistance, which is equal to the force applied at all points throughout the range of motion (ROM). Isokinetics allows maximal dynamic loading of muscle throughout the entire ROM. Isokinetic testing has been used for purposes such as athletic screening, developing normative data and correlating torque curves with certain pathological conditions (Kannus, Jarvinen, & Latvala, 1987). The isokinetic devices commonly used are Biodex, Cybex, Kin-Com, Kintrex and Loriden. The objective data that can be obtained from isokinetic testing includes peak torque,

power and total work. Peak torque is one of the most commonly used parameters and is measured as the point where the highest amount of force is applied as the limb moves through the ROM.

Importance of functional H:Q ratio over conventional concentric H:Q ratio

Studies analyzed isokinetic strength ratios in many different conditions, varying between eccentric and concentric contractions and between many angular velocities. The most functional ratio would be those that are determined by eccentric and concentric contractions of reciprocal muscle groups. It is this ratio that would best replicate what occurs during activity. The conventional concentric H:Q strength ratio is calculated by dividing maximal concentric knee flexor (hamstring) moment by the maximal concentric knee extensor (quadriceps) moment obtained at a given angular velocity. On the other hand, functional H:Q ratio is calculated by dividing maximal eccentric knee flexor moment by the maximal concentric knee extensor moment obtained at a given angular velocity. Coombs and Garbutt (2002) stated that determination of functional H:Q ratio would be rather more significant to know the role of antagonist in knee joint stabilization than the conventional concentric ratio. They concluded that functional H:Q ratio determined over entire ROM could be best used as predictor of knee injuries. An investigation of this agonist-antagonist strength ratio could lead to an enhanced understanding of the concentric and eccentric actions of the hamstring and quadriceps muscles in functional movements.

Gravity correction during isokinetic testing

Most of the commercial dynamometers include a gravity correction mode in order to reduce the errors during measurement of joint torque (Caldwell, Robertson, & Whittlesey, 2004). During knee extension, the quadriceps not only extends the knee, but also lifts the attached lever

arm. During knee flexion, the hamstrings flex the knee and also have the assistance of gravity on both the limb and the dynamometer arm. If this factor is not accounted for correction, the quadriceps activity maybe underestimated and the hamstring activity maybe overestimated. Aagaard et al. (1995) studied the effect of gravity correction on H:Q ratio during eccentric and concentric contractions. They found that gravity correction had high influence on the change in H:Q ratio with variation in extension velocity.

Summary of literature review

Co-activation of antagonist along with the agonist is necessary to reduce the risk of ligamentous damage. The H:Q ratio represents the ratio of hamstrings and quadriceps co-contraction and is thought to be important for optimizing performance through knee joint stabilization. It also plays an important role in prevention of hamstring strains and ACL tears which is usually due to the inability of hamstrings activation to prevent anterior tibial translational stress. Female athletes are thought to have weaker hamstrings or insufficient H:Q ratios compared to male athletes. Therefore strength training plays a critical role in injury prevention and the specific training of these muscle groups must be evaluated. Comprehensive evaluation of gender differences in H:Q ratio after resistance training has not been conducted. However, previous research has shown that females respond to resistance training with similar hypertrophic adaptations as observed in males.

CHAPTER 2

Purpose and Significance of research

From the literature review it is evident that H:Q strength ratio plays a major role in knee joint stabilization. A balance in strength of these thigh muscle groups (hamstrings & quadriceps) is required in order to provide the necessary stabilization of the knee joint during sport specific activities. This H:Q strength ratio is also associated with ACL tears because of the hamstring to quadriceps antagonist to agonist relationship during knee extension. With assistance from the hamstrings, the ACL stabilizes the knee, by preventing anterior translation of the tibia on the femur. Many of the previous studies compared the H:Q ratio between males and females and concluded that the H:Q strength ratio is greater in males than females. Therefore, estimation of gender differences in H:Q strength ratio following training will provide valuable insights into the role of strength training programs that emphasize hamstring activation during dynamic movements to decrease injury rates in both males and females.

Although a few studies focused on the change of the H:Q ratio due to training, none of the previous studies compared the change in H:Q ratio between males and females after resistance training. However, many of the previous studies showed that, under identical strength and hypertrophy based resistance training programs, males and females respond similarly and make similar gains in muscular strength. Knowledge of gender differences in H:Q ratio after a systematic resistance training program may guide to create effective program designs for males and females, characterized by known and prescribed training intensity. Therefore the purpose of this study was to compare the changes in H:Q strength ratio between males and females following a 12-week resistance training program. Specifically, the study used the following aims and hypotheses.

- ❖ Aim 1: To determine, if differences exists in hamstring and quadriceps strength ratio between males and females before training.
 - Null hypothesis: There is no difference in H:Q strength ratio between males and females.
 - Alternative hypothesis: There is a difference in H:Q strength ratio between males and females.

- ❖ Aim 2: To compare the change in H:Q strength ratio following resistance training between males and females.
 - Null hypothesis: There is no difference in H:Q ratios between males and females following resistance training.
 - Alternative hypothesis: There is a difference in H:Q ratio between males and females following resistance training.

CHAPTER 3

Methods

Subjects

Sixteen male and 17 female recreationally active college-age students with no previous history of musculoskeletal conditions affecting the lower limb participated in this study. Their anthropometric characteristics are presented in Table 1. No subjects were actively involved in a systematic resistance training program for nine months immediately prior to the study. All procedures were undertaken with the approval of the Institutional Review Board at the University of Texas at El Paso and all subjects signed informed consents (Appendix 1).

Table 1. Subject's Anthropometric Characteristics. Values are presented as the mean (SD)

Characteristic	Males (n = 16)	Females (n = 17)
Age (years)	23.1(1.62)	22.1 (2.72)
Body mass (kg)	72.7(12.60)	60.0 (6.89)
Height (cm)	171.4 (6.54)	162.1 (5.63)

Subjects were included in this study based on the following criteria: (1) between the ages of 18 and 30 years; (2) participation in any recreational sports or students with participation in 2-4 times/week of aerobic or anaerobic work; (3) have not participated in systematic strength training program in the past 9 months. Subjects were excluded from the study based on the following criteria: (1) with previous history of any lower limb injury; (2) any medical condition that would prevent participation in resistance training; (3) pregnancy; (4) non-compliance with

intervention participation requirements of a minimum of 20 training sessions out of total 24 sessions.

