Onset Timing and Strength Between the Vastus Medialis Obliquus and Vastus Lateralis During Eccentric, Isokinetic Exercise

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Abstract of Thesis

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Background

In the sports medicine clinical setting, 25% of patients with knee related injuries are treated for patellofemoral pain syndrome (PFPS). PFPS is more prevalent in women than in men. Risk factors of interest are weakness of the vastus medialis obliquus (VMO) and delayed timing (i.e., a time lag when the muscle contracts) of the VMO compared with the vastus lateralis (VL). A number of investigators propose that a strength or timing deficiency in this medial quadriceps muscle prevents the patella from tracking correctly in the femoral trochlear groove, thus causing deterioration of structures such as the subchondral bone, retinacula, capsule, and synovial membrane, and thereby causing pain. Unfortunately, there is controversy in the literature as to whether or not this theory is valid.

Purpose

The purpose of this cross-sectional study was to compare the strength ratio of the VMO:VL, as well as the activation timing of the two muscles at varying speeds (60^{o}/sec and 300^{o}/sec) during an isokinetic eccentric open kinetic chain exercise of the quadriceps in a population of asymptomatic female participants.

Procedures

Data for this analysis were collected from 13 asymptomatic female participants (mean height= 165.52cm, mean weight= 66.37kg, mean Q-angle= 20.15^{o}). EMG activity of the dominant leg's VMO and VL was recorded during a maximal isometric hold and during eccentric, isokinetic, open kinetic chain testing at 60^{o}/sec and 300^{o}/sec with use of

a Biodex. EMG data were collected using Noraxon EMG & Sensor Systems, recorded with amplitude normalization at a window of 1000ms. Noraxon MyoResearch XP Master Edition software determined mean onset times and peak strength activations.

Results

The data failed to show a significant difference in the eccentric strength between the VMO and VL at 60^{o}/sec [t(12)= -1.26, p= 0.23] and 300^{o}/sec (s= -24.5, p= 0.09), VL at 60^{o}/sec and 300^{o}/sec [t(12)= 1.17, p= 0.27], and VMO at 60^{o}/sec and 300^{o}/sec [t(12)= 0.99, p= 0.34] in young, asymptomatic women. The data also failed to show a significant difference in the onset timing between the VMO and VL at 60^{o}/sec (s= 9.5, p= 0.54) and 300^{o}/sec [t(12)= -0.23, p= 0.82], VL at 60^{o}/sec and 300^{o}/sec (s= -7.5, p= 0.64), and VMO at 60^{o}/sec and 300^{o}/sec (s= -15.5, p= 0.31).

Principal Conclusions

Activation timing and strength ratio of the VMO and VL should be determined in patients with PFPS to assess if a deficiency in the muscles is a contributing factor. As determined by this population of asymptomatic women, there should be no difference in VMO and VL onset timing at 60^{0}/sec and 300^{0}/sec and no difference in VMO:VL eccentric strength at 60^{0}/sec and 300^{o}/sec.

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Introduction

In the sports medicine clinical setting, 25% of patients with knee related injuries are treated for patellofemoral pain syndrome (PFPS).[1,2] PFPS is more prevalent in women than in men[3,4]; according to a review of PFPS by Hudgins[4], women may be affected two times as often. Taunton and colleagues[5] found a significant sex difference in injury distribution of PFPS in a sample of 2002 patients with running injuries. Of the sample, 331 patients were diagnosed with PFPS, and 62% of the patients were women[5]. Symptoms of PFPS include a general ache in the anterior aspect of the knee, or (less commonly) posterior knee pain, from an unknown onset, which is aggravated by sitting with knees in flexion or by walking up and down stairs.[4] In addition to general discomfort in activities of daily living, the pain of PFPS may discourage women from sporting activities and, in general, staying active.[6] Therefore, a clear understanding of PFPS with clinically proven rehabilitation protocols is needed to help those diagnosed maintain a healthy, active lifestyle.

The etiology of PFPS is complex. Risk factors of interest are weakness of the vastus medialis obliquus (VMO) and delayed onset timing (i.e., a time lag when the muscle contracts) of the VMO compared with the vastus lateralis (VL). The patella is stabilized by the distal quadriceps: Specifically, the VL provides lateral dynamic forces to the patella, while the VMO provides medial dynamic forces.[3] A number of investigators propose that a strength or timing deficiency in this medial quadriceps muscle prevents the patella from tracking correctly in the femoral trochlear groove, thus causing deterioration of structures such as the subchondral bone, retinacula, capsule, and synovial membrane, and thereby causing pain.[3,4,7,8] Unfortunately, there is controversy in

the literature as to whether or not this theory is valid.[3,9,10] A possible reason for the contradictory results is the variety of tasks used to analyze the quadriceps functioning.[3] The literature in this area has focused largely on the onset timing of VMO and VL activation, and on strength ratios of the VMO to VL, in participants with PFPS compared with pain-free participants. Studies have used both open kinetic chain (OKC) and closed kinetic chain (CKC) tasks to examine variations between the quadriceps muscles. OKC exercises involve non-weight bearing, single joint movements that may or may not use external resistance. CKC exercises are multi-joint movements that are weight bearing, using either body weight or additional external resistance. Another variation between studies is the assessment of eccentric or concentric quadriceps activity.

Review of Literature

Some studies suggest that variability in onset timing of VMO and VL in PFPS subjects may be a contributing factor, and not a deciding factor, of PFPS.[10, 11] A meta-analysis of VMO and VL recruitment identified a trend towards delayed VMO onset relative to VL onset in subjects with anterior knee pain, compared with no delayed onset in asymptomatic subjects.[10] In regards to this, Herrington and Pearson's research suggests OKC eccentric and concentric exercises are associated with earlier onset timing of both the VMO and VL than CKC exercises.[12] Therefore, open kinetic chain exercises, eccentric or concentric, can be expected to stimulate VMO contraction sooner than CKC exercises.

Research related to VMO:VL strength ratios has been less conclusive. A critical review by Powers[2] indicated some studies have observed significant inhibition of the VMO of PFPS patients while others have not. Powers suggests the inconsistency arises from variability in the population, and patellar maltracking caused by a VMO:VL strength difference is likely not found in all PFPS patients. A later study by Powers[9] showed no difference in VMO:VL strength ratios between PFPS and healthy subjects during concentric, OKC exercises at a rate of 9^{o}/sec. Note that results at 9^{o}/sec may be misleading, as this is not a speed typical of physical activity.

