Summer 8-2015

EXAMINATION OF HAMSTRING TO QUADRICEP MUSCLE RATIOS IN NCAA DIVISION I WOMEN VOLLEYBALL ATHLETES

Laura S. Miller
lmiller2@siu.edu

EXAMINATION OF HAMSTRING TO QUADRICEP MUSCLE RATIOS IN NCAA DIVISION I WOMEN VOLLEYBALL ATHLETES

By

Laura Miller

B.S., Nicholls State University, 2013

Submitted in Partial Fulfillment of the Requirements for the

Degree of Masters of Science in Education

Department of Kinesiology

In Exercise Science

Southern Illinois University Carbondale

August 2015

EXAMINATION OF HAMSTRING TO QUADRICEP MUSCLE RATIOS IN NCAA DIVISION I WOMEN VOLLEYBALL ATHLETES

By

Laura Miller

A Research Paper Submitted in Partial

Fulfillment of the Requirements

for the Degree of Masters of Science in Education

in the field of Kinesiology

Approved by:

Dr. Michael Olson, Chair

Dr. Juliane Wallace

Graduate School

Southern Illinois University Carbondale

June 22, 2015

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Female athletes in elite sports have a 4 – 6 fold greater chance of suffering an anterior cruciate ligament (ACL) injury than their male counterparts (Myer, Ford, Foss, Liu, Nick, & Hewett, 2009). Increased joint laxity due to an ACL injury leads to reduced neuromuscular control and passive stability of the knee joint, and may predispose female athletes to a higher risk of ACL damage (Myer et al., 2009). Females are also at a greater risk of an ACL injury because of having larger hips than males, causing a greater Q-angle in the lower extremity, and therefore placing more stress on the knee joint ligaments (Myer et al., 2009). It has been suggested that the role of the hamstring muscles during leg extension is to assist the ACL in preventing anterior tibial drawer forces, by increasing the posterior pull, increasing joint stiffness and reducing anterior laxity force during quadriceps loading to oppose its force (Baratta, Solomonow, Zhou, Letson, Chuinard, & D'Ambrosia, 1988). The hamstring muscles play a key function in maintaining knee joint stability, especially when there is a deficient ACL (Coombs & Garbutt, 2002). For many years, management of a patient with an ACL injury has been difficult with rehabilitation and return to play for orthopaedic specialist (Seto, Orofino, Morrissey, Medeiros, & Mason, 1988). After an ACL reconstruction has been performed, the knee joint is vulnerable to extensive progressive damage resulting in chronic instability, meniscal tears, articular degeneration, and arthritic changes (Seto et al, 1988). The goal of the treatment in ACL injured patients is to prevent this damaging progression and return individuals to their pre-injury functional status (Seto et al., 1988). DeProft, Cabri, Dufour, Clarys, and Bollens (1988a, 1988b) showed that soccer players, who incorporated strength training into their normal soccer training, improved strength and kick performance significantly over non-footballers and those who trained without a strength training regimen. They suggested that in addition to normal training, footballers should train their quadriceps concentrically and hamstrings eccentrically for improved kick performance. This implies that the relationship between eccentric hamstring and concentric quadriceps strength is important (Coombs & Garbutt, 2002).

The term “muscular strength” usually refers to a measure describing an individual’s ability to exert maximal force, either statically or dynamically (Moss & Wright, 1993). Traditionally, muscle strength is measured by three different methods: isometric, isotonic, and isokinetic. All three methods demonstrate that the muscle is not always shortening to respond to the external loads in the attempts to contract against resistance (Moss & Wright, 1993). In an isometric exercise the muscle length and joint angle do not change during activation, which can also be referred to as a static contraction (Moss & Wright, 1993). Isotonic actually refers to the external loading which is assumed that the muscle force needed to overcome the resistance does not change, but as movement at the joint does occur, the torque output of the muscle will change (Moss & Wright, 1993). Isokinetic contraction is static muscle activity performed at a constant angular velocity (Moss & Wright, 1993). In the present study the focus will be on isometric and isokinetic contractions being done in the lower limb.

In clinical and scientific research, the function of the thigh muscles crossing the hip and knee joints has been a controversial topic of discussion by containing a variety of techniques in which the joint can be measured (Coombs & Garbutt, 2002). These techniques include visual inspection of the moment-joint angle curve, the single point peak moment, moment at a specified knee joint angle, and most commonly the hamstring-quadriceps ratio (H:Q ratio) (Coombs & Garbutt, 2002). The ratio of maximal isokinetic hamstring muscle strength to maximal isokinetic quadriceps strength has been known to be beneficial in the process of rehabilitation and physical conditioning (Aagaard, Simonsen, Magnusson, Larsson, & Dhre-Poulsen, 1998; Kong & Burns, 2010). The H:Q ratio is a parameter commonly used to describe the muscle strength properties relative to the knee joint (Aagaard et al., 1998). Evaluation of the isokinetic hamstring and quadriceps strength may provide a relationship of value in describing the maximal potential of the muscle groups involved (Coombs & Garbutt, 2002). The H:Q ratio can also be used to measure strength deficits between muscle groups in the lower limb for a pre-season evaluation and possibly as an indicator for return to play status after the athlete has had a thigh or knee injury. There is little research on the H:Q ratio with participants who have chronic knee pain or osteoarthritis, which is associated with the majority of the subjects in this present study.

Knee osteoarthritis (OA) is associated with reduced knee joint stability due to impaired quadriceps strength, pain, and an altered joint structure (Hortobagyi, Westerkamp, Beam, Moody, Garry, Holbert, & DeVita, 2005). These factors lead to a diminished force output from one muscle group on one side of the knee and creates reduced joint stability (Sharma, 2001). To maintain joint function and increase stability, subjects with knee OA must generate compensatory muscle activity (Hortobagyi et al., 2005). The pattern of joint torques in activities of daily living (ADLs) shows an enhanced torque generation at the hip and reduced torque production at the knee in OA compared with healthy, non-injured adults (Hortobagyi et al., 2005). It is also well documented that knee OA is associated with quadriceps weakness (Hortobagyi et al., 2005). This issue raises the question as to whether correction of any muscle imbalance could cause a reduction in the risk of injury, or if muscle imbalance causes injury (Coombs & Garbutt, 2002). With collecting these data it might be useful in determining if the subject is more prone to injury by having strength deficits between muscle groups among the dominant leg to the non-dominant leg (Coombs & Garbutt, 2002).

The H:Q ratio has until recently been based on the concentric strength of these two muscle groups (Coombs & Garbutt, 2002). Co-activation of these muscle groups is known to occur and takes place through opposing activation modes (Coombs & Garbutt, 2002). During knee extension the quadriceps contract concentrically (Qcon) and the hamstrings activate eccentrically (Hecc) (Coombs & Garbutt, 2002). On the contrary, during knee flexion the hamstrings contract concentrically (Hcon) and the quadriceps activate eccentrically (Qecc) (Coombs & Garbutt, 2002). Therefore, in order to accurately assess the balancing nature of the hamstrings about the knee joint, the H:Q ratio should be described either as a Hecc:Qcon ratio representing knee extension, or a Hcon:Qecc ratio representing knee flexion (Coombs & Garbutt, 2002).

Isokinetic moment ratios of the hamstrings and quadriceps muscle groups, and their implication in muscle imbalance, have been investigated for more than three decades (Coombs & Garbutt, 2002). Dvir, Eger, & Halperin (1989) were the first to report the Hecc:Qcon ratio and referred it as a dynamic control ratio. Since then the need to express the H:Q ratio functionally as an eccentric-concentric ratio has become more evident. The most frequently reported strength ratio of the muscles of the knee has been the concentric hamstring-quadriceps ratio (Hcon:Qcon) (Coombs & Garbutt, 2002). Steindler (1955) advanced the generalization that absolute knee extension muscle force should exceed knee flexion force by a magnitude of 3:2 (i.e. Hcon:Qcon of 0.66). Values ranging from 0.43-0.90 for this knee flexor-extensor ratio have been reported, although it is dependent on angular velocity, test position, population group and use of gravity compensation (Nosse, 1982; Kannus, 1994). Throughout the decades, an acceptable percentage has been contemplated when a subject has sustained an injury going from 50%-80% and the optimal goal should be the ratio of the opposite uninjured limb (Kong & Burns, 2010). This difference in H:Q ratio might also influence the occurrence of leg injuries in sports. For instance, soccer players with a significant leg strength difference are more exposed to leg injury, and it has been shown that soccer players with a difference of 15% in leg muscle strength are 2.5 times more likely to get a leg injury (Lanshammar & Ribom, 2011). There has been a trend toward females tearing their left ACL more often than their right regardless of physical activity because of limb dominance (Lanshammar & Ribom, 2011).

Limb dominance can be further explained as the preferred foot used in activities, such as the limb used to kick a ball, while the non-dominant foot provides postural support (Peters, 1988). In the literature, mobilization and stabilization are also used to characterize dominant and non-dominant lower limbs (Dargent-Pare, De Agostini, Mesbah, & Dellatolas, 1992; Gabbard, 1989; Peters, 1988). The mobilizing or manipulating limb is the dominant (preferred) foot, which would be the foot kicking the ball whereas the foot that is used to support the actions of the dominant is considered the non-dominant foot (Dargent-Pare, et al., 1992; Gabbard, 1989; Peters, 1988).

Purpose

The purpose of this study is to examine the isometric and isokinetic hamstring to quadriceps ratio bilaterally in NCAA collegiate women volleyball athletes with 1) previous ACL reconstruction, 2) chronic knee pain, and 3) no presence of pain.

Hypothesis

The primary hypothesis is that participants with ACL reconstruction will demonstrate decrease hamstring strength and increased quadriceps strength compared to uninjured female controls. The secondary hypothesis is participants with chronic knee pain will display decreased quadriceps strength compared to the control.

Definitions

The independent variables for the present study will include will be the 3 groups (no pain, pain, and surgery), 2 conditions (isokinetic and isometric), and sides (left and right). The subject will perform 5 seconds of maximum isometric concentric knee extension and knee flexion to assess quadriceps and hamstring strength at three angles: 30, 60 and 90˚(0˚ being at full extension). Then the subject will perform maximum concentric knee extension and flexion in the range of motion of 30º to 90º at three angular velocities: 60º/s, 90º/s, and 180º/s. When analyzing the electromyographic (EMG) signals from the thigh muscles, the independent variables will be the 3 groups, 2 conditions, 2 sides, and 5 muscles with the EMG output as the dependent variable. The dependent variables for this study will be the peak torque and angle-specific torque at the knee joint collected from all different angles during isokinetic and isometric testing. EMG analysis of the hamstrings and quadriceps will also be included as dependent variables. This is done so that the average and maximal values for each isokinetic and isometric effort can be assessed in the quadriceps and hamstring muscles.

This study compares bilateral strength characteristics of the hamstring and quadriceps muscle groups in 3 groups comprised of NCAA division I women volleyball athletes. The main focus will be to observe if previous injuries, even from several years ago, still influence strength in the lower extremities and hypothesize about future injury. The present study will possibly give the athlete necessary information in order to focus on muscle groups that should become stronger so the likelihood of future injury decreases. Decreased hamstring strength relative to the quadriceps is implicated as a potential mechanism for increased lower extremity injuries, and potentially ACL injury risk, in female athletes (Myer et al., 2009).

Significance

In earlier studies, researchers have reported no difference between the dominant and non-dominant legs in collegiate athletes, or that the dominant side exerted no consistent influence on bilateral muscle imbalance (Grace, Sweetser, Nelson, Ydens, & Skipper, 1984). Studies that isolated subjects by gender reported significant ratio differences, but no reports of between gender differences have been reported in mixed gender studies (Kong & Burns, 2010). In addition, a higher H: Q ratio has been observed in the non-dominant leg for females (Holcomb, Rubley, Lee, & Guadagnoli, 2007) and the dominant leg for males (Ergun, Islegen, & Taskiran, 2004; Voutselas, Papanikolaou, Soulas, & Famisis, 2007). These studies raise the question of whether gender influences the direction of bilateral differences in H:Q ratio (Kong & Burns, 2010).