Isokinetic testing procedures

All subjects attended preliminary training trials to acquaint themselves with the procedures and testing apparatus. A Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Inc, Shirley, New York) was used to evaluate the isokinetic quadriceps and hamstring strength of dominant leg in all subjects before resistance training. Leg dominance of every subject was determined based on their preferred kicking leg in soccer. Drouin and colleagues (2004) had established validity and reliability coefficients for peak torque, angular velocity and position measurements on Biodex system 3 isokinetic dynamometer. The findings of that study (Drouin et al., 2004) demonstrated that the Biodex system 3 isokinetic dynamometer was a mechanically reliable instrument for the valid measurement of angular position, isometric peak torque and slow to moderately high velocities (<300/sec) with reliability coefficients ranging from 0.99-1.0. In this study the primary investigator conducted all Biodex data collection. This primary investigator conducted a pilot study before data collection and achieved a 0.80 test-retest reliability on convention H:Q ratio and 0.88 was obtained on Functional H:Q ratio. Subsequently Biodex System 3 was used for the assessment of concentric and eccentric peak torques of hamstrings and quadriceps.

Before testing, subjects were instructed to wear shorts to allow alignment of the knee joint axis with the dynamometer axis. After a 10 minute warm-up period on a cycle ergometer and stretching of lower limb muscles, subjects were positioned on Biodex isokinetic dynamometer and securely strapped at the hip and thigh of the testing leg in order to minimize extraneous body movements. Their arms and chest were also securely strapped to avoid

additional assistance during isokinetic movement. The dynamometer's lever arm was strapped to the lower leg just above the medial malleolus of the ankle joint. The axis of the dynamometer arm was visually aligned with the anatomical axis of the knee joint during isometric contraction of thigh muscles. Maximal hamstring and quadriceps muscle strengths were obtained by measuring maximal peak torque during isokinetic knee flexion and extension through 0°-90° range of movement (0° = knee fully extended).

Gravity correction was used for all trials. Gravity correction is necessary as during knee extension, the quadriceps not only extends the knee, but also lifts the attached lever arm. Conversely, during knee flexion the hamstrings flex the knee and also have the assistance of gravity on both the limb and the dynamometer arm. If this factor is not accounted for correction, the quadriceps activity may be underestimated and the hamstring activity may be overestimated (Caldwell, Robertson, & Whittlesey, 2004). Initially during this procedure the subjects' knee was passively taken in to full extension and locked at 0°/sec by pressing hold and resume button on isokinetic dynamometer in order to obtain weight of the limb. A graphic display of gravitational torque resulting from the weight of the limb and dynamometer leg attachment was shown on the computer screen, which was recorded as lower limb weight. This value was automatically added to the active knee extension (quadriceps) torque and subtracted from the active knee flexion (hamstrings) torque to negate the effects of gravity (Caldwell, Robertson, & Whittlesey, 2004) by using the computer program in Biodex machine. Then the lever arm was unlocked and the subject was asked to slowly lower the limb to its initial position.

The collected maximal peak torque data were used to calculate both the conventional and functional H:Q ratios. The conventional H:Q ratio was determined by dividing the maximal concentric hamstring peak torque by the maximal concentric quadriceps peak torque. The

functional H:Q ratio was determined by dividing the maximal eccentric hamstring torque by the maximal concentric quadriceps peak torque. Tests were completed at 4 different angular velocities in the following order: 30°/sec, 60°/sec, 180°/sec and 240°/sec with 5 repetitions performed for each angular velocity. The highest peak torque from the 5 trials was recorded for analysis. A 60-second rest period was given between each trial to ensure full recovery. Visual feedback during testing was prevented by turning the computer monitor away from the subject. Verbal encouragement was given throughout the test to motivate each subject to perform maximally during testing procedure.

Posttest

Subjects were asked to report back for isokinetic measurements of concentric and eccentric strength of knee extensors and flexors to biomechanics laboratory after the 12-week resistance training program. All subjects were tested by following the same protocol used in the pretest.

Data collection

Variables that were collected for analysis included peak concentric and eccentric knee flexion and extension torque of dominant leg at angular velocities of 30°/sec, 60°/sec, 180°/sec and 240°/sec. The concentric H:Q ratio was assessed by dividing the concentric hamstring peak torque by concentric quadriceps peak torque, whereas functional H:Q ratio was assessed by dividing the peak eccentric hamstring torque by the peak concentric quadriceps torque.

Resistance training intervention

The resistance training intervention consisted of two training sessions each week for 12 weeks. All resistance training sessions were supervised by a certified personal trainer and several assistant supervisors in order to ensure proper execution of exercise techniques. A periodization

model of resistance training was followed in this study to increase optimal strength gains and to decrease the incidence of overtraining in subjects. The basic principle of periodization used in this training program was a shift from an emphasis of low volume and low intensity training to an increased volume and higher intensity training. The resistance training program was divided into four distinct phases known as mesocycles. Each mesocycle relates to a change in the volume and intensity of training and lasted 3 weeks. Typically each mesocycle reflects a specific training emphasis for that phase of training. The periodization design of the training program in this study was as follows:

- Mesocycle 1: low volume hypertrophy with 10 RM intensity, 4 exercises
- Mesocycle 2: moderate volume hypertrophy with 10 RM intensity, 6 exercises
- Mesocycle 3: high volume hypertrophy with 8 RM intensity, 6-7 exercises
- Mesocycle 4: moderate volume hypertrophy with 6 RM intensity, 4-6 exercises

The training frequency consisted of 2 sessions of 45 minute workout per week for the 12-week intervention period. A sample of the 12-week workout plan is shown in Appendix 3. After 5-10 minutes of dynamic warm-up all subjects completed their given workouts in each training session. Exercises for the lower body resistance training included: squats, deadlift, leg curls, back extensions, back hyperextensions, abdominal exercises, lunges and calf raises. The weekly workouts included some specific hamstring strengthening exercises such as glute-ham leg curls, power wheel hamstring bridges, swiss ball hamstring bridges, lying leg curls, bar and dumbbell Romanian deadlifts, running on incline treadmill, pedaling with high resistance elliptical machine and seated leg curls with cable.

All subjects were asked to perform their sets with starting weight which could be lifted for 10 repetitions. Based on their strength gains the point where they could lift the same weight

for 15 repetitions, additional weight was added, which reduced the number of repetitions back to the initial level. The exercise volume was gradually increased from first mesocycle to third mesocycle by adding 1-2 exercises in each mesocycle and then it was maintained at moderate volume in last mesocycle to elicit muscle hypertrophy changes in subjects.