Related to the VMO:VL strength ratio is the speed of contraction. Results from Ribeiro et al. concluded a stable VMO:VL ratio at 60^{o}/sec and 120^{o}/sec in asymptomatic subjects during OKC tasks.[13] In contrast, Matheson and colleagues determined that as the speed of a concentric, isokinetic task increased in a population of healthy subjects, the VMO:VL strength ratio increased, with 300^{o}/sec having the highest ratio.[14] Matheson

also found the VMO:VL strength ratio to increase during eccentric tasks as speed increased from 60°/sec to 180°/sec. The significance of this is noted in the principle of muscle overloading, which states at least 60% of maximal contraction must be achieved to stimulate hypertrophy.[14] Faster isokinetic speeds may be necessary in consideration of a rehabilitation program for PFPS patients. A limitation of Matheson's study is that the researchers were unable to assess eccentric strength at 300°/sec. Additional research is needed to determine if the strength relationship between the VMO and VL remains constant at varied speeds during eccentric actions.

Notable is the change in the VMO:VL strength ratio with varied combinations of exercise type (OKC or CKC) and quadriceps activity (eccentric or concentric). Tang et al.[15] report no significant difference in VMO:VL strength ratios between PFPS and healthy subjects during squat-to-stand, CKC exercises. However, results for OKC quadriceps activity at 120°/sec concluded the VMO produced less force than the VL at all angles of knee flexion during eccentric and concentric actions in both PFPS and healthy subjects. In comparison of eccentric and concentric actions, VMO force remained greater during eccentric actions in both sets of subjects.[15] Irish and colleagues' findings are in support of Tang: VMO activation intensity during OKC knee extension was significantly less than VMO activation intensity during CKC double leg squat, with no difference in activation of the VL between the two exercises.[16] While Irish et al. do not specify parameters of rate of speed or resistance, it can be concluded the VMO activation deficiency is greatest during OKC, eccentric quadriceps exercises.

The Q-angle is an additional risk factor of interest. The Q-angle is formed at the intersection of two lines. The first connects the anterior superior iliac spine with the

center of the patella, the second connects the center of the patella and the tibial tuberosity. A normal Q-angle is considered to be under 15^{o} in men and 20^{o} in women.[3,4] One theory for this difference is a more laterally placed tibial tuberosity in women than men.[17] Similar to VMO deficiencies, it is widely believed a Q-angle greater than 20^{o} in women causes mal-tracking of the patella and is related to PFPS, though results are inconclusive.[3]

Research supports that exercise intervention is needed to treat patients with PFPS, yet no research has determined what type of intervention is most effective. Few studies meet the standards of random control trials or evidence based studies, resulting in a lack of comparison on the effectiveness between treatment protocols[1]. Though not supported by evidence, conservative rehabilitation through quadriceps strengthening is the most common treatment of PFPS.[18] Many protocols target the VMO because of suspected weakness, however, there has not been a clearly defined program shown to best strengthen the VMO.[18] Nor has it been clearly determined if strength or activation of the VMO and VL are rehabilitation variables of interest. According to Earl, 70% of PFPS patients treated through conservative rehabilitation will be symptomatic again within a year.[3] Such evidence suggests misguided rehabilitation of PFPS patients because the root cause is not addressed.

Purpose

While there is ample research assessing the relationship between VMO and VL and the effect on the PFPS population, debate remains over how the muscles are associated with PFPS. Previous research is limited in the speed and type of muscle actions analyzed. Most of the research has assessed movements of 120^{o}/sec or less during

concentric contractions of the quadriceps; few studies have examined the relationship at greater degrees per second during eccentric actions, which are closely related to game-like situations. A research study comparing the strength ratio and onset timing of the VMO to VL at slow and more dynamic speeds would hopefully gain insight toward the best exercise for rehabilitation of PFPS with symptoms of VMO:VL strength and timing differences. Therefore, the *purpose of this cross-sectional study was to compare the strength ratio of the VMO:VL, as well as the onset timing of the two muscles at varying speeds (60^{o}/sec and 300^{o}/sec) during an isokinetic eccentric open kinetic chain exercise of the quadriceps in a population of asymptomatic female participants*. The hypotheses of this study were that in healthy, asymptomatic women under eccentric circumstances, there would be 1) no significant difference in VMO:VL onset timing at 60^{o}/sec, but a difference at 300^{o}/sec, and 2) no significant difference in VMO:VL strength at 60^{o}/sec, but a difference at 300^{o}/sec. Information gathered may serve as a base line for future studies to determine if the VMO of patients with PFPS should be rehabilitated at more functional speeds. Relationships to be considered include:

- VMO activation timing vs. VL activation timing at both 300^{o}/sec and 60 ^{o}/sec
- VMO activation timing at 300 ^{o}/sec vs. VMO activation timing at 60 ^{o}/sec
- VL activation timing at 300 ^{o}/sec vs. VL activation timing at 60 ^{o}/sec
- VMO eccentric strength vs. VL eccentric strength at both 300^{o}/sec and 60 ^{o}/sec
- VMO eccentric strength at 300^{o}/sec vs. VMO eccentric strength at 60 ^{o}/sec
- VL eccentric strength at 300^{o}/sec vs. VL eccentric strength at 60 ^{o}/sec

Methods

Participants

Based on a similar study[13], it has been suggested that the expected difference in eccentric strength between the VMO and VL will be 0.6 with a standard deviation (SD) of 0.6. With these data, the sample size calculation recommends 13 participants. However, the estimation techniques used to derive the mean difference and SD values in the proposal are unclear. Due to a dearth in literature regarding this subject (with appropriate measurement specifications), it is difficult to obtain better values. A study by Irish[16] suggests the expected mean difference in eccentric strength will be -0.25 and the calculated SD of the difference will be 0.0962. Note that the SD here is obtained using estimation techniques for calculating SDs of mean differences obtained using a simple random sampling scheme. That being said, sample size calculation based on the Irish[16] study recommends four participants would have been needed to note a difference. The relative small size of the sample is a consequence of the small standard deviation (and subsequently variance) in the data.

Based on data from Herrington and Pearson[12], sample size calculations suggest 1228 participants to note a significant difference. On this occasion, it is also important to note that the relatively large sample size is a result of the large SDs associated with each average measurement and subsequently the mean differences.