Other than H:Q ratios, bilateral strength asymmetry ratios of both quadriceps and hamstrings are widely used in sports medicine to measure the functional discrepancy resulting in knee injury and/or surgery and to decide whether the athlete is ready to return to competition (Kong & Burns, 2010). Some authors proposed the use of preseason screening of unilateral and bilateral strength imbalance in healthy subjects to identify athletes at increased risk of lower limb injuries during practice and competition (Croisier, 2004; Heiser, Weber, Sullivan, Clare, & Jacobs, 1984).

In the study from Bennell, Wajswelner, Lew, Schall-Riaucour, Leslie, Plant, and Cirone (1998), Australian football players underwent isokinetic testing to determine the relation of hamstring and quadriceps strength to the coincidence of hamstring strains (Bennell, et al., 1998). The results from their study do not support an association between preseason muscle weakness or imbalance and subsequent occurrence of hamstring muscle strain (Bennell, et al., 1998). There was no significant difference in the H:Q ratio between injured and non-injured legs in those players who sustained a unilateral injury while the relative strength of the non-injured leg of injured players was similar to that of non-injured players (Bennell, et al., 1998). Furthermore, imbalances in hamstring strength of more than 10% or H:Q ratios of less than 60% on either leg did not place a player at greater risk for subsequent hamstring injury (Bennell, et al., 1998). Their results imply that isokinetic muscle strength testing performed at the commencement of a football season is unlikely to predict the risk of hamstring injury during the season (Bennell et al. 1998). The authors also suggested that maybe doing more of a functional testing such as a single leg hop may provide a better indication of the function of the hamstring muscles and in accordance of injury risks (Bennell et al. 1998). In conclusion, isokinetic testing was unable to give these researchers the necessary information to see if the participants were at a high risk of potential injury (Bennell et al. 1998). Therefore, the idea that isometric and isokinetic testing on the dynamometer may not be able to predict the likelihood of injury and the role it has as a preseason and post-season screening tool intrigues my interest in further investigation with functional testing.

Delimitations

The majority of the studies done on the related topic incorporate athletes or individuals that have been in resistance training. In other studies, the subjects have sustained injuries, commonly the ACL. Ideally, a pre-and post-testing sessions should be performed to give researchers more insight on how muscle strength changes over the course of an athlete’s season. The present study is only performing strength tests at the end of the participant’s season because time was only allowed for post-season testing.

Limitations

Limitations for this study include participants being of different positions in volleyball instead of only testing one certain position. Each position in volleyball calls for different skills including outside hitters and middle blockers which requires the athlete to perform repetitive jumping during practice and games, defensive specialists and setters rarely jump but dive quite often. Another limitation for the present study is that only females are being tested instead of noting differences between males and females. Each participant is of different strength level and also with injuries of different severity. One more limitation for the present study is that the participants used were from only one sports team.

CHAPTER 2

METHODS

Participants

Fifteen healthy National Collegiate Athletic Association (NCAA) division I female volleyball athletes participated in the present study (age 19.3 ± 1.2 yrs., height 1.77 ± 0.08 m, and mass 72.3 ± 10.3 kg). Three participants had previous ACL reconstruction surgery, which were all done on the left side and consisted of the non-dominant leg. Six subjects had chronic knee pain lasting more than two weeks, and the remaining six participants did not have any previous knee pain lasting more than two weeks. Once the institutional human subjects committee granted approval for the present study an informed consent form was presented to each participant. Each subject signed the informed consent after reading the requirements and listened to a verbal explanation of the study. After gathering an informed consent from each subject, she then filled out a medical history questionnaire. After completing the questionnaire, the subjects were then placed in the three testing groups depending on their previous medical history. Testing was done one week after completing their competitive fall season.

Apparatus and task

A Biodex System 3 dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA) was used to collect reaction moment data and controlled the movement velocity of the lower extremities, while a Biodex knee (bilateral) attachment unit was secured to the axis. The dynamometer was calibrated before and after data collection. Data were collected at a rate of 100 Hz and saved for future processing. The isometric and isokinetic modes were used for this protocol.

Surface electromyography (EMG) was collected from both lower limbs using a MA-300 system (Motion Lab Systems, Baton Rouge, LA, USA). The skin was abraded and cleaned with alcohol pads prior to electrode placement. Pre-gelled Ag–AgCl electrodes (Biopac Systems, Inc., Goleta, CA, USA) were aligned parallel along the length of the respective muscle. The muscles were palpated and the electrode pairs were positioned over the bilateral vastus lateralis (VL), vastus medialis oblique (VMO), rectus femoris (RF), bicep femoris (BF), and semimembranosus (SM) muscle groups. The muscle activities were recorded during knee flexion and extension movements. A ground electrode was positioned on the skin over the right iliac crest. Surface EMG signals were band-pass filtered 20–500 Hz with a common mode rejection ratio of >100 dB at a frequency of 60 Hz, an input impedance of >100 MΩ and amplified up to 1000 times. Data were collected at a rate of 1200 Hz using a 12 bit A/D board and saved for future processing.

Procedures

Participants were provided questions regarding whether they had previously been injured and, if they had, what was the severity of the injury. Before starting the protocol, participants were given the chance to familiarize themselves with the equipment and the procedures involved in the study. After becoming familiarized with the equipment and procedures, the participants were asked to perform a 5-10 minute warm up walking on the treadmill or around the kinesiology building. After the warm up, surface EMG electrodes were positioned bilaterally on the skin over the aforementioned muscle groups VMO, RF, VL, BF, and SM. Following the EMG protocol, the participant's trunk, pelvis, and thighs were firmly strapped down one at a time, depending on the testing limb, to the seat of the dynamometer. The subject's lateral femoral condyle was visually aligned with the axis of the dynamometer crank arm and the resistance pad was positioned just proximal of the lateral malleolus of the ankle joint. The weights of the testing limb and the crank arm were corrected by measuring a passive isometric torque with the leg relaxed in a close to full knee extension position. Gravity corrections to torque were based on leg weight at the subjects' full knee extension and calculated by the gravity correction program by the Biodex System 3 software package.

The testing protocol included maximum voluntary isometric and isokinetic contractions of both legs. Participants were instructed to exert maximum effort in all testing trials. First, each participant performed 5 seconds of maximum isometric knee extension to assess quadriceps strength at 3 angles: 30º, 60º and 90º (0º being at full extension). After these movements, the participant repeated the same isometric test for knee flexion in order to assess hamstring strength. Third the participant performed maximum concentric knee extension and flexion in the range of motion of 30º to 90º at three angular velocities: 60º/s, 90º/s, and 180º/s. The participant performed three trials at each angle and angular velocity randomly, allowing 60 seconds of rest in between each trial. The dynamometer recorded the torque and time history of all testing.

Data Analysis

Data were arranged into dominant versus non-dominant limbs and in 3 groups consisting of subjects with no pain (Group 1), subjects with knee pain (Group 2), and subjects that have had previous knee surgery (Group 3). The dependent variables included peaks and averages for isokinetic and isometric torques for both the hamstring and quadriceps muscle groups, peak and average EMG values for isokinetic and isometric activations on the VMO, RF, VL, BF, and SM, and H:Q ratios at three angles and three angular velocities.

The raw EMG data from all trials were rectified and then smoothed with a fourth-order zero-lag low-pass Butterworth filter at 3 Hz. Next, the rectified and smoothed EMG data were normalized to each subject's peak value during isometric efforts for that specific muscle for all isokinetic and isometric activations.

Torque data were low-pass filtered at 3 Hz with a fourth-order Butterworth filter. Peak and average (constant velocity) torque values were calculated for each flexion and extension movement phase during the isometric and isokinetic conditions for each leg. The H:Q ratio was calculated for each leg by taking the average hamstring torque and dividing it by the average quadriceps torque for that specific angle or velocity. Since only concentric activations were collected, the Hcon: Qcon ratios were considered.

Statistical Analysis

Statistical analysis were performed for 3 groups (no pain, pain, and surgery), 2 sides (dominant versus non-dominant), 2 movement phases (extension - ext and flexion - flex), 3 velocities (60º/sec, 90º/sec, 180º/sec) or 3 angles (30º, 60º, 90º), and 5 muscle groups for the EMG data (VMO, RF, VL, BF, and SM). A 3 (group) x 2 (side) x 2 (ext-flex) x 3 (angle) ANOVA was performed to test the differences between average and peak torques during the isometric trials. A 3 (group) x 2 (side) x 2 (ext-flex) x 3 (velocity) ANOVA was performed to test differences between average and peak torques during isokinetic trials. Additionally, a 3 (group) x 2 (side) x 2 (ext-flex) x 3 (angle) x 5 (muscle) ANOVA was performed to compare average and peak muscle activities during isometric trials. A 3 (group) x 2 (side) x 2 (ext-flex) x 3 (velocity) x 5 (muscle) ANOVA was performed to compare average and peak muscle activities during isokinetic trials. For the H:Q ratio comparisons, a 3 (group) x 2 (side) x 3 (angle) ANOVA was performed for the isometric trials, while a 3 (group) x 2 (side) x 3 (velocity) ANOVA was performed for the isokinetic trials. When significant interaction effects were present a post-hoc Tukey analysis was performed. Statistical significance was set at $p < 0.05$.

CHAPTER 3

RESULTS

Isometric Torques

The descriptive statistics for isometric peak torque values for the dominant versus non-dominant quadriceps muscle groups with 3 different angles are displayed in Figure 1 for all 3 testing groups. The descriptive statistics for isometric peak torque values for the left and right hamstring muscle groups with 3 different angles are displayed in Figure 2 for all 3 testing groups. Significant interaction effects were present for isometric peak force consists of: Group x angle ($F_{4, 540}$=2.273, $p< 0.03$) (Figure 1 and 2), Extflex x side ($F_{1, 540}$=5.090, $p< 0.03$) (Figure 1 and 2), Extflex x angle ($F_{2, 540}$=115.711, $p< 0.001$) (Figure 1 and 2), Group x extflex x angle ($F_{4, 540}$= 4.074, $p<0.01$) (Figure 1 and 2). The post-hoc Tukey test show that Group 1(no pain) is significantly lower than those from groups 2 (pain) and group 3 (surgery) (Figure 1 and 2). Group 2 (pain) is significantly greater than group 3 (surgery) (Figure 1 and 2). Significant main effects are Extflex ($F_{1, 540}$= 249.487, $p< 0.001$) (Figure 1 and 2). The descriptive statistics for isometric average torque values for the left and right quadriceps muscle groups with 3 different angles are displayed in Figure 3 for all 3 testing groups. The descriptive statistics for isometric average torque values for the dominant versus non-dominant hamstring muscle groups with 3 different angles are displayed in Figure 4 for all 3 testing groups. Significant interaction effects were present for the isometric average force consists of: Group x angle ($F_{4, 540}$=2.680, $p< 0.05$) (Figure 3 and 4), Extflex x side ($F_{1, 540}$=7.525, $p< 0.01$) (Figure 3 and 4), Group x extflex x angle ($F_{4, 540}$=119.635, $p< 0.01$) (Figure 3 and 4). The Post-hoc Tukey tests show Group 1 (no pain) was significantly lower than those than group 2 (pain) and group 3 (surgery) (Figure 3 and 4). Group 2 (pain) was significantly greater than group 3 (surgery) (Figure 3 and 4). Significant main effects consisted of Extflex ($F_{1, 540}$=208.412, $p< 0.001$) (Figure 3 and 4). Post-hoc Tukey tests for angle indicate that 30º is significantly lower than 60º and 90º measures, but average torque at 60º and 90º are not significantly different (Figure 1 and 2).