Statistical design

This study was a 2 [Gender (Males, Females)] × 2 [Test (Pre, Post)] × 4 [Isokinetic speed (30°/sec, 60°/sec, 180°/sec & 240°/sec)] within subjects design. The dependent variable of interest was the H:Q strength ratio. The difference in H:Q strength ratios between males and females at baseline were analyzed by using unpaired t-tests. The percent change in H:Q strength ratios following training in males and females were analyzed by using one way analysis of variance (ANOVA) with repeated measures on all factors. Data were analyzed separately for the conventional and functional H:Q ratios. An alpha level of 0.05 was selected as the level of significance. SPSS, windows 16.0 version and SAS, windows 9.0 version were used for data analysis.

CHAPTER 4

Results

Out of the initial 33 subjects, 4 subjects dropped out of the study. In addition, one subject was excluded from the post-test data collection, as the subject did not comply with the study criterion of attending the required twenty training sessions. Therefore, the results were analyzed for a total of 14 males and 14 females. As a result of the 12-week of resistance training, there was an increase in mean peak torque values for the hamstring and quadriceps muscle groups from pre- to post-test in both males and females. Table 2 and Table 3 illustrate the change in concentric and eccentric hamstring and quadriceps peak torque in both males and females at four angular velocities following training.

At baseline, no statistical differences were observed between males and females for conventional H:Q ratio. Following the 12-week resistance training both males and females increased their conventional H:Q ratios (Table 4). In males the highest conventional H:Q ratio of 0.94 was observed at 240°/sec angular velocity, whereas in females the highest conventional H:Q ratio of 0.96 was observed at 180°/sec angular velocity following training. After 12 weeks of resistance training, a comparison of percent change in conventional ratios in males and females revealed a statistical difference ($p=0.0069$) at 30°/sec angular velocity (Table 6). Specifically, females increased their H:Q ratio by 66% (from a mean \pm SD of 0.54 ± 0.17 to 0.85 ± 0.19) compared to males who increased by 15% (from 0.6 ± 0.05 to 0.68 ± 0.06). No significant statistical differences were found between males and females at other angular velocities (60°/sec, 180°/sec & 240°/sec). However, females demonstrated a greater percent increase in H:Q ratio at 60°/sec and 180°/sec angular velocities (51% and 27%, respectively) compared to males (28% and 11%, respectively).

In terms of functional H:Q ratio, no statistical differences were observed between males and females at baseline. After 12 weeks of resistance training functional H:Q ratios were also increased in males and females from pre- to post-test (Table 5). In males, the highest functional H:Q ratio of 1.22 was observed at 240°/sec, whereas in females the highest functional H:Q ratio of 1.45 was observed at 30°/sec. A comparison of percent changes in H:Q ratios between males and females following resistance training revealed significant statistical differences at 30°/sec ($p=0.0001$), 60°/sec ($p=0.0156$) and 180°/sec ($p=0.0472$) angular velocities. A higher percent increase was observed at 30°/sec angular velocity with females increasing their ratio by 40% (from 1.04 ± 0.02 to 1.45 ± 0.05) compared to males by 7% (from 1.04 ± 0.02 to 1.12 ± 0.02), at 60°/sec females increased their ratio by 40% (0.98 ± 0.98 to 1.36 ± 0.10) compared to males by 17% (from 1.02 ± 0.09 to 1.18 ± 0.22) and at 180/sec females showed 27% (from 1.01 ± 0.15 to 1.28 ± 0.23) increase in their H:Q ratios, while males improved by 25% (from 0.97 ± 0.15 to 1.06 ± 0.08).

Table 2. Peak isokinetic concentric strength (Nm, Mean \pm SD) for the hamstring and quadriceps muscle groups.

Gender	Angular velocity ($^{\circ}$ /sec)	Muscle group tested					
		Hamstrings			Quadriceps		
		Pre	Post	% increase	Pre	Post	% increase
Males	30	103.9 \pm 34	140.4 \pm 37	35	173.9 \pm 25	211.5 \pm 36	21
	60	90.4 \pm 16	133.9 \pm 43	48	164.9 \pm 24	190.9 \pm 30	15
	180	81 \pm 17	107 \pm 19	32	117.6 \pm 38	137.4 \pm 30	16
	240	77.9 \pm 23	104.3 \pm 26	33	101.4 \pm 29	111.6 \pm 22	10
Females	30	78.9 \pm 28	128.8 \pm 34	63	145 \pm 15	152 \pm 17	4
	60	65.8 \pm 15	103.7 \pm 38	37	137.8 \pm 19	144.8 \pm 17	5
	180	62.9 \pm 11	86.1 \pm 12	23	85.4 \pm 25	91.1 \pm 15	6
	240	63.7 \pm 10	73.7 \pm 7	15	77.8 \pm 20	80 \pm 12	2

Table 3. Peak isokinetic eccentric strength (Nm, Mean \pm SD) for the hamstring and quadriceps muscle groups.

Gender	Angular velocity ($^{\circ}$ /sec)	Muscle group tested					
		Hamstrings			Quadriceps		
		Pre-test	Post-test	% increase	Pre-test	Post-test	% increase
Males	30	181.2 \pm 27	234.7 \pm 33	29	99.4 \pm 30	128.9 \pm 47	29
	60	168.3 \pm 24	223.4 \pm 36	32	92.8 \pm 20	109 \pm 31	17
	180	111.1 \pm 35	145.7 \pm 30	31	82.3 \pm 19	83.6 \pm 18	1
	240	101.6 \pm 30	135.9 \pm 26	33	77.6 \pm 14	82.1 \pm 17	5
Females	30	151 \pm 19	218.4 \pm 24	44	73 \pm 20	105.7 \pm 36	44
	60	134.5 \pm 16	196.2 \pm 19	45	68.6 \pm 12	71.7 \pm 22	4
	180	84.4 \pm 20	115.1 \pm 15	36	60.4 \pm 11	71.9 \pm 13	19
	240	71.6 \pm 14	98.2 \pm 18	37	65.2 \pm 11	70.7 \pm 13	8

Table 4: Conventional H:Q ratio (mean \pm SD) for males and females at 4 different angular velocities.