Overall, it seems as though on most occasions, the power analysis yields results suggesting relatively small sample sizes. Particularly with respect to activation timing, it seems as though the literature suggests that smaller sample sizes are adequate to note

statistically significant results. However, concern remains over the lack of reliable literature regarding the mean differences in eccentric strength. A difference noticeable using 4 pairs of measurements would intuitively be noticeable when 13 pairs of measurements are made as well.

Data for this analysis were collected from 13 asymptomatic female participants. Participant demographic information is presented in Table 1.

Table 1: Participant Descriptive Data

	Height (cm)	**Weight (kg)**	**Q-Angle (^{o})**	**ROM (^{o})**
Mean	165.52	66.37	20.15	93.51
Standard deviation	6.75	11.14	2.66	7.54

Participants were recruited by three methods. First, by e-mail over the George Washington University School of Public Health and Health Services and Department of Exercise Science listservs (Appendix I). Second, by announcements in select Exercise Science; Lifestyle, Sport, and Physical Activity; and Health and Wellness classes (Appendix II). Third, by flyers placed around the campus of The George Washington University (Appendix III). Potential participants who expressed interest in the study were phone screened (Appendix IV) to determine if they met study criteria. Inclusion criteria for participants were participation in a minimum of 90 minutes of individual and/or group recreational physical activity or group fitness classes a week. Exclusion criteria included more than five hours of physical activity a week; formal training with a strength and conditioning coach or a personal trainer; a history of knee surgery; current or history of knee injury; and history of knee pain when descending or ascending stairs, squatting, kneeling, prolonged sitting, or jumping within the past year. The participant's dominant

leg was considered. Each participant was issued an identification number for entry in the Biodex, as well as for use in data collection and statistical analysis.

Questionnaire and History

Each participant was asked to complete the Physical Activity Readiness Questionnaire (PAR-Q) created by the British Columbia Ministry of Health and revised by an Expert Advisory Committee of the Canadian Society for Exercise Physiology, to ensure physical activity did not pose a threat (Appendix V).[19] Each participant received a hyperlink to the PAR-Q for their records.

Measuring Q-angle

Q-angle is traditionally measured with the patient lying supine, not accounting for changes in foot position, which can affect the Q-angle. Therefore, measuring the angle with the patient standing is thought to be more reliable.[20] Q-angle was measured on the patient's dominant leg. Marks were made, with a felt tip pen, on the anteriorsuperior iliac spine (ASIS), center of the patella, and center of the tibial tuberosity. With the patient standing, the angle was measured directly with a long-armed goniometer (Baseline Measuring and Diagnostic Instruments).[20] The angle measured is made of the line connecting the ASIS and patella and the line connecting the patella and tibial tuberosity.

Electromyogram (EMG) Recording

EMG activity of the dominant leg's VMO and VL was recorded using disposable, self-adhesive Ag/AgCl dual action, snap surface electrodes. The "figure 8" shaped area of the electrodes measures 4cm x 2.2 cm. Each circular conductive area has a diameter of 1cm, with an inter-electrode distance of 2.0 cm. Electrodes use a hypoallergenic gel (Noraxon). As established by Cowan[11] and Irish[16], electrodes were placed over the

muscle bellies of the VMO and VL. The VMO electrode was placed 4cm superior and 3cm medial to the patella border, arranged at a 55^{o} angle to the vertical as assessed by the same goniometer used to determine Q-angle. The VL electrode was 10cm superior and 6cm lateral to the superior border of the patella, arranged at 15^{o} to the vertical as assessed by a goniometer. The skin was shaven and cleaned with an alcohol wipe to reduce effects of electrical impedance. The participant was informed that there should be no pain produced by the electrodes, the electrodes would measure electrical activity in the quadriceps muscle and would not electrically stimulate the muscle. Data were collected using Noraxon EMG & Sensor Systems. An 8-channel Noraxon TeleMyo DTS Desk Receiver transmitted electrical activity from the electrodes to Noraxon MyoResearch XP Master Edition 1.08.17 software. Data were recorded with amplitude normalization at a window of 1000ms. For the purpose of this study, onset timing may be defined at a threshold sampling frequency of 1000 Hz and minimal sub period duration of 100ms.

Biodex

Biodex System 3, (Biodex Medical Systems), was used in conjunction with Biodex Advantage Software. The Biodex Single Chair Quickset, model #830-135, was set for knee extension and flexion by positioning the chair at a 45^{o} angle and the dynamometer (model #900-850) at a 45^{o} angle with 0^{o} of tilt, allowing the participant to be positioned on the Biodex so the dominant side was at 90^{o} hip flexion and 90^{o} knee flexion.[21] Range of knee flexion was 180^{o} (full extension) to less than 90^{o} knee flexion, as limited by the chair.[22] The participant was secured in the chair with the use of chest straps, a waist strap, and a strap around the dominant thigh; and secured to the arm of the dynamometer with a tibia pad and strap adjusted to immediately superior of the malleoli

of the ankle. The lateral epicondyle was visually aligned with the input shaft of the dynamometer[22], as closely as allowed by the seat and dynamometer height adjustment options. The participant was instructed to remain sitting upright, facing forward, with her hands held across her chest, holding the chest straps, to avoid use of accessory muscles during testing. The participant's height, sex, weight, dominant leg, and identification number were entered into the Biodex system. First and last name are mandatory patient information in the Biodex software. To maintain confidentiality, the last name entered was identical to the identification number, with the first initial "X", to prevent bias.

