

Effects of Foot Position during Squatting on the Quadriceps Femoris: An Electromyographic Study

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ABSTRACT

International Journal of Exercise Science 6(2) : 114-125, 2013. Weightlifters have commonly believed that changing joint position can alter specific muscle activation. The magnitude of force produced by a muscle is highly dependent upon the length of the muscle. The purpose of this study was to determine the effect of foot positioning on muscle activation of the superficial quadriceps as measured by surface electromyography (sEMG) during a functional squatting movement in healthy adults. Twenty physically active asymptomatic adults (7 females and 13 males) were included in the study while four different foot positions (Neutral, Internally Rotated, Externally Rotated, and Staggered) were assessed. Three quadriceps muscles (Rectus Femoris (RF), Vastus Medialis Oblique (VMO), and Vastus Lateralis Oblique (VLO)) were measured. Raw EMG was transformed using a root mean square algorithm. Six one-way repeated measure ANOVAs were conducted to examine the peak and average RMS amplitude for each muscle across each condition, with an alpha level of 0.05 set a priori. Across all foot positions only the Staggered foot position reached statistical significance when compared to all other foot positions for each muscle group. Results suggest that altering the foot position during a partial weight squat has little to no effect on the EMG amplitudes of the quadriceps. However, more research is needed to examine the concentric and eccentric phases of the squatting motion separately with the addition of full weight bearing squats.

KEY WORDS: Length tension, Q-angle, quadriceps angle, lower extremity biomechanics

INTRODUCTION

Weightlifters have commonly believed that changing joint position can alter specific muscle activation (16). Changing joint position can alter the line of pull of the muscles (16, 18), altering the natural length

tension relationship of the muscle (3). The length tension relationship is a biomechanics principle where variation in muscle tension occurs due to changes in muscle length. The length of the internal muscle fibers, which are the actin and myosin filaments of the sarcomere,

determines the magnitude of force produced by that muscle fiber and ultimately the whole muscle (1, 3). Higher magnitudes of force are produced when more actin-myosin cross bridges are available (1, 13). Therefore, when the length of the sarcomere produces an optimal number of actin-myosin cross bridges, the highest magnitude of force is produced. However, if the sarcomere is elongated past its optimal range, the magnitude of force will decrease due to a reduced number of actin-myosin couplings (1, 13). As such, a key requirement in exercise related professions is to determine the optimal length tension relationship of muscles to produce the highest magnitude of force.

Previous studies have assessed the length tension relationship of muscles in the lower extremity (LE) by altering the joint position of the ankle, knee, and hip (12, 18, 20, 21). In previous literature, the quadriceps femoris have been used as a common muscle to test the theory of the length tension relationship through modification of foot position during a LE movement (12, 18, 20). Of the quadriceps muscles, the vastus lateralis oblique (VLO), vastus medialis oblique (VMO), and the rectus femoris (RF) comprise the superficial quadriceps femoris (12, 18, 20). These muscles are typically targeted to test the effects of joint positioning effects on muscle force because of their accessibility for surface electromyography (21) and the ability to isolate these muscles by manipulating joint positions of the lower extremity via the ankle, knee, and hip joints. This is particularly useful for lifters and therapists who, in theory, could isolate different muscles of the superficial quadriceps through manipulation of foot position during a squatting activity. For

example, a person suffering from Patellar Femoral Pain Syndrome (PFPS) could attribute the syndrome to muscular imbalances between the VLO and the VMO (6). In order to reduce imbalances and promote symmetry; foot position could be changed during squatting exercises to isolate either the VLO or VMO and promote strengthening of the weak muscle without over strengthening the other.