Gender	Angular velocity($^{\circ}$ /sec)	Pre-test	Post-test	Difference
Males	30	0.60 \pm 0.18	0.68 \pm 0.22	0.08
	60	0.54 \pm 0.07	0.70 \pm 0.21	0.16
	180	0.73 \pm 0.17	0.80 \pm 0.19	0.07
	240	0.79 \pm 0.21	0.94 \pm 0.19	0.15
Females	30	0.54 \pm 0.17	0.85 \pm 0.19	0.31
	60	0.48 \pm 0.12	0.72 \pm 0.27	0.24
	180	0.78 \pm 0.18	0.96 \pm 0.20	0.18
	240	0.84 \pm 0.16	0.93 \pm 0.14	0.09

Table 5: Functional H:Q ratio (mean \pm SD) for males and females at 4 different angular velocities.

Gender	Angular velocity($^{\circ}$ /sec)	Pre-test	Post-test	Difference
Males	30	1.04 \pm 0.09	1.12 \pm 0.10	0.08
	60	1.02 \pm 0.09	1.18 \pm 0.22	0.16
	180	0.97 \pm 0.15	1.06 \pm 0.08	0.09
	240	1.04 \pm 0.31	1.22 \pm 0.14	0.18
Females	30	1.04 \pm 0.11	1.45 \pm 0.21	0.41
	60	0.98 \pm 0.98	1.36 \pm 0.10	0.38
	180	1.01 \pm 0.15	1.28 \pm 0.23	0.27
	240	0.94 \pm 0.17	1.24 \pm 0.24	0.30

Table 6. Percent (%) increase in conventional H:Q ratio (Percentage \pm SD) between males and females at 4 angular velocities following resistance training

Angular velocity	% increase in females	% increase in males
30/sec*	66% \pm 56%	15% \pm 30%
60/sec	51% \pm 52%	28% \pm 52%
180/sec	27% \pm 27%	11% \pm 19%
240/sec	12% \pm 23%	27% \pm 46%

*significant statistical difference ($p \leq 0.05$) between males and females

Table 7. Percent (%) increase in functional H:Q ratio (Percentage \pm SD) between males and females at 4 angular velocities following resistance training

Angular velocity	% increase in females	% increase in males
30/sec *	40% \pm 23%	7% \pm 12%
60/sec *	40% \pm 18%	17% \pm 27%
180/sec *	27% \pm 21%	12% \pm 16%
240/sec	35% \pm 33%	25% \pm 31%

*significant statistical difference ($p \leq 0.05$) between males and females

CHAPTER 5

Discussion

The purpose of this study was to assess gender differences in H:Q ratio and to compare the percent change in H:Q ratio in males and females following a 12 week resistance training program. Evaluation of H:Q ratio is an important practical consideration to discriminate those individuals who have a relatively greater risk of knee injury from those whose risk is lower (Wilkerson et al., 2004). Dunnam et al. (1988) and Clanton and Coupe (1998) identified a conventional H:Q ratio of 0.6 at 60°/sec angular velocity as the minimum H:Q ratio to avoid knee injuries. In our study the mean gravity corrected conventional H:Q ratios at 60°/sec angular velocity for males and females were 0.54 and 0.48, respectively, in the dominant leg at baseline, which were less than the previously recommended ratios by Clanton and Coupe, 1998 and Dunnam et al. (1988). Consequently the subjects in our study were categorized as “at-risk” for knee injuries as per their baseline values, in reference of the above stated standards.

Studies from Holmes and Alderink (1984) and from Ahmed and colleagues (2006) found that males had higher H:Q ratio than females. This indicates that females tend to rely more on their quadriceps than hamstrings during functional movements, which stresses the ACL at higher risk for injury. Data from the present study were not in accordance with these previous findings. While at all angular velocities the mean H:Q ratio of males was higher than that of females, our data indicated no statistical differences in H:Q ratios between males and females at baseline. Since all subjects in our study were recreationally active, their knee strength properties may be similar in relation to one another. In the referenced previous studies (Holmes & Alderink, 1984; Ahmed et al., 2006) authors assessed H:Q ratio in high school recreational soccer players and

non-athletes. These differences in population characteristics may be the reason for discrepancies in findings.

In this study functional H:Q ratios showed greater statistical differences between males and females than conventional H:Q ratio at all angular velocities. This suggests that the hamstring and quadriceps exercises included in the resistance training intervention were functionally based and affected the functional ratios to a greater degree. Before the intervention both males and females had lower functional H:Q ratios, indicating a higher quadriceps dominance in the knee joint. The conventional H:Q ratio at 60°/sec angular velocity was initially tested below 0.6 for both males and female, however, after 12 weeks resistance training program the conventional H:Q ratios were increased in males and females above the recommended ratio (Table 4). Functional ratios both for males and females were greater than 0.6 at pre-test, yet subjects showed further improvement for these ratios as well (Table 5). These findings suggest that there was an increase in hamstring co-activation compared to pre-test ratios.

Similarly to previous reports (Wilmore, 1974; Ivey et al., 2001) females responded to a similar resistance training program with higher percent gains in their strength ratios compared to their male counterparts. In this study a higher percent change was observed at 30°/sec angular velocity with females increasing their conventional H:Q ratio by 66% compared to males by 15%. Also at the same angular velocity females increased their functional H:Q ratio by 40% compared to males by 7%. Even though there were no statistical differences found at 60°/sec and 180°/sec angular velocities in conventional H:Q ratio following training, the mean percent increase in H:Q ratios were higher in females than in males (Table 6). Before training, females had equal or slightly lower mean H:Q ratios than males suggesting that they were more quadriceps dominant than their male counterparts. However, by post-test females had higher H:Q

ratios than males in most measures. This indicates that with training there was an increase in the hamstring co-activation in females, which may also attribute to a greater percent change in H:Q ratio among females compared to males.

After 12 weeks of resistance training program, a tendency was observed for the mean quadriceps and hamstring peak torque values to increase in both males and females at all four angular velocities, although these increases were not validated by statistical calculations. For instance, at 30°/sec angular velocity the quadriceps concentric peak torque increased 21% in males and 4% in females, and the hamstring concentric peak torque increased 34% in males and 63% in females. Eccentrically, hamstring peak torque in males and females increased at 29% and 44%, respectively. The greater percent increase in the hamstring peak torques that were observed in females explains the higher percent change in H:Q ratio in females compared to males.

However, the greater mean quadriceps and hamstring peak torques that were observed in males at pre-test remained greater than that of females by post-test (Table 2 & Table 3). This indicates that males were stronger in both quadriceps and hamstring concentric and eccentric strength at all angular velocities at pre-test, and despite the greater increases observed in females, males remained stronger by the post-test. At post-test, the eccentric quadriceps and hamstring peak torques were greater for both males and females than the concentric hamstring and quadriceps peak torques. The findings of this study partially conflict with the Holcomb et al. (2007), who tested hamstring and quadriceps peak torques in females and found that only eccentric hamstring peak torque was increased at greater percentage than concentric hamstring and quadriceps peak torque following resistance training.