Isokinetic torque

The descriptive statistics for isokinetic peak torque values for the left and right quadriceps muscle groups with 3 different angles are displayed in Figure 5 for all 3 testing groups. The descriptive statistics for isokinetic peak torque values for the dominant and non-dominant hamstring muscle groups with 3 different angles are displayed in Figure 6 for all 3 testing groups. Significant interaction effects were present for peak torque during the isokinetic efforts consisted of: Group x Extflex: ($F_{2, 540}$=12.724, $p < 0.001$) (Figure 5 and 6), Extflex x Velocity: ($F_{2, 540}$ =23.603, $p < 0.001$) (Figure 5 and 6), Group x Extflex x Velocity: ($F_{4, 540}$ =2.792, $p<0.03$) (Figure 5 and 6). A Post-hoc Tukey analysis indicated that Group 1 (no pain) and Group 2 (pain) were both significantly lower than Group 3 (surgery), but Group 1 (no pain) and Group 2 (pain) were not significantly different from each other (Figure 5 and 6). The descriptive statistics for isokinetic average torque values for the dominant versus non-dominant quadriceps muscle groups with 3 different angles are displayed in Figure 7 for all 3 testing groups. The descriptive statistics for isokinetic average torque values for the left and right hamstring muscle groups with 3 different angles are displayed in Figure 8 for all 3 testing groups. Significant interaction effects were present for isokinetic average force consists of: Group x extflex: ($F_{2, 540}$ = 12.775, $p < 0.001$) (Figure 7 and 8), Group x velocity ($F_{4, 540}$= 2.443, $p< 0.05$) (Figure 7 and 8), Extflex x velocity ($F_{4, 540}$= 18.906, $p< 0.001$) (Figure 7 and 8), Group x extflex x velocity ($F_{4, 540}$= 3.280, $p< 0.02$) (Figure 7 and 8). From the post-hoc tests Group 1 (no pain) was significantly lower compared to Group 3 (surgery), Group 1 (no pain) was not significantly different from Group 2 (pain), and Group 2 (pain) was not significantly different from Group 3 (surgery) (Figures 7 and 8). For velocity, post-hoc Tukey showed that average torque at velocities 60º/s and 90º/s were both significantly greater than at 180º/s, but average torque at 60º/s and 90º/s were not significantly different from each other (Figures 5 and 6).

Isometric H:Q Ratio

Significant interaction effects for the isometric H:Q ratio are Group x angle ($F_{2, 270}$= 6.473, p< 0.001, Figure 9). Post-hoc Tukey analysis shows Group 1(no pain) is significantly lower than group 2(pain) (Figure 9). Post-hoc Tukey tests for angle indicate that the H:Q ratio at 30º is significantly greater than at 60º and 90º, but the H:Q ratio at 60º and 90º are not significantly different (Figure 9). A significant main effect was Side ($F_{1, 270}$= 13.418, p< 0.001) (Figure 9).

Isokinetic H:Q Ratio

Significant interaction effects for the isokinetic H: Q ratio as shown in Figure 10 were Group x velocity ($F_{5, 270}$= 4.411, p< 0.01), and Side x velocity ($F_{3, 270}$= 3.439, p< 0.05) (Figure 10). For velocity post-hoc Tukey shows that H:Q ratio at velocities 60º/s and 90º/s were both significantly greater than at 180º/s, but 60º/s and 90º/s were not significantly different (Figure 10).

Isometric EMG

Significant interaction effects for isokinetic average EMG are shown in Tables 1 and 2 consists of: Group x extflex ($F_{2, 2685}$= 4.6, p< 0.001) (Tables 1 and 2), Group x muscle ($F_{8, 2685}$= 2.583, p< 0.01) (Tables 1 and 2), Extflex x muscle ($F_{1, 2685}$= 64.075, p<0.001) (Tables 1 and 2), Side x muscle ($F_{4, 2685}$= 8.130, p< 0.001) (Tables 1 and 2), Group x side x muscle ($F_{4, 2685}$= 7.029, p< 0.001) (Tables 1 and 2), Group x extflex x side x muscle ($F_{8, 2685}$= 4.063, p< 0.001) (Tables 1 and 2). The Post-hoc Tukey tests show Group 1(no pain) is significantly greater than group 2(pain), but Group 2 is significantly lower than group 3(surgery) (Tables 1 and 2). Group 1(no pain) is not significantly different than Group 3 (surgery) (Tables 1 and 2). RF activity is significantly lower than VMO, but greater than BF activity, VMO is activated with significantly greater activity than VL, SM, and BF (Tables 1 and 2). VL activity is significantly greater than the BF (Tables 1 and 2). Significant main effects were Extflex ($F_{1, 2685}$= 14.788, $p< 0.001$) (Tables 1 and 2). Significant interaction effects for isometric peak EMG are shown in Tables 3 and 4: Group x side ($F_{2, 2685}$= 3.509, $p< 0.05$) (Tables 3 and 4), Group x muscle ($F_{8, 2685}$= 3.003, $p< 0.01$) (Tables 3 and 4), Extflex x muscle ($F_{4, 2685}$= 42.084, $p< 0.001$) (Tables 3 and 4), Side x muscle ($F_{4, 2685}$= 6.787, $p< 0.001$) (Tables 3 and 4), Group x extflex x side ($F_{2, 2685}$= 3.845, $p< 0.05$) (Tables 3 and 4), Group x side x muscle ($F_{8, 2685}$= 10.324, $p< 0.001$) (Tables 3 and 4), Group x extflex x side x muscle ($F_{8, 2685}$= 4.773, $p< 0.001$) (Tables 3 and 4). The Post-hoc Tukey tests show Group 1 (no pain) is significantly greater than group 2 (pain) (Tables 3 and 4), and Group 2 is significantly lower than group 3 (surgery) (Tables 3 and 4). RF activity is significantly less than VMO activity (Tables 3 and 4), while VMO activity is significantly greater than VL, SM, and BF (Tables 3 and 4). SM activity is significantly different lower than VMO activity (Tables 3 and 4). Significant main effects are Extflex ($F_{1, 2685}$= 14.81, $p< 0.001$), and Side ($F_{1, 2685}$= 4.823, $p<0.05$) (Tables 3 and 4).

Isokinetic EMG

Significant interaction effects for isokinetic average EMG as shown in Tables 5 and 6 consisted of: Group x extflex ($F_{2, 2685}$= 4.60, $p< 0.001$) (Tables 5 and 6), Group x muscle ($F_{8, 2685}$= 2.583, $p< 0.01$) (Tables 5 and 6), Extflex x muscle ($F_{4, 2685}$= 64.075, $p< 0.001$) (Tables 5 and 6), Side x muscle ($F_{4, 2685}$= 8.130, $p< 0.001$) (Tables 5 and 6), Group x side x muscle ($F_{8,}$

$_{2685}$= 7.029, $p < 0.001$) (Tables 5 and 6), Group x extflex x side x muscle ($F_{8, 2685}$= 4.063, $p < 0.001$) (Tables 5 and 6). The Post-hoc Tukey tests show Group 1(no pain) possessed significantly greater activity than group 2 (pain), while Group 2 was significantly lower than group 3(surgery), but Group 1(no pain) was not significantly different from group 3(surgery) (Tables 5 and 6). The RF activity was significantly less than VMO, but higher than BF activity, while VMO activity was significantly greater than VL, SM, and BF (Tables 5 and 6). The VL activity was significantly lower than BF activity (Tables 5 and). A significant main effect for Extflex ($F_{1, 2685}$= 14.788, $p < 0.001$) was present (Tables 5 and 6).

Significant interaction effects for isokinetic peak EMG as shown in Tables 7 and 8 consisted of: Group x side ($F_{2, 2685}$= 3.509, $p < 0.04$) (Tables 7 and 8), Group x muscle ($F_{8, 2685}$= 3.003, $p < 0.01$) (Tables 7 and 8), Extflex x muscle ($F_{4, 2685}$= 42.084, $p < 0.001$) (Tables 7 and 8), Side x muscle ($F_{4, 2685}$= 6.787, $p < 0.001$) (Tables 7 and 8), Group x extflex x side ($F_{4, 2685}$= 3.845, $p < 0.03$) (Tables 7 and 8), Group x side x muscle ($F_{8, 2685}$= 10.324, $p < 0.001$) (Tables 7 and 8), Group x extflex x side x muscle ($F_{8, 2685}$= 4.773, $p < 0.001$) (Tables 7 and 8). The Post-hoc Tukey tests show Group 1(no pain) was significantly greater than group 2(pain), while Group 2 was significantly greater than group 3(surgery) (Tables 7 and 8). The RF activity was significantly lower than VMO activity, while VMO activity was significantly greater than VL, SM, and BF (Figure 7 and 8). Significant main effects were Extflex ($F_{1, 2685}$= 14.810, $p < 0.001$), and Side ($F_{1, 2685}$= 4.823, $p < 0.03$) (Tables 7 and 8).

Table 1. Data for average normalized EMG, means (± sd) for the isometric conditions during extension.

		Group 1 [a]						Group 2 [b]						Group 3					
Angle		30		60		90		30		60		90		30		60		90	
Muscle	Side	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D
RF[d]		.326 (.12)	.600 (.55)	.382 (.13)	.630 (.92)	.426 (.11)	.903 (1.38)	.271 (.17)	.292 (.16)	.209 (.17)	.286 (.14)	.375 (.25)	.392 (.12)	.294 (.15)	.447 (.09)	.293 (.15)	.395 (.12)	.312 (.14)	.360 (.06)
VMO[c]		1.254 (2.27)	.510 (.10)	.793 (1.3)	.350 (.21)	.433 (.14)	.480 (.33)	.375 (.15)	1.076 (2.05)	.331 (.21)	1.205 (1.89)	.355 (.20)	1.158 (1.72)	.418 (.15)	.801 (1.09)	.345 (.11)	1.488 (1.59)	.420 (.12)	.338 (.14)
VL[d]		.456 (.15)	.417 (.17)	.328 (.10)	.258 (.19)	.358 (.12)	.283 (.19)	.465 (.23)	.401 (.15)	.357 (.22)	.278 (.11)	.436 (23)	.375 (.15)	.364 (.16)	.493 (.09)	.271 (.03)	.395 (.08)	.442 (.26)	.337 (.08)
SM[f]		.147 (.27)	.158 (.24)	.055 (.05)	.089 (.11)	.096 (.12)	.067 (.07)	.140 (.27)	.145 (.17)	.219 (.45)	.187 (.23)	.205 (.38)	.170 (.21)	.051 (.01)	.159 (.20)	.052 (.01)	.108 (.12)	.051 (.01)	.056 (.02)
BF[c,d,e]		.205 (.07)	.249 (.26)	.211 (.09)	.242 (.25)	.254 (.09)	.248 (.25)	.283 (.20)	.159 (.05)	.252 (.22)	.215 (.17)	.277 (.22)	.174 (.11)	.259 (.14)	.204 (.12)	.194 (.07)	.159 (.12)	.251 (.16)	.156 (.12)

Angle is in degrees. ND= non-dominant, D=dominant. RF= rectus femoris, VMO= vastus medialis oblique, VL= vastus lateralis, SM= semimembranosus, BF= biceps femoris. For Significant differences: a- Group 1 different than Group 2, b- Group 2 is different than Group 3, c- significantly different from RF, d- significantly different than VMO, e- significantly different than VL.

Table 2. Data for average normalized EMG, means (± sd) for the isometric conditions during flexion.