Previous research suggests that muscle isolation of the quadriceps femoris is possible (18, 20), but findings have been based on non-weight bearing activities. Signorile, Kacsik, Perry, Robertson and Williams (1995) determined that by changing the foot position during an isometric constant resistance exercise, the specific muscles of quadriceps femoris could be isolated to produce higher muscle activation in an Internally rotated foot position (TI) when compared to an Externally rotated (ET) and neutral position (18). Signorile et al. found that the VMO and VLO produces the greatest magnitude of normalized RMS EMG while in the neutral foot position through a range of 90° to 150° of knee flexion (18). Though, in comparison, the VLO was shown to have a greater activation than VMO across all foot conditions. In contrast, the RF demonstrated similar magnitudes of RMS EMG in all three foot positions (TI, neutral, and ET) through a range of 90° to 150° of knee flexion (18). Interestingly, the greatest magnitude of activity for all three muscles, VMO, VLO, and RF, occurred in the Internally rotated foot position while in 175 ° of knee flexion. Of particular importance was the similar muscular activation of the VMO and VLO in the Internally rotated foot position during the 175 ° of knee flexion, where both muscles demonstrated

near normal amplitude values (18). These authors concluded that in the early stages of knee rehabilitation, training in the Internally rotated foot position could reduce the amount of patellar pressure, reduce the risk of injury, and potentially enhance muscular strengthening, promoting muscular symmetry of the VMO and VLO (18). Stoutenberg, Alessandra, Fangchao, Jennifer, and Signorile (2005) attempted to test the theory of Signorile's earlier work by replicating the methodology of their study (20). Stoutenberg et al. found that when the leg was medially rotated (equivalent to an Internally rotated foot position) the VLO and VMO demonstrated the highest amount of muscle activation as measured by normalized RMS EMG, compared to the laterally rotated position (20). Furthermore, they found that lateral rotation (equivalent to an external foot position) of the leg produced the highest amount of RF normalized RMS EMG muscle activation when compared with the medially rotated position. Together the results of Stoutenberg et al. (20) and Signorile et al. (18), suggest that changing the foot position does have an effect on the magnitude of quadriceps muscle activation. However, a limitation of these previous studies was that both studies performed activities that were non-weight bearing. Therefore the question as to whether the quadriceps femoris respond differently to foot position during weight bearing activity still remains to be answered

Hung and Gross (1999) addressed alternation of foot positioning during a weight-bearing squat (13). They suggested that there are no statistically significant differences found between the VLO and the VMO for slight Internally and slight

Externally rotated foot positions when compared to neutral foot positions. Hung and Gross assessed different foot positions during squatting using a wooden wedge placed under the participant's feet (13). The addition of the wooden wedge would force the ankle complex into plantar flexion thus preventing activation of the gastrocnemius-soleus muscle complex. Removing activation of the gastrocnemius-soleus muscle complex from the squat movement would reduce the stability of the lower extremity. Reduced stability could place additional stress on the quadriceps femoris and potentially inflate the muscle activation required to perform the movement (13). Additionally, Hung and Gross did not record how the RF activated during this squatting technique.

While the non-weight bearing isokinetic and isometric exercises in the aforementioned research suggest that changing foot position will effect quadriceps activation, strength training and rehabilitation experts have placed a greater emphasis on functional weight bearing exercises (8, 16). The squat is an excellent determinant of lower extremity strength and a functional movement of everyday life due to its replication in activities of daily living such as a sit to stand (1, 8, 16). Squats have been used in prior research to determine lower extremity strength (1, 8, 16, 17, 18, 20). Strength and conditioning experts can agree that a standardized squatting posture (feet shoulder width apart) will increase strength and decrease the potential for injury (1, 2, 8). However, rarely does a human perform the proper lifting position when lifting an object in daily life (9,10).

The purpose of this study was to determine the effect of foot positioning on muscle activation of the superficial quadriceps as measured by surface electromyography (sEMG) during a functional squatting movement in asymptomatic healthy male and female adults. It was hypothesized that changing the foot position during a functional weight bearing squat motion would influence activation of the superficial quadriceps. Specifically, an Internally rotated foot position would result in higher muscle activation of the VLO, an Externally rotated foot position would result in higher muscle activation of the VMO, while a Staggered foot position would result in higher muscle activation of the RF. Additionally the Staggered foot position would demonstrate the highest muscle activation overall.

METHODS

Participants

Subjects were recruited via email, upon prior approval by the instructor of the course, and by the principal investigator. This study was approved by the Institutional Review Board (IRB) of San Diego State University. All subjects signed a written consent prior to all data collection. Twenty physically active asymptomatic adults (7 females and 13 males; Mean \pm SD, 23.45 \pm 2.94 years; range = 20-33 years) were included in the study. Subjects were not included in the study if they were not physically active twice a week with a minimum of six months of weight lifting experience. Subjects were recruited from a pool of approximately 300 students at San Diego State University from the Exercise and Nutritional Sciences Department. Subjects were asked by the investigators if they had previous lower extremity injury or

pain in the last 6 months and subsequently subjects were not included in the study if they responded yes to the aforementioned questions. Subjects completed an informed consent and received instruction in regards to the data collection process.