The mean functional H:Q ratios of males and females in this study were greater than conventional H:Q ratios at both slower and faster angular velocities (Table 4 & Table 5). This

greater functional H:Q ratio indicates a significant contribution from the antagonist muscles (hamstrings) to counteract the concentric agonist muscles (quadriceps) during knee joint extension (Holcomb et al., 2007). The results of this study indicated that in males increased conventional and functional H:Q ratios were observed at higher angular velocities compared to low angular velocities. For instance, increases in conventional H:Q ratios from 0.68 (observed at 30°/sec) to 0.94 (at 240°/sec), and in functional H:Q ratios from 1.12 (at 30°/sec) to 1.22 (at 240°/sec) were noted at post-test. These findings are in accordance with previous findings from Holcomb et al. (2007). On the contrary, these trends were observed only for conventional H:Q ratios in females, as for instance an H:Q ratio of 0.84 (at 30°/sec) increased to 0.93 (at 240°/sec). For functional H:Q ratios in females values were actually lower at higher angular velocities; for instance an H:Q ratio of 1.45 (at 30°/sec) decreased to 1.24 (at 240°/sec). The most plausible explanation would be that the hamstring muscle group produced a greater concentric peak torque than quadriceps during knee extension. At terminal knee extension hamstring would be at its optimal length and thus produces greater momentum, while quadriceps in shortening and there by unable to produce sufficient peak torque than hamstrings (Coombs & Garbutt, 2002).

There were some limitations to this study. The strength ratios that were assessed using isokinetic machine were more based on non-weight bearing and open kinematic chain exercises as opposed to functional movements, which were more of weight bearing and closed kinematic chain exercises. Therefore the isokinetic strength data can not be correlated strongly with the functional activities. Also most of the functional movements are subject to forces of gravity and in this study the lower extremity during isokinetic testing was free to move without any ground reaction forces. The precision of the torque readings was limited to the accuracy of isokinetic machine and also to the manual calibration process. The ability of producing peak torque during

isokinetic testing was depended upon the maximum effort exerted by the subject during testing procedures, which is the nature of isokinetic data collection.

CHAPTER 6

Conclusion

In summary, it was evident that the 12-week resistance training program was effective in increasing H:Q ratios both in males and females with females increasing their H:Q ratios at higher percentage than their male counterparts. This supports our hypothesis that males and females differ in percent change in their H:Q ratios following training. The results of this study also showed a higher percent increase in eccentric hamstring and quadriceps peak torque than concentric hamstring and quadriceps peak torque among all subjects. This suggests that the training program was effective in increasing hamstring co-activation with more eccentric momentum than concentric quadriceps momentum during knee extension. It is recommended that athletes' conventional H:Q ratio should be higher than 0.6 (Clanton & Coupe, 1998; Dunnam et al., 1988) and their functional ratio higher than 1.0 (Dunnam et al., 1988) to prevent ACL injuries and hamstring strains. In the present study all subjects achieved these recommended ratios following the 12-week resistance training program. Therefore, it is the conclusion of this study that both males and females respond positively to resistance training, and 12 weeks of periodized resistance training that focuses on the functional development of the quadriceps and hamstring muscles may increase H:Q ratios both in males and females to the recommended levels. It is also the conclusion of the present study that although males may possess higher H:Q ratios prior to training, females can achieve greater absolute and relative (percent) increases in H:Q ratios than males and may demonstrate similar H:Q ratios as males following a 12-week periodized resistance training program.

Future research should focus on assessing strength ratios during functional movements to have better understanding of agonist and antagonist relationship during range of motion of a

joint. Also future research should include sport specific strength tests and speed tests along with isokinetic strength data to comprehensively evaluate the performance of athletes.

LIST OF REFERENCES

- Aagard, P., Simonsen, E., Trote, M., Bangsbo, J., and Klausen, K. (1995). Isokinetic hamstring/quadriceps strength ratio: influence from joint angular velocity, gravity correction and contraction mode. *Acta Physiologica Scandinavica*, 154(4), 421-427.
- Aagard, P., Simonsen, E., Trote, M., Bangsbo, J., and Klausen, K. (1996). Specificity of training velocity and training load on gains in isokinetic knee joint strength. *Acta Physiologica Scandinavica*, 156(2), 123-129.
- Aagard, P., Simonsen, E., Magnusson, P., Larsson, B., and Poulsen, P. (1998). A new concept for Isokinetic hamstring: quadriceps muscle strength ratio. *American Journal of Sports Medicine*, 26, 231-6.
- Ahmad, C., Clark, A., Heilman, N., Schoeb, J., and Levine, W. (2006). Effect of gender and maturity on quadriceps-to-hamstring strength ratio and anterior cruciate ligament laxity. *American Journal of Sports Medicine*, 34(3), 370-374.
- Always, S., Grumbt, W., Gonyea, P., and Gunderson, J. (1989). Contrasts in muscle and myofibers of elite male and female bodybuilders. *Journal of Applied Physiology*, 67(1), 24-31.
- Arendt, E., and Dick, R. (1995). Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *American Journal of Sports Medicine*, 23, 694-701.
- Baratta, R., Solomonow, M., Zhou, B. H., Letson, D., Chuinard, R., and D' Ambrosia, R. (1988). Muscular coactivation: The role of the antagonist musculature in maintaining knee stability. *American Journal of Sports Medicine*, 16(2), 113-122.