		Group 1[a]						Group 2[b]						Group 3					
Angle		30		60		90		30		60		90		30		60		90	
Muscle	Side	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D
RF[d]		.056 (.08)	.039 (.01)	.046 (.03)	.041 (.01)	.060 (.07)	.042 (.01)	.043 (.02)	.053 (.07)	.256 (.43)	.063 (.08)	.204 (.25)	.133 (.20)	.068 (.11)	.124 (.13)	.055 (.02)	.168 (.20)	.109 (.08)	.158 (.09)
VMO[c]		.071 (.08)	.207 (.29)	.082 (.05)	.338 (.59)	.075 (.05)	.164 (.19)	.122 (.20)	1.069 (2.25)	.218 (.25)	.111 (.07)	.149 (.17)	.406 (1.26)	.079 (.07)	.112 (.05)	.088 (.08)	.171 (.12)	.090 (.08)	.151 (.08)
VL[d]		.064 (.05)	.035 (.02)	.078 (.06)	.045 (.04)	.062 (.02)	.033 (.01)	.160 (.25)	.166 (.12)	.160 (.24)	.420 (1.23)	.179 (.26)	.167 (.13)	.054 (.04)	.031 (.01)	.089 (.06)	.041 (.02)	.173 (.12)	.032 (.01)
SM[d]		.306 (.08)	.371 (.29)	.419 (.10)	.397 (.17)	.530 (.10)	.443 (.27)	.984 (1.50)	.436 (.12)	.776 (.92)	.403 (.12)	.839 (.84)	.493 (.17)	.361 (.04)	.305 (.05)	.509 (.07)	.445 (.20)	.573 (.06)	.465 (.17)
BF[c,d,e]		.400 (.14)	.345 (.14)	.716 (.45)	.462 (.14)	.531 (.17)	.501 (.08)	.499 (.14)	.417 (15)	.492 (.14)	.409 (.20)	.488 (.16)	.451 (.22)	.391 (.12)	.381 (.05)	.522 (.08)	.486 (.11)	.561 (.08)	.458 (.06)

Angle is in degrees. ND= non-dominant, D=dominant. RF = rectus femoris, VM = vastus medialis, VL = vastus lateralis, SM = semimebranosus, BF = biceps femoris. For Significant differences: a- Group 1 different than Group 2, b- Group 2 is different than Group 3, c- significantly different from RF, d- significantly different than VMO, e- significantly different than VL.

Table 3. Data for peak normalized EMG, means (± sd) for the isometric conditions during extension.

		Group 1[a]						Group 2[b]						Group 3					
Angle		30		60		90		30		60		90		30		60		90	
Muscle	Side	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D
RF[d]		.594 (.20)	1.285 (1.48)	.675 (.22)	1.134 (1.60)	.743 (.18)	1.621 (2.57)	.531 (.29)	.520 (.27)	.360 (.29)	.544 (.27)	.610 (.37)	.745 (.25)	.677 (.51)	.790 (.15)	.517 (.26)	.734 (.22)	.600 (.26)	.626 (.11)
VMO[c]		2.21 (3.60)	.923 (.25)	2.46 (4.11)	.653 (.39)	.839 (.24)	.851 (.64)	.701 (.26)	2.317 (4.35)	.600 (.42)	3.379 (5.12)	.560 (.28)	2.290 (5.02)	.746 (.23)	1.276 (1.54)	.601 (.22)	2.374 (2.44)	.735 (.22)	.578 (.26)
VL[d]		.826 (.23)	.833 (.25)	.521 (.17)	.480 (.35)	.578 (.19)	.579 (.37)	.705 (.29)	.715 (.22)	.525 (.28)	.492 (.19)	.660 (.31)	.642 (.30)	.640 (.30)	.866 (.14)	.521 (.20)	.699 (.18)	.852 (.49)	.614 (.12)
SM[d]		.243 (.44)	.310 (.58)	.120 (.15)	.153 (.19)	.179 (.26)	.095 (.10)	.271 (.57)	.277 (.37)	.397 (.74)	.398 (.52)	.433 (.84)	.309 (.41)	.072 (.02)	.473 (.79)	.080 (.01)	.225 (.35)	.071 (.01)	.121 (.06)
BF[d]		.307 (.14)	.325 (.28)	.351 (.40)	.310 (.25)	.501 (.51)	.305 (.25)	.365 (.23)	.236 (.10)	.316 (.26)	.356 (.33)	.361 (.26)	.255 (.16)	.391 (.25)	.306 (.16)	.307 (.12)	.198 (.13)	.374 (.25)	.204 (.14)

Angle is in degrees. ND= non-dominant limb, D=dominant limb. RF = rectus femoris, VMO = vastus medialis oblique, VL = vastus lateralis, SM = semimebranosus, BF = biceps femoris. For Significant differences: a- Group 1 different than Group 2, b- Group 2 is different than Group 3, c- significantly different from RF, d- significantly different than VMO.

Table 4. Data for peak normalized EMG, means (± sd) for the isometric conditions during flexion.

		Group 1[a]						Group 2[b]						Group 3					
Angle		30		60		90		30		60		90		30		60		90	
Muscle	Side	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D
RF[d]		.110 (.18)	.054 (.02)	.081 (.05)	.072 (.06)	.095 (.11)	.059 (.01)	.078 (.04)	.072 (.08)	.744 (1.34)	.094 (.10)	.535 (.83)	.224 (.33)	.133 (.24)	.278 (.30)	.100 (.05)	.329 (.37)	.208 (.15)	.341 (.23)
VMO[c]		.168 (.31)	.436 (.80)	.154 (.10)	.538 (.92)	.158 (.14)	.556 (.96)	.163 (.23)	2.439 (5.19)	.395 (.53)	.231 (.20)	.218 (.19)	.972 (3.22)	.136 (.13)	.182 (.13)	.142 (.12)	.326 (.29)	.154 (.12)	.272 (.15)
VL[d]		.117 (.16)	.052 (.03)	.151 (.18)	.074 (.09)	.095 (.03)	.056 (.04)	.216 (.33)	.316 (.28)	.207 (.29)	.886 (2.76)	.242 (.31)	.394 (.34)	.071 (.05)	.054 (.02)	.131 (.09)	.065 (.03)	.312 (.29)	.048 (.01)
SM[d]		.505 (.17)	.923 (1.61)	.712 (.20)	.628 (.29)	.889 (.11)	.894 (1.09)	1.71 (2.68)	.708 (.32)	1.232 (1.38)	.685 (.23)	1.675 (1.55)	.801 (.30)	.573 (.11)	.598 (.26)	.813 (.11)	.771 (.43)	.941 (.05)	.841 (.18)
BF[d]		.604 (.21)	.509 (.23)	1.251 (1.01)	.712 (.25)	.793 (.22)	.796 (.17)	.687 (.17)	.647 (.20)	.669 (.18)	.616 (.30)	.693 (.18)	.678 (.32)	.637 (.21)	.557 (.08)	.814 (.13)	.770 (.18)	.861 (.11)	.714 (.16)

Angle is in degrees. ND= non-dominant limb, D=dominant limb. RF = rectus femoris, VM = vastus medialis oblique, VL = vastus lateralis, SM = semimebranosus, BF = biceps femoris. For Significant differences: a- Group 1 different than Group 2, c- Group 2 is different than Group 3, c- significantly different from RF, d- significantly different than VMO.

Table 5. Data for average normalized EMG, means (± sd) for the isokinetic conditions during extension.

		Group 1[a]						Group 2[b]						Group 3					
Angle		60		90		180		60		90		180		60		90		180	
Muscle	Side	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D
RF		.326 (.12)	.600 (.55)	.382 (.13)	.630 (.92)	.426 (.11)	.903 (1.38)	.271 (.17)	.292 (.16)	.209 (.17)	.286 (.14)	.375 (.25)	.382 (.12)	.294 (.15)	.447 (.09)	.293 (.15)	.395 (.12)	.312 (.14)	.360 (.06)
VMO[c]		1.254 (2.27)	.510 (.10)	.793 (1.31)	.350 (.21)	.433 (1.31)	.480 (.33)	.375 (.15)	1.076 (2.05)	.331 (.21)	1.205 (1.89)	.355 (.20)	1.157 (1.72)	.418 (.15)	.801 (1.09)	.345 (.11)	1.488 (1.59)	.420 (.12)	.338 (.14)
VL[d]		.486 (.15)	.417 (.17)	.328 (.10)	.258 (.19)	.358 (.12)	.283 (.19)	.465 (.23)	.401 (.15)	.357 (.22)	.278 (.11)	.436 (.23)	.375 (.15)	.364 (.16)	.493 (.09)	.271 (.03)	.392 (.08)	.442 (.26)	.337 (.08)
SM[d]		.147 (.27)	.158 (.24)	.055 (.05)	.089 (.11)	.096 (.12)	.067 (.07)	.140 (.27)	.145 (.17)	.219 (.45)	.187 (.23)	.205 (.38)	.170 (.21)	.051 (.01)	.159 (.20)	.052 (.01)	.109 (.12)	.051 (.01)	.056 (.02)
BF[c,d,e]		.205 (.07)	.249 (.26)	.211 (.09)	.242 (.25)	.254 (.09)	.248 (.25)	.283 (.20)	.159 (.05)	.252 (.22)	.215 (.17)	.277 (.22)	.174 (.11)	.259 (.14)	.204 (.12)	.194 (.07)	.159 (.12)	.251 (.16)	.156 (.12)

Angle is in degrees. ND= non-dominant limb, D=dominant limb. RF = rectus femoris, VMO = vastus medialis oblique, VL = vastus lateralis, SM = semimebranosus, BF = biceps femoris. For Significant differences: a- Group 1 is different than Group 3, b- Group 2 is different than Group 3, c- significantly different from RF, d- significantly different than VMO, e- significantly different than VL.

Table 6. Data for average normalized EMG, means (± sd) for the isokinetic conditions during flexion.

		Group 1[a]						Group 2[b]						Group 3					
Angle		60		90		180		60		90		180		60		90		180	
Muscle	Side	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D
RF		.056 (.08)	.039 (.01)	.046 (.03)	.041 (.01)	.059 (.07)	.042 (.01)	.043 (.02)	.053 (.07)	.256 (.43)	.063 (.08)	.204 (.25)	.133 (.20)	.068 (.11)	.124 (.13)	.055 (.02)	.168 (.20)	.109 (.08)	.158 (.09)
VMO[c]		.071 (.08)	.207 (.29)	.082 (.05)	.338 (.59)	.075 (.05)	.164 (.19)	.122 (.19)	1.069 (2.25)	.218 (.25)	.111 (.07)	.149 (.17)	.406 (1.26)	.079 (.08)	.112 (.05)	.088 (.08)	.172 (.12)	.090 (.08)	.151 (.08)
VL[d]		.064 (.05)	.035 (.02)	.078 (.06)	.045 (.04)	.062 (.02)	.033 (.01)	.160 (.25)	.166 (.12)	.160 (.24)	.420 (1.23)	.179 (.26)	.167 (.13)	.054 (.04)	.031 (.01)	.089 (.06)	.041 (.02)	.173 (.12)	.032 (.01)
SM[d]		.306 (.08)	.371 (.29)	.419 (.10)	.397 (.17)	.530 (.10)	.443 (.27)	.984 (1.50)	.436 (.12)	.776 (.92)	.403 (.12)	.839 (.84)	.493 (.17)	.361 (.04)	.305 (.05)	.509 (.07)	.445 (.20)	.573 (.06)	.465 (.17)
BF[c,d,e]		.400 (.14)	.345 (.14)	.716 (.45)	.462 (.14)	.531 (.17)	.501 (.08)	.499 (.14)	.417 (.15)	.492 (.14)	.409 (.20)	.488 (.16)	.451 (.22)	.391 (.12)	.381 (.05)	.522 (.08)	.486 (.11)	.561 (.08)	.458 (.06)

Angle is in degrees. L = Left, R = right. RF = rectus femoris, VM = vastus medialis, VL = vastus lateralis, SM = semimebranosus, BF = biceps femoris. For Significant differences: a- Group 1 is different than Group 3, b- Group 2 is different than Group 3, c- significantly different from RF, d- significantly different than VMO, e- significantly different than VL.

Table 7. Data for peak normalized EMG, means (± sd) for the isokinetic conditions during extension.