Procedure

After expressing an interest to volunteer for the study, the participant was sent a copy of the informed consent (Appendix VI) and a link to the PAR-Q over email. After confirming interest and the participant's eligibility for the study, two testing dates and times, 48-72 hours apart, were scheduled. To minimize risk of breach of confidentiality, data collected were linked to an identification number, not the participant's name. Before their testing date, participants were randomly assigned a five digit identification number using a random string generator[23]. The first testing date was used to familiarize the participant with the Biodex. At the time of appointment, the participant reported to the George Washington University's EXSC Exercise Physiology Lab. When the participant arrived, she was asked to sign a consent form and complete a PAR-Q. Each participant was given a copy of the informed consent form to keep for her records. The examiner took baseline measurements of age, height (Seca), mass (Detecto), and Q-angle. This data were related to the participant's identification number only, and a written copy was kept. The participant performed a five minute, self-paced warm-up on a stationary Ergomedic

894 Ea Peak Bike (Monark), due to convenience, with a load 2% that of their body mass.[24] Warming-up before physical activity has been shown to decrease risk of injury.[25,26] A critical review by Woods, Bishop and Jones concludes warm-up intensity should be between 40-60% VO_{2max} to increase muscle temperature without depleting available energy. The participant was instructed that at the end of the warm-up they should experience light to moderate sweating without fatigue, an effective indicator that the participant is in the 40-60% VO_{2max} range[25]. A lower extremity stretching protocol[25] (Appendix VII) was then completed. While controversy exists in regards to stretching and the reduction of injury, recent studies show static stretching before activity does not increase the risk of injury.[25, 27] The participant then removed shoes[22] and was positioned in the Biodex chair. The chair was then adjusted accordingly and the participant was secured with chest, waist, and thigh straps as well as the tibia pad and strap. Verbal instructions for the Biodex were given (Appendix VIII). Before the testing date, participants were randomly assigned to Protocol One (Appendix IX) or Protocol Two (Appendix X) using randomization.com.[28] Instructed to perform at 50% of her best, the participant performed the previously, randomly assigned protocol. Each consisted of two, ten-repetition trials separated by a three minute rest. The trials were isokinetic, eccentric knee extension/flexion exercises, one at 60^{o}/sec and the other 300^{o}/sec. Trials were separated by a three minute rest to avoid fatigue effects.[21] No data was collected at this time. An outline of testing session one can be found in Appendix XI. Data were collected at the second testing date. At the time of the second appointment, the participant reported to the George Washington University's EXSC Exercise Physiology Lab. The participant again performed a 5 minute, self-paced warm-up followed by the stretching protocol.

Next, verbal instructions for the electrodes were given (Appendix VIII) and the surface electrodes were placed on the dominant leg. The patient was placed on a chair; EMG data were recorded with the participant at rest to ensure proper EMG set-up and recording. Next, EMG recordings of VL and VMO activity were recorded as the participant stood up and sat down three times. The participant then removed her shoes.[22] The participant was positioned in the Biodex chair, the chair was adjusted accordingly and the participant was secured with straps. Instructed to perform her best, the participant first performed a pre-entered protocol (Appendix XII) to test maximal isometric quadriceps contraction at 65^{o} knee flexion, followed by a three minute rest, then again at 30^{o} knee flexion, followed by a three minute rest.[21] Each isometric contraction was held for 5 seconds. After a three minute rest, the participant performed the same protocol she had been assigned for familiarization. An outline of testing session two can be found in Appendix XIII. At the conclusion of the study, participants were reminded there was risk of soreness in the quadriceps muscles that may take a day or two to develop and can be expected to disappear within one week.[29] To minimize potential soreness, participants were encouraged to apply ice to sore areas to alleviate discomfort, and to limit exercises that add stress to the quadriceps in the days leading up to and following the study.

Data Collection

The height and weight of each participant along with Q-angle measurements were made for each participant. Data collected from quadriceps activity were saved in three phases. The first phase was the participant's sit-to-stand, the second phase was the isometric protocol, and the third phase was the isokinetic protocol. The second phase was recorded as a Maximum Voluntary Contraction (MVC). During the third phase for each

participant, markers were set during the isokinetic protocol to help distinguish eccentric quadriceps actions from concentric actions. After data were collected, markers were adjusted to identify periods of eccentric quadriceps actions. Only periods that could be clearly identified as a repetition of the eccentric action were considered. The average number of periods from each subject was 9.58 at 60^{o}/s and 9.33 at 300^{o}/s. Based on Noraxon's recommendations for timing analysis[30], phase three data were rectified, then smoothed with a low pass filter at 50 ms using a Root Mean Square (RMS) algorithm. To obtain mean onset times, two Noraxon timing analysis Onset/Offset Trend Reports were created for each participant, one for 60^{o}/sec and one for 300^{o}/sec. The sub period threshold definition was set to 3 SD and the minimal sub period duration was 100ms in all frames. To obtain peak strength activations, two Noraxon Average Activation Pattern Reports were created for each participant, one for 60^{o}/sec and one for 300^{o}/sec.

Results

The eccentric strengths and onset timings of the VMO and VL muscle groups in each participant was measured during isokinetic eccentric open kinetic chain exercises. The Noraxon software normalized the isokinetic activity to the participant's recorded MVC to determine the mean and peak values for the VMO and VL contraction forces, expressed as a percent of the MVC.[29] As mentioned, the difference between the eccentric strengths and onset timings were assessed for each participant at low (60^o/sec) and high (300^o/sec) speeds (Table 2). Available data was analyzed considering the fact that the 95% confidence intervals contained the null value for all mean differences obtained.

Table 2: Timing and Strength of VMO and VL at 60^o/sec and 300^o/sec

	VMO 60^o	**VMO 300^o**	**VL 60^o**	**VL 300^o**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Onset Timing (s)	0.312 (0.121)	0.283 (0.091)	0.305 (0.107)	0.284 (0.088)
Peak Strength (%MVC)	101.315 (33.017)	107.154 (42.268)	107.823 (35.770)	115.369 (50.791)

It was determined that the difference between the VMO and VL onset timing at 300^o/sec was normally distributed. Using the paired sample t-test, it was determined that there was not a significant difference between the VMO and VL in onset timings at 300^o/sec [$t(12)= -0.23$, $p= 0.82$, power= 0.053]. The difference between the VMO and VL onset timing at 60^o/sec, between the onset timing of the VL group at 60^o/sec and 300^o/sec, and the difference between the onset timing of the VMO group at 60^o/sec and 300^o/sec, were not normally distributed. Therefore, nonparametric tests were considered and the Wilcoxon signed rank test was used to examine the difference. The Wilcoxon

signed rank test suggests no significant difference between the onset timing of the VMO and VL at 60^{o} /sec (s= 9.5, p= 0.54, power= 0.051), VL at 60^{o}/sec and 300^{o}/sec (s= -7.5, p= 0.64, power= 0.095), or the VMO at 60^{o}/sec and 300^{o}/sec (s= -15.5, p= 0.31, power= 0.125) (Table 3).