- Che Tin Li, R., Maffulli, N., Hsu, C., and Chan, K. M. (1996). Isokinetic strength of quadriceps and hamstrings and functional ability of anterior cruciate deficient knees in recreational athletes. *British Journal of Sports Medicine*, 30, 161-164.
- Caldwell, G. E., Robertson, G. E., and Whittlesey, S. N. (2004). Forces and their measurement. In D. Robertson., G. Caldwell., J. Hamill., G. Kamen., & S. Whittlesey (10th edition), *Research methods in biomechanics* (pp. 73-102). Illinois: Human kinetics.
- Carcia, C., Schultz, J. S, Granata, K. P., Perrin, H. D., and Martin, R. L. (2005). Females recruit quadriceps faster than males at multiple knee flexion angles following a weight-bearing rotary perturbation. *Clinical journal of Sports Medicine*, 15(3), 167-171.
- Clanton, T. O., and Coupe, K. J. (1998). Hamstring strains in athletes: diagnosis and treatment. *Journal of American Academy of Orthopedic surgeons*, 6, 237-248.
- Clark, R., Bryant, A., Culgan, J., and Hartley, B. (2005). The effects of eccentric hamstring strength training on dynamic jumping performance and isokinetic strength parameters : a pilot study on the implications for the prevention of hamstring injuries. *Physical Therapy in Sport*, 6(2), 67-73.
- Coombs, R., and Garbutt, G. (2002). Developments in the use of the hamstring/quadriceps ratio for the assessment of muscle balance. *Journal of Sports Science and Medicine*, 1, 56-62.
- Cureton, K., Collins, D., Hill, W., and Mcelhannon, F. (1988). Muscle hypertrophy in men and women. *Medicine and Science in Sports and Exercise*, 20(4), 338-344.

- Dunnam, L. O., Hunter, G. R., Williams, B. P., and Dremsa, C. J. (1988). Comprehensive evaluation of the University of Alabama at Birmingham women's volleyball training program. *National Strength and Conditioning Association Journal*, 10, 43–49.
- Drouin, J., Valovich-Mcleod, T., Shultz, S., Ganseneder, B., and Perrin, D. (2004). Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *European Journal of Applied Physiology*, 91, 22-29.
- Evetovich, T., Housh, T., and Johnson, G.(1998). Gender comparisons of the mechanomyographic responses to maximal concentric and eccentric Isokinetic muscle actions. *Medicine and Science in Sports and Exercise*, 30, 1697-1702.
- Hewett, T. (1996). Plyometric training in female athletes: Decreased impact forces and increased hamstring torques. *The American Journal of Sports Medicine*, 24, 765-773.
- Hewett, T., Lindenfeld, T., Riccobene, J and Noyes, F. (1999). The effect of neuromuscular training on the incidence of knee injury in female athletes. *The American Journal of Sports Medicine*, 27, 699-706.
- Holmes, J., and Alderink, G. (1984). Isokinetic strength characteristics of the quadriceps Femoris and hamstring muscles in high school students. *Physical Therapy*, 64(6), 914-918.
- Holcomb, W. R., Rubley, M. D., Lee, H. J., and Guadagnoli, M. A. (2007). Effect of hamstring – emphasized resistance training on H:Q strength ratios. *The Journal of Strength and Conditioning Research*, 21(1), 41-47.
- Ivey, F., Tracy, B., Lemmer, J. T., Nissaiver, M., Metter, E., Fozard, J., and Hurley, B. (2000). Effects of strength training and detraining on muscle quality. Age and

- Gender comparisons. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 55, 152-157.
- Kannus, P., Jarvinen, M., and Latvala, K. (1987). Knee strength evaluation: A standardized test protocol and scoring scale for isokinetic and isometric strength measurements of the knee joint for evaluation of long-term healing results of knee problems and their treatment procedures. *Scandinavian Journal of Sports Sciences*, 9, 9-13.
- Kisner, C., and Colby, L. A. (3rd edition). *Therapeutic Exercise: Foundation and Techniques*. Philadelphia: F. A. Davis.
- Kvist, J., Karlberg, C., Gerdle, B., and Gillquist, J. (2001). Anterior tibial translation during different isokinetic quadriceps torque in anterior cruciate ligament deficient and nonpaired individuals. *Journal of Orthopedic Sports and Physical therapy*, 31(1), 4-15.
- Leyek, D., Ridder, D., Wunderlich, M., Ruther, T., Sievert, A., and Essfeld, D. (2007). Hand-grip strength of young men, women and highly trained female athletes. *European Journal Applied Physiology*, 99(4), 415-421.
- Miller, E. J., MacDougall, J., Tarnopolsky, M., and Sale, D. (1993). Gender differences in strength and muscle fiber characteristics. *European Journal of Applied Physiology*, 66(3), 254-262.
- More, R.C., Karras, B.T., Neiman, R., Fritschy, D., Woo, Y., and Daniel, D.M. (1993). Hamstrings – an anterior cruciate ligament protagonist: an in vitro study. *American Journal of Sports Medicine* 21, 231-237.

- Nagano, Y., Ida, H., Akai, M., and Fukubayashi, T. (2007). Gender differences in knee kinematics and muscle activity during single limb drop landing. *The Knee*, 14 (3), 218-223.
- O' Hagan, F., Sale, D., MacDougall, J., and Garner, S. (1995). Response to resistance training in young women and men. *International Journal of Sports Medicine*, 16(5), 314-321.
- Solomonow, M., Baratta, R., Zhou, B. H., and D'Ambrosia, R. (1988). Electromyogram coactivation patterns of the elbow antagonist muscles during slow isokinetic movement. *Experimental Neurology*, 100(3), 470-7.
- Staron, R., Karaponda, D., Kraemer, W., Fry, A., Gordon, S., Falkel, S., and Hikida, R. (1994). Skeletal muscle adaptations during early phase of heavy resistance training in men and women. *Journal of Applied Physiology*, 76(3), 1247-1255.
- Weiss, L., Clark, F., and Howard, D. (1988). Effects of heavy-resistance triceps surae muscle training on strength and muscularity of men and women. *Physical therapy*, 68(2), 208-213.
- Westin, S., Noyes, F., and Galloway, M. (2006). Jump-land characteristics and muscle strength development in young athletes: a gender comparison of 1140 athletes 9 to 17 years of age. *The American Journal of Sports Medicine*, 34, 375-385.
- White, K., Lee, S., and Cutuk, A. (2003). EMG power spectra of intercollegiate athletes and anterior cruciate ligament injury risk in females. *Medicine and Science in Sports Exercise*, 35, 371-376.

- Wilkerson, G., Colston, M., and Short, N. (2004). Neuromuscular changes in female collegiate athletes resulting from a plyometric jump-training program. *Journal of Athletic Training*, 39, 17-23.
- Wilkinson, J., and Meyers, M. (1993). Isokinetic leg strength and power in collegiate rodeo athletes. *The Journal of Strength and Conditioning Research*, 7(1), 22-25.
- Wilmore, J. (1974). Alterations in strength, body composition and anthropometric measurements consequent to 10-week weight training program. *Medicine and Science in Sports*, 6(2), 133-138.
- Wojtys, E., Huston, L., Schock, H., Boylan, J., and Miller, A. (2003). Gender differences in muscular protection of the knee in torsion in size-matched athletes. *Journal of Bone and Joint Surgery of America*, 85(5), 782-789.
- Youdas, J. W., Hollman, J. H., Hitchcock, J. R., Hoyme, J., and Johnsen, J. (2007). Comparison of hamstring and quadriceps femoris electromyographic activity between men and women during a single-limb squat on both a stable and liable surface. *The Journal of Strength and Conditioning Research*, 21(1), 105-111.