		Group 1[a]						Group 2[b]						Group 3					
Angle		60		90		180		60		90		180		60		90		180	
Muscle	Side	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D
RF		.594 (.20)	1.285 (1.48)	.675 (.22)	1.134 (1.60)	.743 (.18)	1.621 (2.57)	.531 (.29)	.519 (.27)	.360 (.29)	.544 (.27)	610 (.37)	.745 (.25)	.677 (.51)	.790 (.15)	.517 (.26)	.734 (.22)	.600 (.26)	.626 (.11)
VMO[c]		2.212 (3.60)	.923 (.25)	2.463 (4.11)	.653 (.39)	.839 (1.99)	.851 (.64)	.701 (.26)	2.317 (4.35)	.600 (.42)	3.379 (5.12)	.560 (.28)	2.905 (5.02)	.746 (.23)	1.276 (1.54)	.601 (.22)	2.374 (2.44)	.735 (.22)	.578 (.26)
VL[d]		.826 (.23)	.833 (.25)	.521 (.17)	.480 (.35)	.578 (.19)	.579 (.37)	.705 (.29)	.715 (.22)	.525 (.28)	.492 (.19)	.660 (.31)	.642 (.30)	.640 (.30)	.866 (.14)	.521 (.20)	.699 (.18)	.852 (.49)	.614 (.12)
SM[d]		.243 (.44)	.310 (.58)	.120 (.15)	.153 (.19)	.179 (.26)	.095 (.10)	.271 (.57)	.277 (.37)	.397 (.74)	.398 (.52)	.433 (.84)	.309 (.41)	.072 (.02)	.473 (.79)	.080 (.01)	.225 (.35)	.071 (.01)	.121 (.06)
BF[d]		.307 (.14)	.325 (.28)	.351 (.40)	.310 (.25)	.501 (.51)	.305 (.25)	.365 (.23)	.236 (.10)	.316 (.26)	.356 (.33)	.361 (.25)	.255 (.16)	.391 (.25)	.306 (.16)	.307 (.12)	.198 (.13)	.374 (.25)	.204 (.14)

Angle is in degrees. ND= non-dominant limb, D=dominant limb. RF = rectus femoris, VM = vastus medialis, VL = vastus lateralis, SM = semimebranosus, BF = biceps femoris. For Significant differences: a- Group 1 different than Group 2, b- Group 2 is different than Group 3, c- significantly different from RF, d- significantly different than VMO.

Table 8. Data for peak normalized EMG, means (± sd) for the isokinetic conditions during flexion.

		Group 1[a]						Group 2[b]						Group 3					
Angle		60		90		180		60		90		180		60		90		180	
Muscle	Side	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D
RF		.110 (.18)	.054 (.02)	.081 (.05)	.072 (.06)	.095 (.11)	.059 (.01)	.078 (.04)	.072 (.08)	.744 (1.34)	.094 (.10)	.535 (.83)	.224 (.33)	.133 (.24)	.278 (.30)	.100 (.05)	.329 (.37)	.208 (.15)	.341 (.23)
VM[c]		.168 (.31)	.436 (.80)	.154 (.10)	.538 (.92)	.158 (.14)	.556 (.96)	.163 (.23)	2.439 (5.19)	.395 (.53)	.231 (.20)	.218 (.19)	.972 (3.22)	.136 (.13)	.182 (.13)	.142 (.12)	.326 (.29)	.154 (.12)	.272 (.15)
VL[d]		.117 (.16)	.052 (.03)	.151 (.18)	.074 (.09)	.095 (.03)	.056 (.04)	.216 (.33)	.316 (.28)	.207 (.29)	.886 (2.76)	.242 (.31)	.394 (.34)	.071 (.05)	.054 (.02)	.131 (.09)	.065 (.03)	.312 (.29)	.048 (.01)
SM[d]		.505 (.17)	.923 (1.61)	.712 (.20)	.628 (.29)	.889 (.11)	.894 (1.09)	1.712 (2.68)	.708 (.32)	1.232 (1.38)	.685 (.23)	1.675 (1.55)	.801 (.30)	.573 (.11)	.598 (.26)	.813 (.11)	.771 (.43)	.941 (.05)	.841 (.18)
BF[d]		.604 (.21)	.509 (.23)	1.251 (1.01)	.712 (.25)	.793 (.22)	.796 (.17)	.687 (.17)	.647 (.20)	.669 (.18)	.616 (.30)	.693 (.18)	.678 (.32)	.637 (.21)	.557 (.08)	.814 (.13)	.770 (.18)	.861 (.11)	.714 (.16)

Angle is in degrees. ND= non-dominant limb, D=dominant limb. RF = rectus femoris, VM = vastus medialis, VL = vastus lateralis,SM = semimebranosus, BF = biceps femoris. For Significant differences: a- Group 1 different than Group 2, b- Group 2 is different than Group 3, c- significantly different from RF, d- significantly different than VMO.

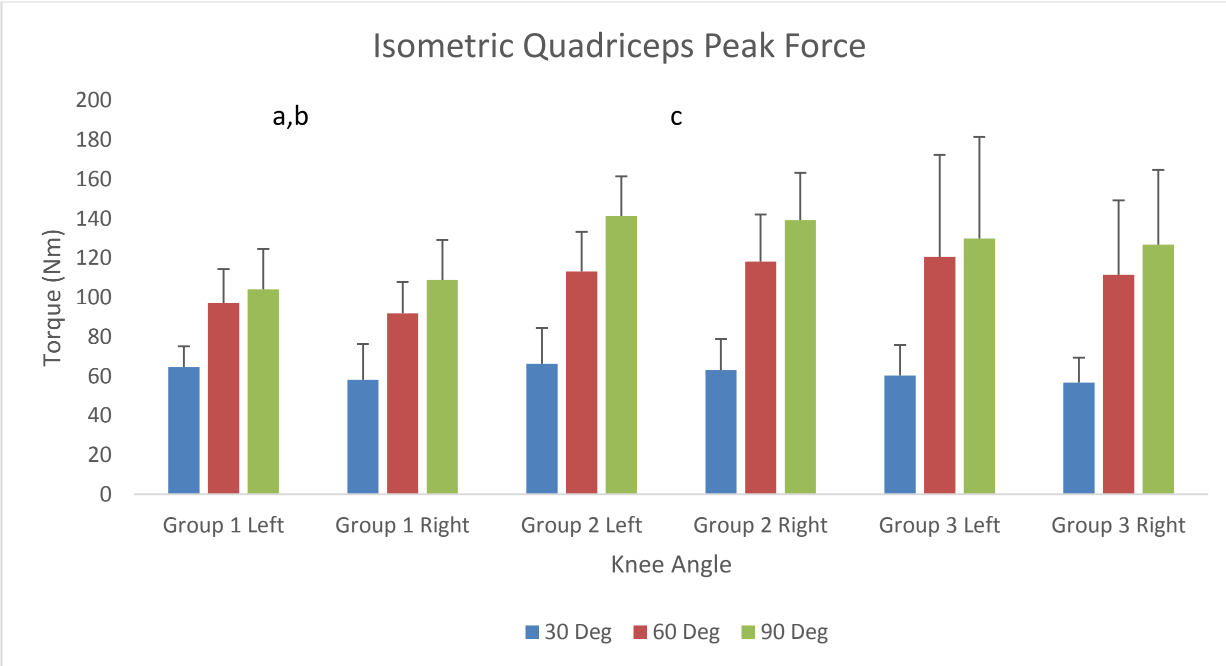

Figure 1. Means (± sd) for Quadriceps Isometric Peak Torque, Left and Right knees for Group 1(No pain), Group 2(Pain), and Group 3(Surgery). For Significant differences: a- Group 1 different than Group 2, b- Group 1 is different than Group 3, c- Group 2 is different than Group 3, angle 30º is significantly lower than 60º and 90º measures, but 60º and 90º are not significantly different.

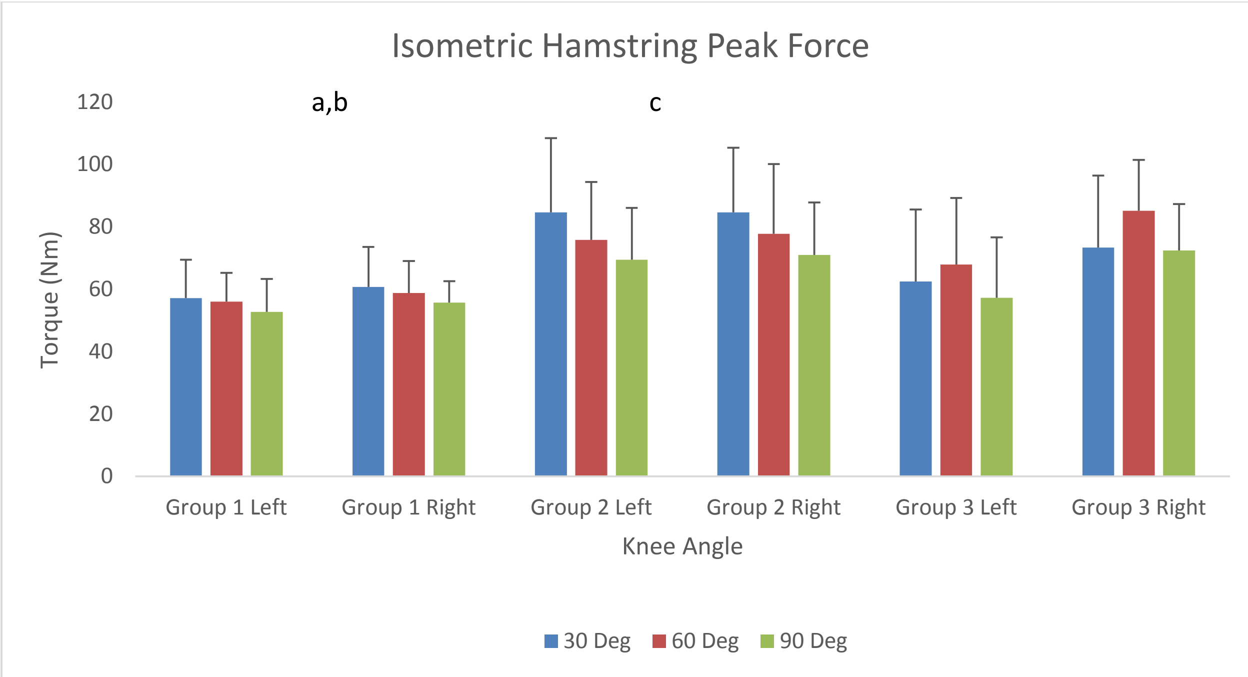

Figure 2. Means (± sd) for Hamstring Isometric Peak Torque, Left and Right knees for Group 1(No pain), Group 2(Pain), and Group 3(Surgery). For Significant differences: a- Group 1 different than Group 2, b- Group 1 is different than Group 3,c- Group 2 is different than Group 3, angle 30º is significantly lower than 60º and 90º measures, but 60º and 90º are not significantly different.

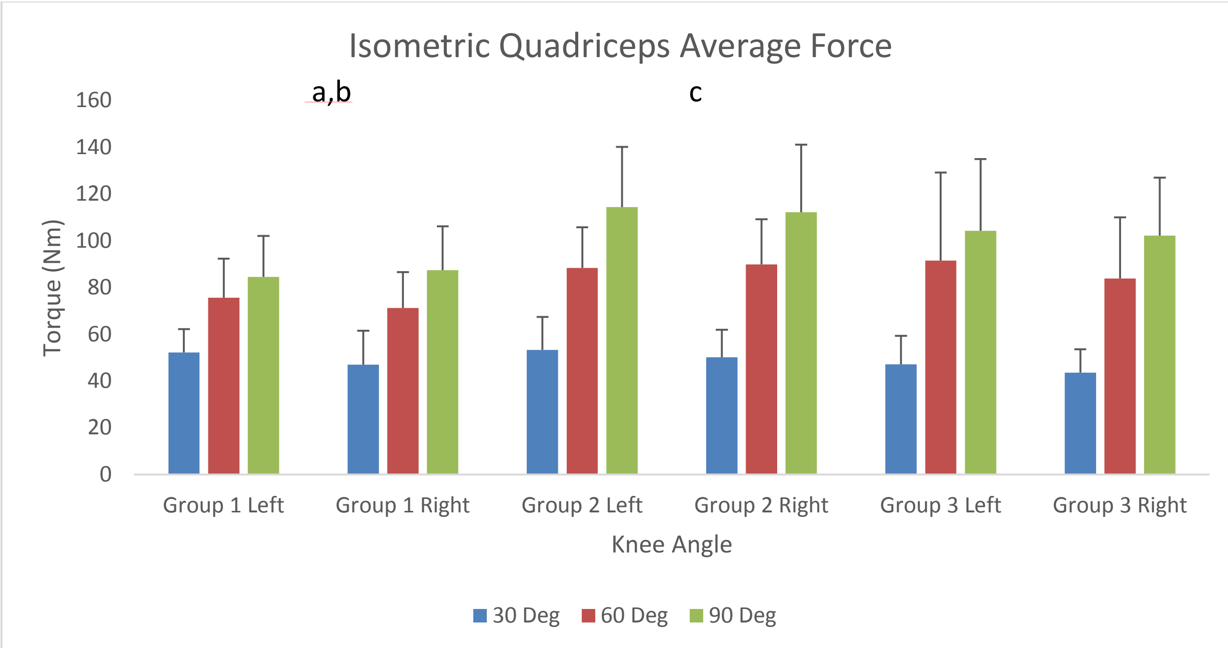

Figure 3. Means (sd±) for Quadriceps Isometric Average Torque, Left and Right knees for Group 1(No pain), Group 2(Pain), and Group 3(Surgery). For Significant differences: a- Group 1 different than Group 2, b- Group 1 is different than Group 3, c- Group 2 is different than Group 3, angle 30º is significantly lower than 60º and 90º measures, but 60º and 90º are not significantly different.