Table 3: Onset Timing Comparisons

	VMO:VL 60^{o}/sec	**VMO:VL 300^{o}/sec**	**VMO: 60^{o}/sec to VMO 300^{o}/sec**	**VL: 60^{o}/sec to VL 300^{o}/sec**
Paired Sample T-test		t(12)= -0.23 p= 0.82 power= 0.053		
Wilcoxon Signed Rank Test	s= 9.5 p= 0.54 power= 0.051		s= -15.5 p= 0.31 power= 0.125	s= -7.5 p= 0.64 power= 0.095

The difference between the VMO and VL for peak eccentric strength at 60^{o}/sec was normally distributed. The paired sample t-tests revealed no significant difference between the VMO and VL in eccentric strength at 60^{o}/sec [t(12)= -1.26, p=0.23, power= 0.212]. The difference between the peak eccentric strengths of the VMO and VL at 300^{o}/sec was not normally distributed. The Wilcoxon signed rank test showed no significant difference between the peak eccentric strengths of the VMO and VL at 300^{o}/sec (s= -24.5, p= 0.09, power= 0.080). The difference between the peak eccentric strengths of the VL group at 60^{o}/sec and 300^{o}/sec, as well as the difference between the peak eccentric strengths of the VMO group at 60^{o}/sec and 300^{o}/sec, were normally distributed. The paired sample t-tests suggest no significant difference between the eccentric strengths of the VL group at 60^{o}/sec and 300^{o}/sec [t(12)= 1.17, p= 0.27, power= 0.189] or between the eccentric strengths of the VMO group at 60^{o}/sec and 300^{o}/sec [t(12)= 0.99, p= 0.34, power= 0.149] (Table 4).

Table 4: Peak Eccentric Strength Comparisons

	VMO:VL 60°/sec	**VMO:VL 300°/sec**	**VMO: 60°/sec to VMO 300°/sec**	**VL: 60°/sec to VL 300°/sec**
Paired Sample T-test	t(12)= -1.26 p= 0.23 power= 0.212		t(12)= 0.99 p= 0.34 power= 0.149	t(12)= 1.17 p= 0.27 power= 0.189
Wilcoxon Signed Rank Test		s= -24.5 p= 0.09 power= 0.080		

Under the assumption that data would be normally distributed, power analyses may be run for each difference. Results do not reveal good statistical power in our tests. Statistical power for small samples is not typically assessed, since a limitation to smaller sample sizes is compromised power. In addition, the power analysis was done separately for differences that were normal and differences that were not. Therefore, statistical power for the paired T-tests is approached differently than the 2-sided Wilcoxon Signed Rank tests. Note the 2-sided estimators are relatively close.

It is important to note that the absence of evidence does not imply evidence for absence. Therefore, though there is no statistically significant difference seen, further tests need to be done before stating that there are no differences between the muscle groups at those conditions. These tests suggest that there is no evidence for a statistically significant difference between the specified conditions.

Discussion

The data failed to show a significant difference in the eccentric strength between the VMO and VL at 60°/sec and 300°/sec, VL at 60°/sec and 300°/sec, and VMO at 60°/sec and 300°/sec in young, asymptomatic women. The data also failed to show a significant difference in the onset timing between the VMO and VL at 60°/sec and 300°/sec, VL at 60°/sec and 300°/sec, and VMO at 60°/sec and 300°/sec.

Our results support previous studies that have failed to suggest a delay in VMO onset relative to VL onset in asymptomatic subjects during eccentric quadriceps activity.[10,11,12] Our results also support previous studies that have failed to suggest a VMO:VL strength difference during eccentric quadriceps activity at slower speeds in asymptomatic populations. Powers[9] observed a constant strength ratio at 9°/sec, and Ribeiro et al.[13] concluded a stable VMO:VL strength ratio at 60°/sec and 120°/sec. Our study contradicts Matheson and colleagues,[14] who found an increased VMO:VL strength ratio at 180°/sec in eccentric, isokinetic tasks compared to slower speeds. Our study adds to the discrepancy in the literature and supports the need for additional studies assessing the ideal VMO:VL strength ratio in healthy, asymptomatic subjects at the more dynamic speed of 300°/sec.

Research supports that exercise intervention is needed to treat patients with PFPS, but not what type of intervention is most effective. Few studies meet the standards of random control trials or evidence based studies, resulting in a lack of comparison on the effectiveness between treatment protocols.[1] We conclude that onset timing and strength ratio of the VMO and VL should be determined in patients with PFPS to assess if a deficiency in the muscles is a contributing factor to the syndrome. As determined by this

population of asymptomatic women, there should be no difference in VMO and VL onset timing at 60^0/sec and 300^0/sec and no difference in VMO:VL peak eccentric strength at 60^0/sec and 300^o/sec.

This study utilized eccentric action at 60^0/sec and 300^0/sec. Timing and strength relationships between the VMO and VL should be assessed in situations that are closely related to physical activity. Eccentric quadriceps actions are found in situations such as the landing phase of jumping, heel strike during gait, and deceleration. The angular speed at the knee during activity is fast, with an average of 725^o/sec during the landing phase in females.[31] To our knowledge, this is the first study to assess the onset timing and peak strength between the VMO and VL at a slower and a more dynamic speed. Future research should focus on determining if a difference in VMO and VL onset timing and strength ratios is found during faster eccentric actions in females with PFPS. If a difference in strength and/or timing is found in females with PFPS, future research should also focus on determining the most efficient and effective rehabilitation protocol to meet normal ratios when a deficiency is observed.

There are limitations to this study. To begin with, only 13 subjects participated. A larger sample size may yield different results. A conservative power analysis, assuming normality in the data and stating a lower correlation between measurements, suggests a measurable difference may show a stronger statistical power with a sample size of 21 (power= 0.901). Also, our subject pool was limited to asymptomatic females, aged 18-25, who are not in training and participate in physical activity for 1.5 to 5 hours a week. Therefore, our results can only be applied to this population.

Clinical Implications

Onset timing and strength ratio of the VMO and VL should be determined in patients with PFPS. As determined by this study, there should be no difference in VMO and VL onset timing at 60^0/sec and 300^0/sec and no difference in VMO:VL peak eccentric strength at 60^0/sec and 300^o/sec. If a deficiency is found in patients with PFPS, it may be a contributing factor to the syndrome. Clinically, the rehabilitation program should address these imbalances.