APPENDIX 1

Institutional Review Board Approval, Informed Consent form, Solicitation Questionnaire,

Additional Questionnaire about Experience in Resistance training

Institutional Review Board Approval (Copy of an online document)

The screenshot shows a web browser window titled "IRBNet: Study Manager - Mozilla Firefox". The address bar shows a file path: "file:///C:/Documents%20and%20Settings/Owner/Desktop/Application%20for%20Graduate%20enhanceme...". The browser's toolbar includes navigation buttons and a search bar with "Google". A row of application icons is visible below the toolbar, including Gmail, roj, and others. The main content area of the browser displays the IRBNet Study Manager interface. At the top right of the interface are links for "USER PROFILE" and "LOGOUT". The left sidebar contains the text "Welcome to IRBNet Pradeep Edupuganti" and a menu with "Study Manager" and "Create New Study". The main content area is titled "Study Manager" and displays a table of studies. The table has columns for "Study Title", "Status", and "IRBNet ID". One study is listed: "Gender Differences in the Improvement of Hamstring to Quadriceps Ratio following Resistance Training Program" with a status of "Approved" and an ID of "80191-1". Below the table, there is a "[Search]" link and the text "One Study found.". At the bottom of the browser window, the Windows taskbar is visible, showing the "start" button and several open applications, including "IRBNet: Study Manag...", "C:\Documents and Se...", and "temp - Windows Pictu...". The footer of the web page contains the text "Copyright © 2002-2007 Research Dataware. All Rights Reserved."

Study Title	Status	IRBNet ID
Gender Differences in the Improvement of Hamstring to Quadriceps Ratio following Resistance Training Program	Approved	80191-1

Informed Consent Form

Name: _____ School: _____ Subject ID#: _____

I agree to participate in the research entitled as Effect of Resistance Training in the Improvement of Hamstring to Quadriceps (H:Q) Strength ratio in males and females, which is being conducted by Pradeep Edupuganti under the supervision of Dr. Sandor Dorgo, Ph.D.

General information:

Pradeep Edupuganti, B.P.T, NSCA-CPT would be the principal researcher in this study. I am invited voluntarily to participate in this study. The study involves hamstring to quadriceps strength ratio testing and 12-week resistance training.

I understand that I will be asked to be involved in the following:

1. I will fill out a questionnaire covering my health and training background information.
2. I will attend one practice session where I will familiarize with Isokinetic testing on a Biodex machine at angular velocities of 30, 60, 180 and 240°/s and learn the resistance exercise techniques.
3. I will complete the pre-isokinetic testing before the resistance training.
4. I will complete 35-45 minute resistance training workout sessions two times a week for 12-weeks.
5. I will follow the instructions of the researchers and I will be provided an exercise program.
6. I will complete a post-isokinetic testing session after 6 and 12-weeks of resistance training.

The benefits that I may gain from this study are:

1. Participation in a carefully planned and supervised resistance training program
2. Improvement in physical fitness
3. Learning correct forms of various resistance training exercises
4. Learning new resistance training exercises and techniques
5. Observe a change in the hamstring to quadriceps strength ratio over a period of 12-weeks resistance training.
6. Understanding of how the increased strength balance between hamstring and quadriceps may help to prevent knee ligament injuries and hamstring injuries.
7. Better understanding of the concepts of physical fitness.

Risks of participation in the study:

I understand that only minor physical discomforts, stresses or risks (muscle soreness) are expected during this research, associated with the Isokinetic testing and training session. I understand that the researchers will strive to protect my safety by providing supervision of qualified personnel.

Voluntary participation:

My participation in this study is voluntary. I may refuse to participate in this study or in any part of the study. In order to enhance the validity of this study, I will not have any radical changes in my life-style during the course of the study. I am encouraged to ask questions about this study at the beginning or any time during the research study. I have a right to ask about the findings of the research study. I understand that my participation will be prohibited if I have any health related problems that are contraindicated to resistance training.

Confidentiality:

My personal information gathered from the questionnaire and from the tests will be known only by the researchers. My name and any details that might identify me will be changed to a subject number in any written reports to protect confidentiality. Documents will be kept on the UTEP campus in the researcher's office in a locked cabinet and destroyed 3 years after completion of the research study.

Contact information:

I can contact researchers in this study at any time via phone: 915-540-4975 or by email: pedupuganti@utep.edu.

My signature below indicates that I agree to participate in this research study and procedures have been explained to me, and any questions have been answered to my satisfaction. I have read the above information and give my consent to participate in this research study. A copy of this form has been given to me. I am at least 18 years of age.

Signature of the participant

Date

Signature of the investigator

Date

Solicitation Questionnaire

1. Are you between the ages of 18-30 years? Yes/No
2. How many times you workout in a week?
3. Have you been diagnosed by a physician with any pathology of the lower extremities that restrict movement at any of your body parts? Yes/No
4. Have you been diagnosed by a physician with any cardiovascular disease or any Neurological abnormality or impairment? Yes/No
5. Do you have a history of previous surgery of the lower extremities? Yes/No
6. Do you currently have any medical condition that would keep you from performing maximum contractions of the thigh muscles on an Isokinetic machine or in participating in a resistance training session? Yes/no

If you meet the inclusion/exclusion criteria:

7. Would you like to make an appointment for inclusion in the research study? Yes/no

Signature of the Participant

Date

Signature of the Investigator

Date

Questionnaire – About Experience In Resistance Training

Subject Name: _____

1. Have you ever participated in a systematic lower body resistance training program?
 Yes
 No
2. If yes, how many times per week you were trained for lower body workout?
___ times per week.
3. Have you been participating for the last 6-9 months in a lower body resistance training program with a minimum of 1 training sessions per week?
 Yes
 No
4. If yes, when did you begin and how many times per week have you been performing lower body resistance training lately?
Date started _____, and ___ times per week.
5. If you are not participating in a systematic lower body resistance training program, are you performing any occasional lower body resistance training?
 Yes
 No
6. If yes, approximately how often do you perform lower body resistance training exercises?
___ times per week.
7. Do you have experience in performing the following lower body and core exercises? If yes, please select from the following list of exercises.
 Back and Front Squats
 Barbell and dumbbell deadlifts
 Stationary and walking lunges
 Leg curls
 None of the above