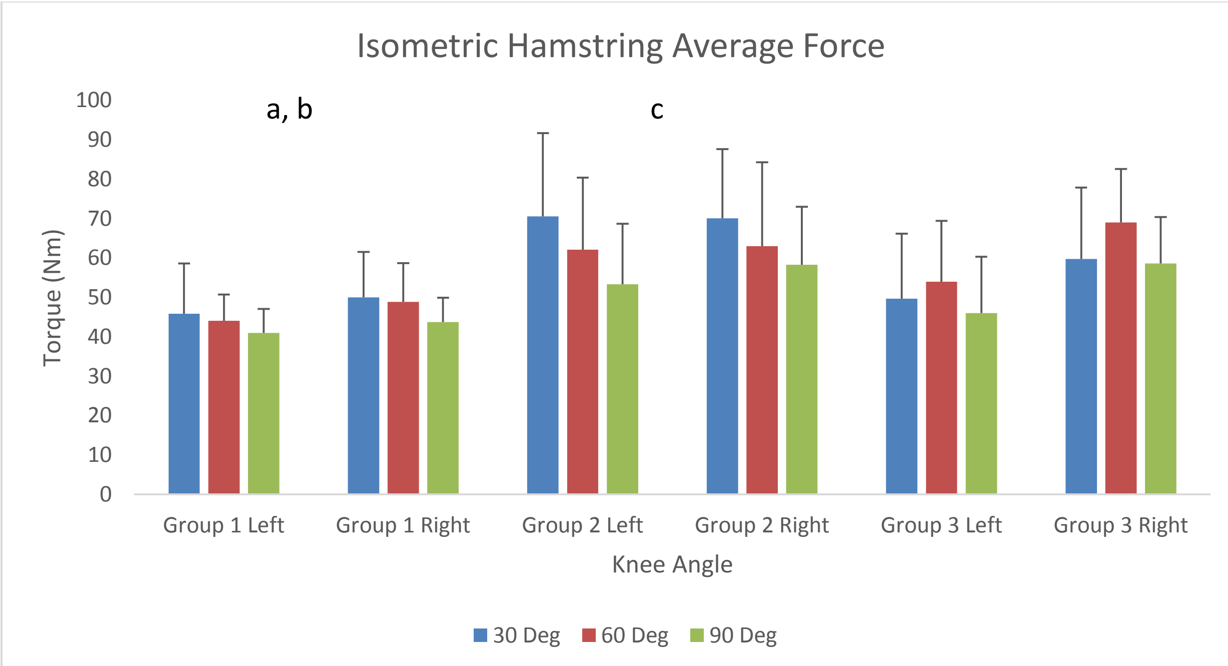

Figure 4. Means (sd±) for Isometric Hamstring Average Torque, Left and Right knees for Group 1(No pain), Group 2(Pain), and Group 3(Surgery). For Significant differences: a- Group 1 different than Group 2, b- Group 1 is different than Group 3, c- Group 2 is different than Group 3, angle 30º is significantly lower than 60º and 90º measures, but 60º and 90º are not significantly different.

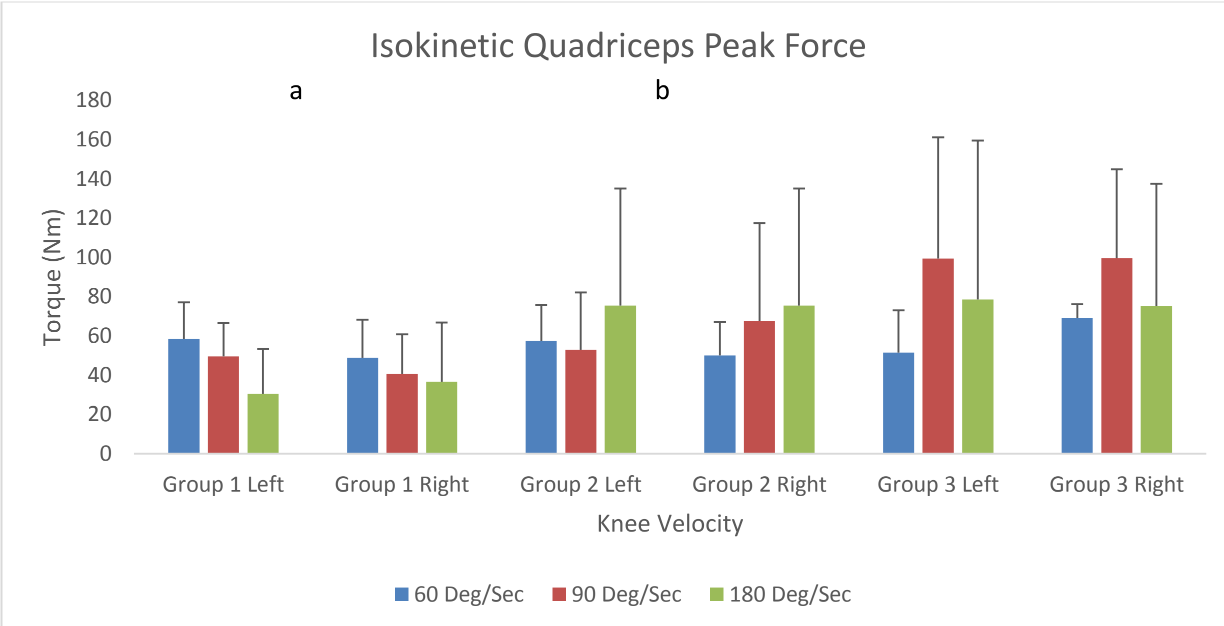

Figure 5. Means (sd±) for Quadriceps Isokinetic Peak Torque, Left and Right knees for Group 1(No pain), Group 2(Pain), and Group 3(Surgery). For Significant differences: a- Group 1 is different than Group 3, b- Group 2 is different than Group 3, velocities 60º/s and 90º/s are both significantly different by having greater values than 180º/s 60º/s and 90º/s are not significantly different.

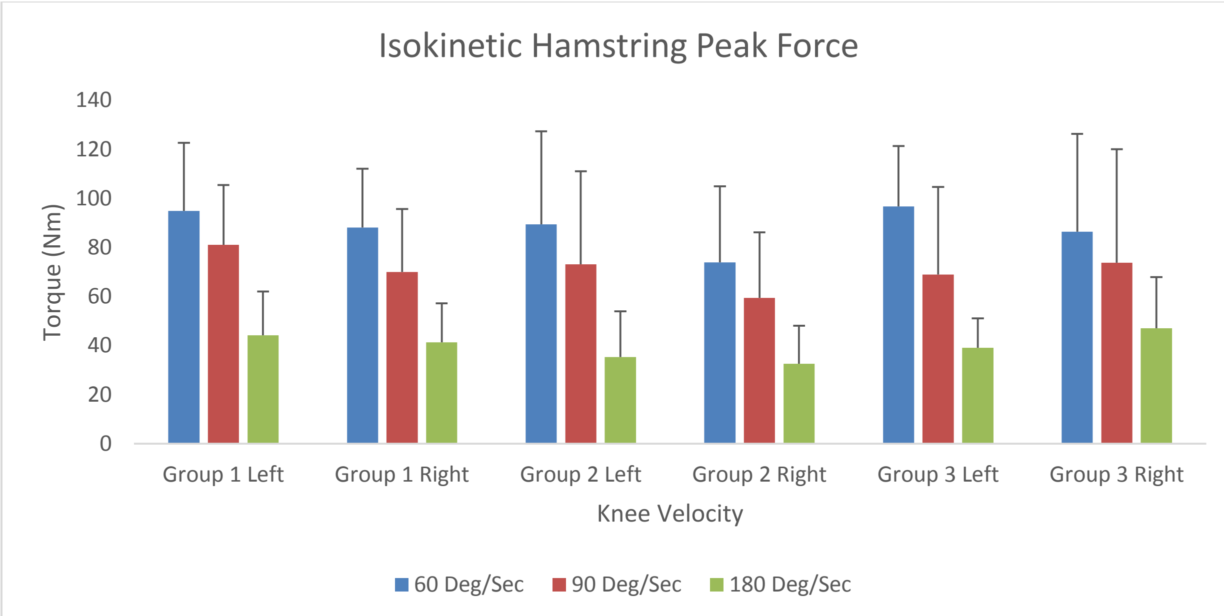

Figure 6. Means (sd±) for Hamstring Isokinetic Peak Torque, Left and Right knees for Group 1(No pain), Group 2(Pain), and Group 3(Surgery). For Significant differences: a- Group 1 is different than Group 3, b- Group 2 is different than Group 3, velocities 60º/s and 90º/s are both significantly different by having greater values than 180º/s 60º/s and 90º/s are not significantly different.

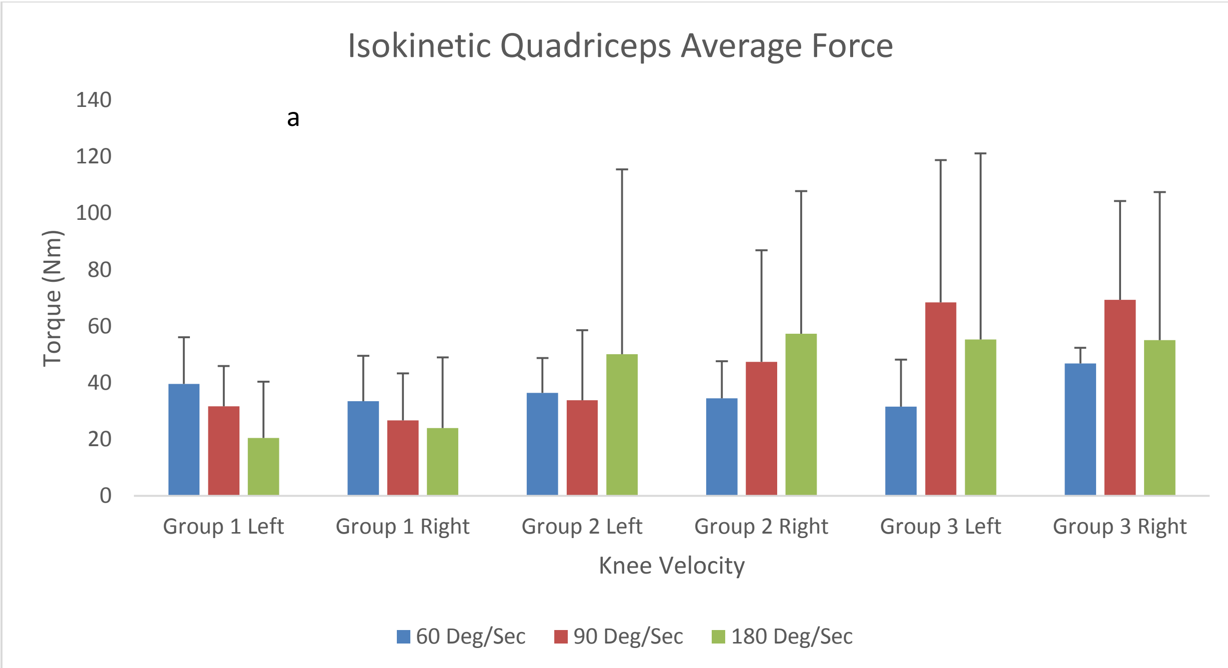

Figure 7. Means (sd±) for Quadriceps Isokinetic Average Torque, Left and Right knees for Group 1 (No pain), Group 2 (Pain), and Group 3 (Surgery). For Significant differences: a- Group 1 is different than Group 3, velocities 60º/s and 90º/s are both significantly different by having greater values than 180º/s 60º/s and 90º/s are not significantly different.