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Appendix I:
Subject Email Recruitment Script

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

January 2013

Email Subject: Participation in Quadriceps Study

Dear Student,

My name is Erin and I am a Master's Student in the Department of Exercise Science. I am conducting research with students to determine the differences in strength and time of activation in two muscles of the quadriceps. The testing protocol is completed in two sessions, the first about 45 minutes and the second about 30 minutes, at the George Washington University Exercise Physiology Lab. The protocol will include three tests on a Biodex during the second testing session. A Biodex is a machine that we will use to measure strength of your quadriceps at a constant speed. Electrodes will be placed on the skin over the muscles, and will read the electrical activity but do not cause pain or any other sensation. To be included in this study you will have to be a woman aged 18-25, participate in individual or group recreational physical activity for 1 ½-5 hours a week. You will not be able to participate if you have had knee pain in the last year while walking up and down stairs, squatting, kneeling, sitting, or jumping; a current or previous knee injury; or current formal training with a strength and conditioning coach or personal trainer. If you volunteer to participate and meet the requirements, which will be determined by a phone interview, we will set a date and time for you to report to the lab. If you have any questions or concerns regarding the study protocol or other requirements, please feel free to contact me. If you are interested in participating in this study, please email me at ewill@gwmail.gwu.edu. Thank you in advance for your help!

Sincerely,

Erin Will, B.S., ATC
Teaching Graduate Assistant
Department of Exercise Science
The George Washington University
2033 K Street, NW
Washington, DC

Appendix II:
Subject Verbal Announcment Recruitment Script

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

Hello. I am Erin and I am a Master's Student in the Department of Exercise Science. I am conducting research with students to determine the differences in strength and time of activation in two muscles of the quadriceps. The testing protocol is completed in two sessions, the first about 45 minutes and the second about 30 minutes, at the George Washington University Exercise Physiology Lab. The protocol will include three tests on a Biodex during the second testing session. A Biodex is a machine that we will use to measure strength of your quadriceps at a constant speed. Electrodes will be placed on the skin over the muscles, and will read the electrical activity but do not cause pain or any other sensation. To be included in this study you will have to be a woman aged 18-25, participate in individual or group recreational physical activity for 1 ½-5 hours a week. You will not be able to participate if you have had knee pain in the last year while walking up and down stairs, squatting, kneeling, sitting, or jumping; a current or previous knee injury; or current formal training with a strength and conditioning coach or personal trainer. If you volunteer to participate and meet the requirements, which will be determined by a phone interview, we will set a date and time for you to report to the lab. If you have any questions or concerns regarding the study protocol or other requirements, please feel free to contact me. If you are interested in participating in this study, please email me at ewill@gwmail.gwu.edu. Thank you in advance for your help!

Appendix III:
Subject Recruitment Flyer

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

Volunteers Needed!!!

For a Master's Thesis in the Department of Exercise Science

Looking for women, ages 18-25, who are involved in physical activity for 1 ½- 5 hours a week and do not experience knee pain.

The testing protocol is completed in two sessions, the first about 45 minutes and the second about 30 minutes, at the George Washington University Exercise Physiology Lab in Mitchell Hall. The protocol will include three quadriceps tests. Electrodes will be placed on the skin over the muscles, and will read the electrical activity but do not cause pain or any other sensation.

If you are interested in participating in this study, please contact Erin Will at ewill@gwmail.gwu.edu

Appendix IV:
Phone Screen for Orthopedic History and Current Training Level

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

1. Name? Please spell.
2. How old are you?
3. On average, how many days a week do you participate in physical activity?
4. About how long do these bouts of activity last?
5. What type of activities do you participate in?
6. Have you ever been diagnosed with an injury to your dominant knee? If yes, how long ago and what was the injury?
7. Have you ever felt you suffered from an undiagnosed knee injury? If yes, how long ago did the injury happen and to which knee?
8. Do you ever experience pain in either knee, including but not limited to when sitting for extended periods or going up and down stairs? If yes, how often and with what activities? Which knee is affected?
9. Is there anything else I should know?

Thank you for answering these questions. Based on your responses, you are (qualified/not qualified) for the study. You will receive an email within the next day containing information on when and where to report, as well as dress guidelines. Thank you for your voluntary participation.

Appendix V:
PAR-Q & You

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____ DATE _____

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) _____ WITNESS _____

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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...continued from other side

PAR-Q & YOU

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

Source: Canada's Physical Activity Guide to Healthy Active Living, Health Canada, 1998 http://www.hc-sc.gc.ca/hppb/paguide/pdf/guideEng.pdf

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FITNESS AND HEALTH PROFESSIONALS MAY BE INTERESTED IN THE INFORMATION BELOW:

The following companion forms are available for doctors' use by contacting the Canadian Society for Exercise Physiology (address below):

The **Physical Activity Readiness Medical Examination (PARmed-X)** – to be used by doctors with people who answer YES to one or more questions on the PAR-Q.

The **Physical Activity Readiness Medical Examination for Pregnancy (PARmed-X for Pregnancy)** – to be used by doctors with pregnant patients who wish to become more active.

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References:

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Thomas, S., Reading, J., Shephard, R.J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). **Can. J. Spt. Sci.** 17:4 338-345.

For more information, please contact the:

Canadian Society for Exercise Physiology
202-185 Somerset Street West
Ottawa, ON K2P 0J2
Tel. 1-877-651-3755 • FAX (613) 234-3565
Online: www.csep.ca

The original PAR-Q was developed by the British Columbia Ministry of Health. It has been revised by an Expert Advisory Committee of the Canadian Society for Exercise Physiology chaired by Dr. N. Gledhill (2002).

Disponible en français sous le titre «Questionnaire sur l'aptitude à l'activité physique - Q-AAP (revisé 2002)».

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Appendix VI:
Informed Consent Form

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

INTRODUCTION

You are invited to participate in a research study conducted by Dr. Mary Barron and Erin Will from the George Washington University's Department of Exercise Science. You are being asked to partake in this study because you are currently a healthy, asymptomatic female college student between the ages of 18-25. There are approximately 15 students participating in the study. Your participation is greatly appreciated, and is entirely voluntary, thus, you may withdraw at any time. You may not receive any benefits from taking part in this study. However, the research may provide us insight into optimal rehabilitation for individuals who experience knee pain.

PURPOSE
The purpose of this cross-sectional study is to compare the strength ratio of two quadriceps muscles, as well as the activation timing of the two muscles at varying speeds (60^{o}/sec and 300^{o}/sec) during an exercise of the quadriceps in a population of asymptomatic female participants.