APPENDIX 2

Procedures for Biodex Multi-Joint System 3 Testing and Data Retrieval

Testing Procedures

Setup and positioning of subject

1. Seat subject on chair
2. Rotate chair to 45 degrees
3. Rotate dynamometer to 45 degrees
4. Attach knee attachment to dynamometer
5. Move subject into position
6. Align subject's knee axis of rotation with dynamometer shaft.
7. Adjust knee attachment so that it is proximal to medial malleoli. Secure with straps
8. Stabilize subject with shoulder, waist and thigh straps
9. Set ROM stops

Biodex System 3 operating procedures

10. Click on Patient icon
11. Add patient (for new subjects only)
12. Open patient- select patient – click NEW at the bottom toolbar
13. Select a Protocol
 - a. Click on Protocol icon
 - b. Double click on Isokinetic Unilateral
 - c. Select Knee (Extension/Flexion)
 - d. Select Protocol
 - e. For concentric/eccentric, select Pradeep Quadriceps Thesis

- f. For eccentric/concentric, select Pradeep Hamstring Thesis
 - g. Close protocol screen
14. Set range of motion
- a. Click on Goniometer icon
 - b. Select side (right/left)
 - c. Select Clear Limits
 - d. To set Away limit, have patient move through appropriate range of motion (kicking out - extension). Have subject hold position and click on SET away
 - e. To set toward limit, have subject move through appropriate range of motion (kicking back - flexion). Have subject hold position and click on SET towards
 - f. Click on Continue button
15. Set Anatomical reference
- a. Move the subject's leg to 90° knee angle. Press "Hold and Resume" button.
 - b. Press the Position icon
 - c. The position icon should display 90
 - d. Press again Hold and Resume button to release the leg attachment. The leg attachment should move freely.
16. Set an appropriate toward torque for eccentric contraction before each new angular velocity.
- Recommended toward torque for males – 300-400 Nm
 - Recommended toward torque for females – 150-300 Nm
17. Test is ready to begin

18. Press green Go button. Follow screen instructions. Release the limb by pressing the Hold and Resume button for testing.

Testing opposite side:

19. Unstrap subject's knee from attachment and thigh strap
20. With subject remaining in chair, slide chair back away from dynamometer
21. Press hold button to retain dynamometer shaft position. Move chair away from dynamometer and remove attachment.
22. Get knee attachment for opposite side
23. Follow the same procedure from step 5 to step 18 for the opposite knee

Retrieving data:

24. Click on Patient icon
25. Select subject name
26. Select Report icon
27. Select required test
28. Click on General evaluation icon
29. Record the peak torques values

APPENDIX 3

Resistance Training workouts and Exercises

Resistance Training Workouts

Program duration: 12 weeks

Program mesocycles: 4 x 3-week cycles

- Mesocycle 1: low volume hypertrophy with 10 RM intensity, 4 exercises
- Mesocycle 2: moderate volume hypertrophy with 10 RM intensity, 6 exercises
- Mesocycle 3: high volume hypertrophy with 8 RM intensity, 6-8 exercises
- Mesocycle 4: moderate volume hypertrophy with 6 RM intensity, 4-6 exercises

Sample training plan

Training Program Plan						
	Tuesday			Friday		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Week 1: <u>4/1/08-4/4/08</u> Each exercise: 2x10	- Deadlift from Stands - Dumbbell Step-ups - Cable Back Ext. - Rubber Band RDLs	- Bar Back Squats - Alt. lunges w/ bar - Dumbbell RDLs - Incline Treadmill	- One Db. Sumo Sq. - Db. Squat-Lunge - Ham. Bench Bridge - Leg Curl Machine	- One Db. Sumo Sq. - Db. Squat-Lunge - Ham. Bench Bridge - Leg Curl Machine	- Deadlift from Stands - Dumbbell Step-ups - Cable Back Ext. - Rubber Band RDLs	- Bar Back Squats - Alt. lunges w/ bar - Dumbbell RDLs - Incline Treadmill
Week 2: <u>4/8/08-4/11/08</u> Tuesday: 2x10 Friday: 3x10	- Bar Back Squats - Alt. lunges w/ bar - Dumbbell RDLs - Incline Treadmill	- One Db. Sumo Sq. - Db. Squat-Lunge - Ham. Bench Bridge - Leg Curl Machine	- Deadlift from Stands - Dumbbell Step-ups - Cable Back Ext. - Rubber Band RDLs	- Deadlift from Stands - Dumbbell Step-ups - Cable Back Ext. - Rubber Band RDLs	- Bar Back Squats - Alt. lunges w/ bar - Dumbbell RDLs - Incline Treadmill	- One Db. Sumo Sq. - Db. Squat-Lunge - Ham. Bench Bridge - Leg Curl Machine
Week 3: <u>4/15/08-4/18/08</u> Each exercise: 3x10	- One Db. Sumo Sq. - Db. Squat-Lunge - Ham. Bench Bridge - Leg Curl Machine	- Deadlift from Stands - Dumbbell Step-ups - Cable Back Ext. - Rubber Band RDLs	- Bar Back Squats - Alt. lunges w/ bar - Dumbbell RDLs - Incline Treadmill	- Bar Back Squats - Alt. lunges w/ bar - Dumbbell RDLs - Incline Treadmill	- One Db. Sumo Sq. - Db. Squat-Lunge - Ham. Bench Bridge - Leg Curl Machine	- Deadlift from Stands - Dumbbell Step-ups - Cable Back Ext. - Rubber Band RDLs

CURRICULUM VITA

Pradeep Edupuganti was born on December 14, 1982 in Vijayawada, Andhra Pradesh, India. He is the son of Edupuganti Lakshmana Rao and Venkata Lakshmi and has one brother, Sai kumar. He graduated from N.T.R Health University with bachelor's degree in Physical Therapy and traveled to the University of Texas at El Paso (UTEP) to pursue his Master's degree and awarded the Graduate Athletic Trainer Scholarship. While a graduate student, Pradeep was an athletic trainer in UTEP Sports Medicine department and worked for Football and Women's Tennis teams. In the fall of 2008 he graduated with a Master's of Science in Kinesiology and Exercise Science.

Permanent Address: Pradeep Edupuganti

s/o E. Lakshmana Rao

D-no: 9-22

Poranki, Vijayawada,

Andhra Pradesh

India - 521137