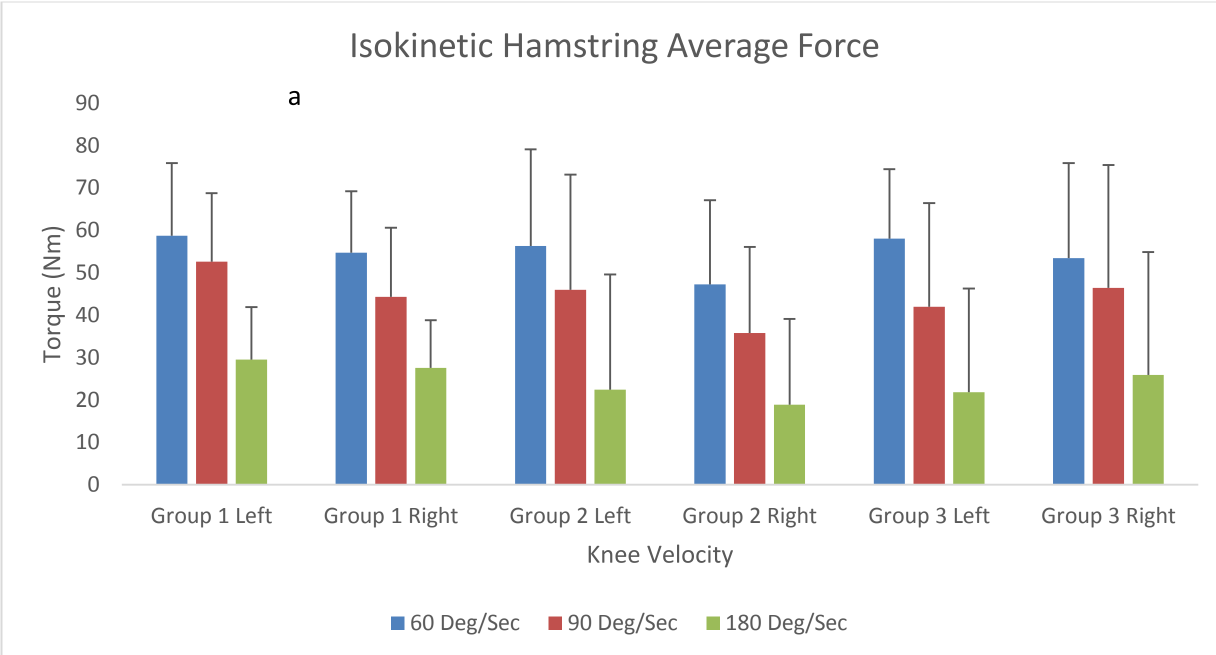

Figure 8. Means (sd±) for Hamstring Isokinetic Average Torque, Left and Right knees for Group 1(No pain), Group 2(Pain), and Group 3(Surgery). For Significant differences: a- Group 1 is different than Group 3, velocities 60º/s and 90º/s are both significantly different by having greater values than 180º/s 60º/s and 90º/s are not significantly different.

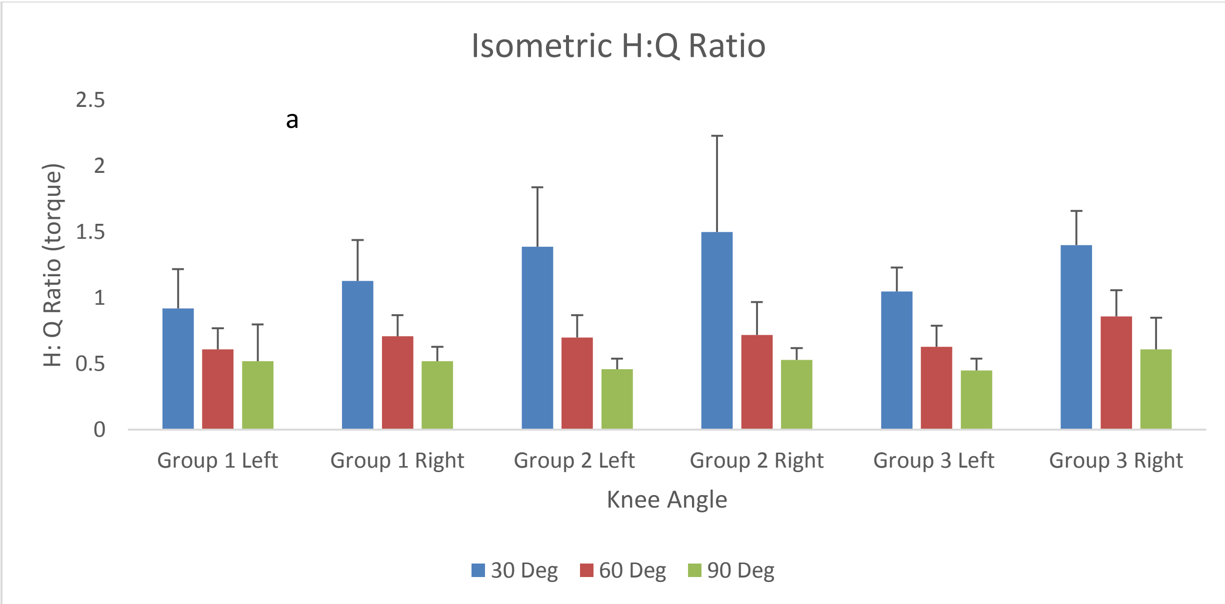

Figure 9. Means (sd±) for Isometric H: Q Ratio, Left and Right knees for Group 1(No pain), Group 2(Pain), and Group 3(Surgery). For Significant differences: a- Group 1 different than Group 2, 30º is significantly lower than 60º and 90º measures, but 60º and 90º are not significantly different

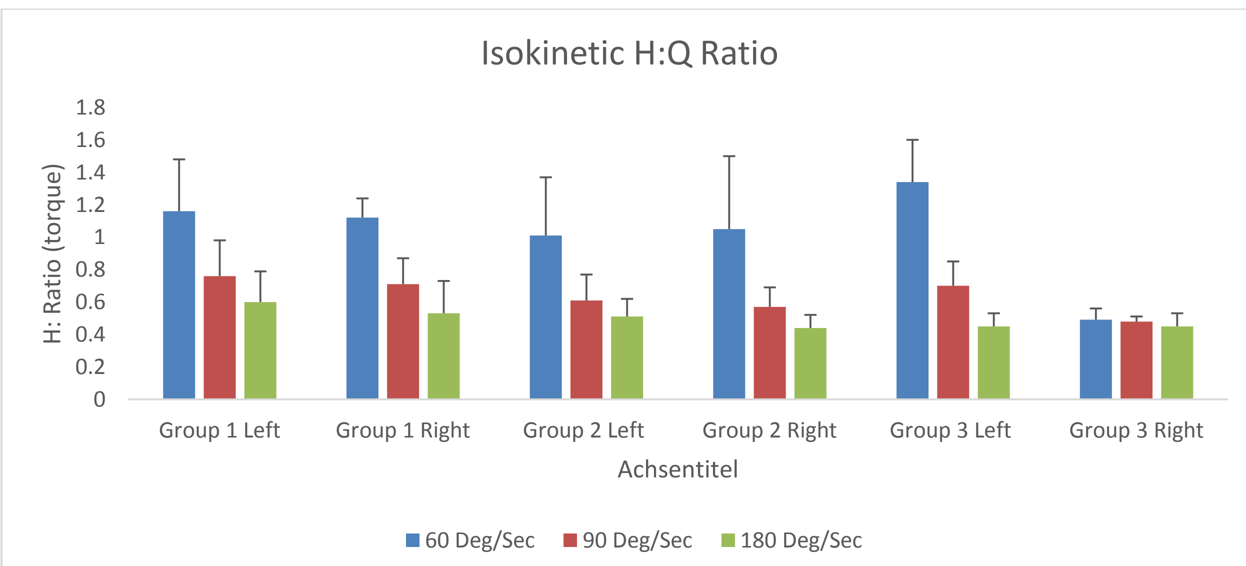

Figure 10. Means (sd±) for Isokinetic H: Q Ratio, Left and Right knees for Group 1(No pain), Group 2(Pain), and Group 3(Surgery). For significant differences: velocities 60º/s and 90º/s are both significantly different by having greater values than 180º/s 60º/s and 90º/s are not significantly different.

CHAPTER 4

DISCUSSION

This study compared bilateral strength differences of the hamstrings and quadriceps muscle groups in division I volleyball athletes by finding the torque values of isometric and isokinetic measurements, along with H:Q ratios, and EMG values. The data do not support the portion of the hypothesis which suggested that quadriceps strength would be less than the control participants, but the results suggested hamstring torque was higher than the control along with the same quadriceps torque when compared. No limb was significantly higher than the other. The data did support the other portion of the hypothesis that suggested the participants with previous knee surgery had greater quadriceps torque, also the hamstring torque was about the same when compared to the control.

Comparing the present results with those previously reported, Kong and Burns (2010) demonstrated that the isometric contractions for quadriceps increased as the angle increased and the hamstrings decreased as the angle increased which agrees with the results of the present study. For the isokinetic conditions in the Kong and Burns (2010) article as the velocity increased the torque decreased, which is also supported with the present study.

In most studies the values of the H:Q ratio increased as the velocity for isokinetic conditions increased (Kong & Burns, 2010; Aagaard et al., 1998; Stafford & Grana, 1984; Rosene, Tracey, Forgarty, Mahaffey, 2001). However in the study by Yoon, Park, Kang, Chun, & Shin (1991) and Rosene et al., (2001), the H: Q ratio decreased as the velocity increased which is similar to the results of the present study. During isometric contractions from the study of Kong and Burns (2010), the H:Q ratio percentage decreases as the angle increases which is similar to the present study, along with having higher values on the right knee in all groups which primarily was the dominant leg. This difference could be caused by possibly having stronger hamstrings in the dominant leg while quadriceps strength was mostly similar between legs. At least one other study also found differences in the hamstring torque but not the quadriceps torque among volleyball and soccer players (Magalhaes, Oliveria, Ascensae, & Soares, 2004). While results of the study by Magalhaes et al., (2004) could be influenced by training background, the study by Kong & Burns (2010) were those not specializing in any sports, which had similar findings as the present study. Another factor could be the velocities and angles tested, the velocities 60°/s, 90°/s, 180°/s were used in the present study, while other studies used 60°/s, 180°/s, 300°/s or 60°/s, 120°/s, and 180°/s (Kong & Burns, 2010; Rosene et al., 2001). Other factors that could explain why other studies receive different results could be that of age, gender, and training background.