PROCEDURES

On the day of your scheduled first visit, you will report to The George Washington University Exercise Physiology Laboratory in Mitchel Hall located at 514 19th St. Washington, DC. This session is expected to last 45 minutes. Please be dressed in athletic clothing. You will be asked to complete a Physical Activity Readiness Questionnaire (PAR-Q), a copy of which can be found at http://uwfitness.uwaterloo.ca/PDF/par-q.pdf. Non-invasive measurements of height, mass, age, and Q-angle will be taken. You will then perform a five minute, non-fatiguing warm-up on a stationary bicycle and a lower-extremity stretching protocol. After this, you will be familiarized with the Biodex machine, which is used for the quadriceps testing.

On the day of your scheduled second visit, you will again report to The George Washington University Exercise Physiology Laboratory in Mitchel Hall located at 514 19th St. Washington, DC. This session is expected to last 30 minutes. Please be dressed in athletic clothing.

Again, you will be asked to complete a five minute warm-up on a stationary bicycle and a lower-extremity stretching protocol. You will then go through several tests of the quadriceps in your dominant leg while on a Biodex, which will record your strength. The first will assess the isometric (no movement) strength of your quadriceps in two positions. The next two tests will assess the strength of the quadriceps during knee flexion and extension, at two different speeds. In addition, EMG sensors placed on your skin will record the electrical activity in your muscles, though you will not feel anything from this.

RISKS AND CONFIDENTIALITY

The study has a risk of soreness in your quadriceps, which may take a day or two to develop. The soreness can be expected to subside within a week. To alleviate some of the risk, you may try applying ice to the sore areas, and adjust your exercise routine in the days leading up to and following the study by reducing exercises that add stress to the quadriceps.

The records of the study will be kept private to the extent permitted by law. Your name will not be associated with your results. In any published articles or presentations, no information will be used that would allow for identification of you as a subject. Your results may be looked at by members of The George Washington University Department of Exercise Science and by University officials responsible for overseeing research safety and compliance.

For further information regarding your participation rights, please contact The George Washington University Office of Human Research at 202.994.2715. For further information regarding the study, please contact principle investigator Mary Barron at mjbarron@email.gwu.edu or at 202.994.4818; or principle contact Erin Will at ewill@gwmail.gwu.edu or at 443.340.2726.

BENEFITS

There are no direct benefits to subjects. Benefits to you as well as to the class of research subjects will be aiding in the determination of effective rehabilitation methods for individuals with knee pain.

CONSENT DOCUMENT

If you agree to participate in the research study above, please sign below. The researchers will provide you a copy of the signed consent form. Please keep it for reference.

Your academic status will not, in any way, be affected should you chose not to participate in this study or if you withdraw from the study at any time.

Should you wish to withdrawal from the study, notify the test administrator and you will be permitted to leave, no questions asked.

DOCUMENTATION OF CONSENT

Participant's Name (Please Print)	Date
Participant's Signature	Date
Principle Investigator's Signature	Date

Mary Barron, Ph.D.
Assistant Professor
The George Washington University
School of Public Health and Health Services
Department of Exercise Science
2033 K St., NW
Suite 210
Washington, D.C. 20006

Phone: 202.994.4818
Email: mjbarron@email.gwu.edu

Appendix VII:
Stretching Protocol

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

Instructions

- Follow the two exercises below. Please complete the first before moving on to the second.
- Stretch your dominant leg only.
- Hold each stretch for three sets of 30 seconds, as timed by a stopwatch, with five seconds of rest in-between sets.

Stretches

- Standing Quadriceps stretch: Stand near a table, upright in pelvic neutral. One hand may be used on the table for balance; the other should grasp the ankle so that you feel a stretch without pain in your quadriceps muscle group.
- Seated Hamstring stretch: Sit with your hip positioned at 90^{o} flexion, knee extended and the uninvolved leg positioned in hip external rotation and knee flexion ("figure 4" position). Next move towards anterior pelvic tilt (tilt forward at the pelvis) until you feel a stretch without pain in your hamstring muscle group.

Appendix VIII:
Verbal Instructions

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

Electrodes: I will be placing two electrodes on your quadriceps, one over the vastus lateralis and the other over the vastus medialis obliquus. First, I am going to shave the two areas and clean each with an alcohol wipe. This will ensure a clearer signal read by the electrode. The electrodes will not stimulate the muscle, and you will not feel anything. They measure the electrical activity in the muscle. Do you understand? Do you have any questions?

Biodex: The Biodex machine will be providing resistance against your lower leg during the trials. Please sit up straight. The straps we are using will secure you in the seat and prevent you from using other muscles, so we can best measure the strength of your quadriceps. Please hold on to the chest straps while being tested. You will also be holding this comfort-stop button. If at any time you feel unsafe, pressing the button will immediately stop the test.

First, we will be performing two isometric contractions. During these, try to extend your leg with as much force as possible for the entire five seconds. After you have rested for 3 minutes, we will continue with the trials. You will perform 10 repetitions at two different speeds. Before each trail, you will have a chance to perform submaximal repetitions to help you get used to the movement of the machine and the speed at which you will be moving. During the trials, resist the motion of knee flexion to the best of your ability. Do you understand? Do you have any questions?

Appendix IX:
Biodex Protocol One

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

Description/ Title: Will Thesis Isokinetic One
Mode: Isokinetic

Joint: Knee	Pattern: Extension/Flexion
Contraction Direction: concentric/eccentric	Unilateral
Number of Sets: 2	End by Repetitions: 10
Speeds: 60^{o}/sec, 300^{o}/sec	Anatomical Reference: 90
Contraction Time: 5 seconds	Rest Time: 180 seconds
Attachment Sensitivity: 1-Knee	Cushion: 5
End by: Repetitions	Torque: 30 (default)

After selecting the protocol and positioning the participant on Biodex seat, range of motion is set for "away" and "towards". After selecting "Go", the screen will read, "Begin Trial Reps". Upon clicking "close", the participant will be instructed to perform five submaximal repetitions to become familiarized with how the machine works[20] at the pace of the trial. After 10 eccentric, isokinetic repetitions at 60^{o}/sec, the dynamometer stops. The participant will have a 180 second rest period, after which they will be instructed to perform five submaximal repetitions at the pace of the second trial. After 10 eccentric, isokinetic repetitions at 300^{o}/sec, the dynamometer stops. During both contractions, the participant will be verbally encouraged.