For preseason screening, finding the H: Q ratios could be a great way to see if individuals are more susceptible to injury and then rescreen the athletes for their post season to see if there are any differences in the H: Q ratio. For rehabilitation use, goals should be set to where the H: Q ratio for the injured limb should be compared to that of the uninjured limb. Differences in the H: Q ratio between athletes in different sports may depend on the sport that is played, level of competition, or both, while sports with similar lower limb demands and similar competition levels may produce no differences (Rosene et al., 2001). Differences in limb dominance with the H: Q ratio may not occur because specific loads enforced with training and competition may be similar for both limbs (Rosene et al., 2001). The consistent higher H:Q ratios in the dominant leg in all 3 groups in the isometric conditions raises the question of appropriateness of using the non-dominant limb as the rehabilitation goal of the involved limb after injury. In the study from Holcomb et. al. (2007), the authors found lower H:Q ratios in the dominant leg than the non-dominant leg measured at 60°/s, 180°/s, and 240°/s similar to the study by Kong and Burns (2010). Although our main focus was not to distinguish significant differences between dominant and non-dominant limbs but to find H: Q ratio and torque differences in the groups. It is safe to say there are slight differences between the two limbs primarily higher values in the right limb which calls for further investigation with the data collected from the subjects.

With the results collected from isokinetic and isometric conditions along with H: Q ratios, therapists can produce the idea that patients with chronic knee pain should work on quadriceps strength with non-painful exercises to possibly help decrease pain. The participants that have had ACL surgery, showed a slight increase in force values in the quadriceps of the right knee. As stated from the study by Rosene et al. (2001), female athletes tend to be quadriceps dominant, contracting the quadriceps muscles in response to anterior tibial translation, versus non-athletes, who tend to contract the hamstrings. If the hamstrings are ignored during training, quadriceps dominance in the trained female athlete influences the H: Q ratio when compared with the non-athlete (Rosene et al, 2001). To reduce the incidence of knee injury in female athletes, conditioning should include measures to increase H: Q ratio and decrease abduction-adduction moments (Rosene et al, 2001).

In order to collect proper hamstring and quadriceps muscle readings, EMG variables were collected to research the isokinetic and isometric conditions further and separated into extension and flexion conditions. In the isometric conditions, the average recorded values were higher on the D limb and in the VMO muscle for the extension conditions. For flexion conditions the BF values are higher in groups 1 and 3 with having higher values in the SM in group 2. In the peak conditions, the higher values were on the D leg in extension and for flexion ND values were higher in groups 2 and 3 and D in group 1. In the isokinetic conditions, group 1 had higher values in the D limb for RF and lesser values in VMO and VL when compared to the ND limb in extension conditions. During extension group 2 and 3 had greater values in all muscle groups in the D limb with VMO having the highest values. During flexion the values were the highest in the D limb in all three groups. The BF had higher values in groups 1 and 3 and reduced values in group 2. For peak values in extension, the values were higher in the ND limb except for the muscles VMO and RF. Values were higher in the D for group 3. For the flexion conditions, values were higher in the ND limb and the SM had higher values when compared to the BF. EMG has been used to examine the neuromuscular activity of the knee muscles under different isometric and isokinetic conditions (Kellis & Baltzopoulos, 1998). In the article by Kellis and Baltzopoulos, (1998) the same quadriceps and hamstring muscle groups were used with isokinetic conditions as the present study which resulted in increasing values as the velocity increased, which agrees with the results in the present study. In the article by Kubo, Tsunoda, Kanehisa, and Fukunaga (2004), results show that values for the quadriceps muscle group were less when in the more extended position than when flexed which is similar to the results of the present study. However, most of the studies researched performed eccentric and concentric conditions with EMG variables and reported that eccentric conditions had higher values than concentric (Kellis & Baltzopoulos, 1998). It is also concluded that the knee joint is protected by a lower activation level of agonist at the knee-extended position and by a higher activation level of antagonist at the knee-flexed position (Kubo et al., 2004). From rehabilitation stand point the main goal is to strengthen the extensor mechanism, especially the VMO muscle which helps stabilize the patella. If the VMO is not strong enough it can cause the patella to shift or possibly tibial translation and therefore can produce an injury. In the present study results the VMO muscle had the highest values which are the goal for preventing injuries. Recovery from an extensor or flexor mechanism problem requires a disciplined rehabilitation program. A proper exercise strengthening program and correct exercise technique can relieve knee pain and prevent further injury from occurring.

CHAPTER 5

CONCLUSION

The present study has demonstrated differences in hamstring and quadriceps muscle groups for the isometric and isokinetic average and peak torque, H: Q Ratios, and EMG values among division I volleyball players. Although the present study only collected concentric conditions for torque and ratios, eccentric conditions could also be collected to get a better idea of the strength in the relevant muscles. The H: Q ratio can be used to examine similarities between quadriceps and hamstring moment velocity patterns and angles in isokinetic and isometric testing (Rosene et al., 2001). These ratios, however, are velocity and angle dependent as shown in this study, that as the velocity or angle increased the ratio decreased (Rosene et al., 2001). When using this ratio as a tool the velocity or angle must not be ignored because this can lead to inaccurate readings for leg strength (Rosene et al., 2001). The main focus was to find out if there were any differences in H:Q ratios between different groups as well as seeing what muscle groups activated more so than others in certain velocities or angles.

Overall, athletes with chronic knee pain or that have had knee surgery should constantly be strengthening quadriceps and hamstring strength, more so the quadriceps because the present study demonstrated less quadriceps strength in these groups. Patients with previous ACL surgery should be consistently working on hamstring strength since that is what is lost the quickest post-op (Myer et al., 2009). Female athletes who demonstrate the combination of decreased relative hamstrings strength and high relative quadriceps strength may be at increased risk for ACL injury (Myer et al., 2009). Preseason screening programs monitor hamstrings and quadriceps strength, especially relative to comparable values in male athletes, may be warranted to identify female athletes with potential deficits. Targeted neuromuscular interventions that increase relative hamstrings muscle strength and recruitment may decrease injury risk and potentially increase performance in this population (Myer et al., 2009). Lastly, the H: Q ratio is a great way to see if individuals are more susceptible to injury or use it as a return to play/ activity goal based on the uninvolved leg with consideration of leg dominance.

REFERENCES

Aagaard, P., Simonsen, E., Magnusson, P., Larsson, B., Dyhre-Pousen, P. (1998). A new concept for isokinetic hamstring: quadriceps muscle strength ratio. *The American Journal of Sports Medicine, 26,* 231-235.

Baratta R., Solomonow M., Zhou B.H., Letson D., Chuinard R., D'Ambrosia R. (1988) Muscular coactivation: The role of the antagonist musculature in maintaining knee stability. American Journal of Sports Medicine 16, 113-122

Bennell K., Wajswelner H., Lew P., Schall-Riaucour A., Leslie S., Plant D., Cirone J. (1998). Isokinetic strength testing does not predict hamstring injury in Australian Rules footballers. Br J Sports Med, 32, 309-314.

Coombs, R., & 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.

Dargent-Pare C, De Agostini M, Mesbah M, Dellatolas G. (1992). Foot and eye preferences in adults: relationship with handedness, sex and age. Cortex, 28(3):343–51.

DeProft E., Cabri J., Dufour W., Clarys J.P. (1988a) Strength training and kick performance in soccer players. Science & Football - Proceedings of the 1st World Congress of Science and Football. : Reilly T., Lees A., Davids K., Murphy W, editors. London: E&FN Spon; 108-113

DeProft E., Clarys J.P., Bollens E., Cabri J., Dufour W. (1988b) Muscle activity in the soccer kick. Science & Football - Proceedings of the 1st World Congress of Science and Football. : Reilly T., Lees A., Davids K, Murphy W, editors. London: E&FN Spon; 434-440

Dvir Z., Eger G., Halperin N., Shklar A. (1989) Thigh muscle activity and anterior cruciate ligament insufficiency. *Clinical Biomechanics 4*, 87-91.

Ergun, M., Islegen, C., & Taskiran, E. (2004). A cross-sectional analysis of sagittal knee laxity and isokinetic muscle strength in soccer players. *International Journal of Sports Medicine, 25*, 594–598

Gabbard C. (1989). Foot lateralization and psychomotor control in four-year olds. *Percept Motor Skills, 68*,675–678.

Grace, T., Sweetser, E., Nelson, M., Ydens, L. & Skipper, B. (1984). Isokinetic muscle imbalance and knee-joint injuries. A prospective blind study. *Journal of Bone and Joint Surgery, 66*, 734-740.

Heiser T.M., Weber J., Sullivan G., Clare, P., & Jacobs, R. R. (1984). Prophylaxis and management of hamstring muscle injuries in intercollegiate football players. *American Journal of Sports Medicine, 12*, 368–70.

Holcomb, W. R., Rubley, M. D., Lee, H. J., & Guadagnoli, M. A. (2007). Effect of hamstring-emphasized resistance training on hamstring: quadriceps strength ratios. *Journal of Strength and Conditioning Research, 21*, 41–47.

Hortobagyi, Westerkamp, Beam, Moody, Garry, Holbert, DeVita. (2005). Altered hamstring-quadriceps muscle balance in patients with knee osteoarthritis. *Clinical Biomechanics, 20,* 97-104.

Kannus, P. (1994). Isokinetic evaluation of muscular performance: Implications for muscle testing and rehabilitation. *International Journal of Sports Medicine 1*, 11-15.

Kellis, E., & Baltzopoulos, V. (1998). Muscle activation differences between eccentric and concentric isokinetic exercise. *Medicine & Science in Sports & Exercise, 98*, 1616-1623.

Kong, P., & Burns, S. (2010). Bilateral difference in hamstring to quadriceps ratio in healthy males and females. *Physical Therapy in Sport, 11*, 12-17.

Kubo, K., Tsunoda, N., Kanehisa, H., Fukunaga, T. (2004). Activation of agonist and antagonist muscles at different joint angles during maximal isometric efforts. *European Journal of Applied Physiology, 91*, 349-352.

Lanshammar, K., & Ribom, E. (2011). Differences in muscle strength in dominant and non-dominant leg in females aged 20-39 years- A population-based study. *Physical Therapy in Sport, 12,* 76-79.

Magalhaes, J., Oliveira, J., Ascensao, A., & Soares, J. (2004). Concentric quadriceps and hamstring isokinetic strength in volleyball and soccer players. *Journal of Sports Medicine and Physical Fitness, 44*, 119-125.

Moss, C., & Wright, P. (1993). Comparison of three methods of assessing muscle strength and imbalance ratios of the knee. *Journal of Athletic Training, 28*, 55-58

Myer, G., Ford, K., Foss, B., Liu, C., Nick, T., Hewett, T. (2009). The relationship of hamstring and quadriceps strength to anterior cruciate ligament injury in female athletes. *Clinical Journal of Sports Medicine*, *19*, 3-8.

Nosse, L. (1982). Assessment of selected reports on the strength relationship of the knee musculature. *Journal of Orthopaedics and Sports Physical Therapy, 4*, 45-80

Peters M. (1988). Footedness: asymmetries in foot preference and skill and neuro-psychological assessment of foot movement. *Psychological Bull, 103,* 179–92.

Rosene, J., Fogarty, T., Mahaffey, B. (2001). Isokinetic hamstrings: quadriceps ratios in intercollegiate athletes. *Journal of Athletic Training, 36*, 378-383.

Seto, J., Orofino, A., Morrissey, M., Mereiros, J., Mason, W. (1988). Assessment of quadriceps/hamstring strength, knee ligament stability, functional and sports activity levels five years after anterior cruciate ligament reconstruction. *The American Journal of Sports Medicine, 16,* 170-178.

Sharma, L., (2001). Local factors in osteoarthritis. *Current Opinion in Rheumatology,* 13, 441–446.

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

Steinder, A. (1955). *Kinesiology of the Human Body under Normal and Pathological Conditions*. Charles C Thomas Publisher, Springfield, IL.

Voutselas, V., Papanikolaou, Z., Soulas, D. & Famisis, K. (2007). Years of training and hamstring-quadriceps ratio of soccer players. *Physiological Reports, 101*(3 Pt 1), 899-906.

Vita

Graduate School

Southern Illinois University

Laura Miller

Laura.miller3191@gmail.com

Nicholls State University

Bachelors of Science in Athletic Training, May 2013

Research Paper Title:

EXAMINATION OF HAMSTRING TO QUADRICEP RATIOS IN NCAA DIVISION I WOMEN VOLLEYBALL ATHLETES

Major Professor: Dr. Michael Olson