Appendix X:
Biodex Protocol Two

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

Description/ Title: Will Thesis Isokinetic Two
Mode: Isokinetic

Joint: Knee	Pattern: Extension/Flexion
Contraction Direction: concentric/eccentric	Unilateral
Number of Sets: 2	End by Repetitions: 10
Speeds: 300^{o}/sec, 60^{o}/sec	Anatomical Reference: 90
Contraction Time: 5 seconds	Rest Time: 180 seconds
Attachment Sensitivity: 1-Knee	Cushion: 5
End by: Repetitions	Torque: 30 (default)

After selecting the protocol and positioning the participant on Biodex seat, range of motion is set for "away" and "towards". After selecting "Go", the screen will read, "Begin Trial Reps". Upon clicking "close", the participant will be instructed to perform five submaximal repetitions to become familiarized with how the machine works[20] at the pace of the trial. After 10 eccentric, isokinetic repetitions at 300^{o}/sec, the dynamometer stops. The participant will have a 180 second rest period, after which they will be instructed to perform five submaximal repetitions at the pace of the second trial. After 10 eccentric, isokinetic repetitions at 60^{o}/sec, the dynamometer stops. During both trials, the participant will be verbally encouraged.

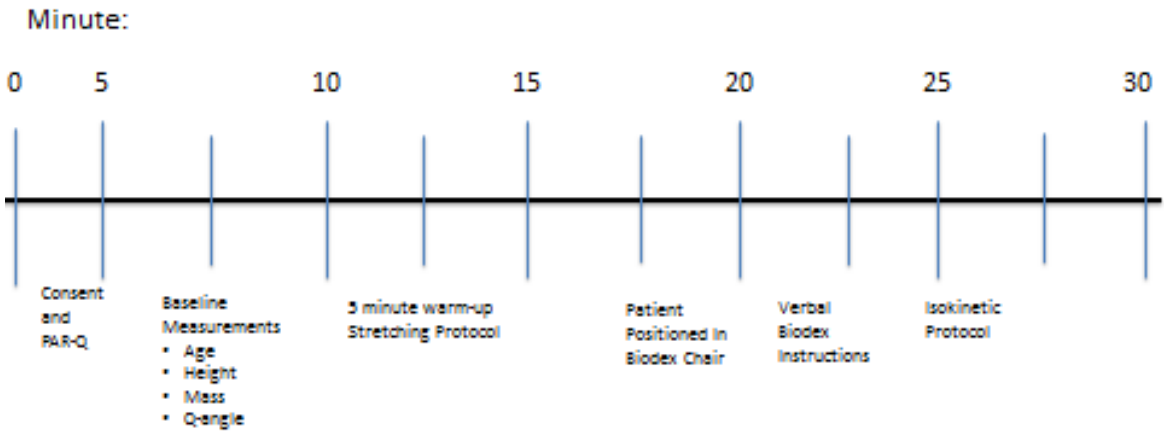
Appendix XI:
Testing Session One

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

Procedure: Biodex Familarization



Appendix XII:
Biodex Isometric Protocol

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

Description/ Title: Will Thesis Isometric
Mode: Isometric
Joint: Knee
Contraction Direction: Away
Number of Positions: 2
Angles: 65^{o}, 30^{o}
Contraction Time: 5 seconds
Attachment Sensitivity: 1-Knee
End by: Repetitions

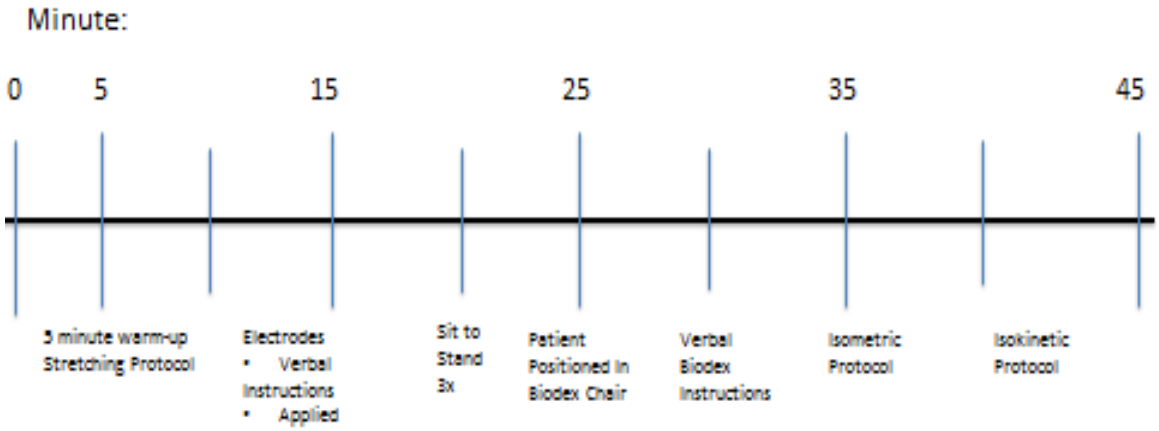
Pattern: Extension/Flexion
Unilateral
End by Repetitions: 1
Anatomical Reference: 90
Rest Time: 180 seconds
Cushion: 5

After selecting the protocol and positioning participant on Biodex seat, range of motion is set for "away" and "towards". The participant is placed at 65^{o} of knee flexion, as indicated on the System 3 Software identifying "position". The knee is kept in this position by pressing the "hold & resume" button on the dynamometer. After selecting "Go", dynamometer will self-adjust to be sure position is correct. The screen will read, "Begin Trial Reps". Upon clicking "close", test begins. After a 5 second isometric contraction, the dynamometer re-adjusts to 30^{o} knee flexion, and a second isometric test is performed. During both contractions, the participant will be verbally encouraged.

Appendix XIII:
Testing Session Two

DIFFERENCES IN ACTIVATION TIMING AND STRENGTH BETWEEN THE VASTUS MEDIALIS OBLIQUUS ANS VASTUS LATERALIS DURING ECCENTRIC, ISOKINETIC EXERCISE

IRB # 021312

Principle Investigator: Dr. Mary Barron
Sub Investigator: Erin Will
Sponsor: George Washington University, Department of Exercise Science

Procedure: Data Collection