Protocol

Measurement: For the electromyography (EMG), surface electrodes were attached at the distal 1/3 of the muscle belly to measure muscle activation (12, 13, 21). The electrodes used were Ag/AgCl with an inter-electrode distance of 1.5 cm to reduce cross-talk and maximize the differential amplification process (12, 13, 21). Prior to placement of the electrodes, the subject's skin was cleansed with alcohol to reduce impedance excess hair was removed to eliminate shifting of the electrodes, if needed. Electrodes were placed by palpation over the distal 1/3 of the muscle belly (12, 13, 21) the superficial quadriceps muscles (Vastus Medialis Oblique (VMO), Vastus Lateralis Oblique (VLO), and Rectus Femoris (RF) using placement charts by Noraxon (Noraxon USA, Inc. Scottsdale Az 2008). The ground electrode was placed on the patella or the medial tibial joint line. To retain consistency between measurements, all electrodes were attached to the right leg of the subject.

Noraxon software and hardware (Telemyo 2400R, and MyoResearch XP version 1.06 software (Noraxon USA, Inc. Scottsdale Az) were used to acquire, process, and measure the EMG activity of the subjects. An electric goniometer was attached to the lateral aspect of the knee prior to collection to determine the knee joint angle of the subject during testing (Noraxon USA, Inc. Scottsdale AZ).

EFFECTS OF FOOT POSITION DURING SQUATTING: AN EMG PERSPECTIVE

Conditions: Subjects performed functional squats, at their own pace, on a Power Tower (EFI, San Diego CA), a partial weight bearing squat machine. The Power Tower was used for its mechanical design where the subject lies on a sliding board that is supported with a fixed footplate allowing a fluid squatting motion and controlling for any abnormal or exaggerated hip movement. The Power Tower was set at an inclination of 35° relative to the ground. This inclination angle uses gravity and the subject's body weight to apply approximately 55% of the each subject's own body weight.



Figure 1. Neutral foot position.



Figure 2. Internally rotated foot position (TI).

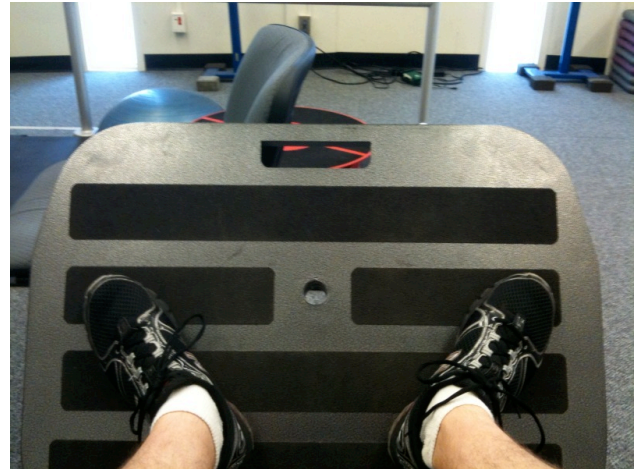


Figure 3. Externally rotated foot position (ET).



Figure 4. Staggered foot position.

Neutral positions were performed with the legs at shoulder width apart and the toes pointed forward at a 90 degree angle (Figure 1). The TI condition (Figure 2) was where the toes were rotated to the maximal position that was considered comfortable for the subject while performing the full range of motion of the squat. ET (Figure 3) was the opposite of the TI condition, with the same parameters as the TI condition. The Staggered position (Figure 4) the right leg was placed toe to heel of the left foot (legs being shoulder width apart) while the right leg was the main weight bearing leg and the left leg is the guiding/support leg. A one legged squat (Figure 5) was used for

normalizing the EMG data instead of using a maximal voluntary contraction. The one legged squat was performed by the subject by placing the left leg on the slide board next to the individual's body and the right leg on the middle of the fixed platform.



Figure 5. One legged squat foot position.

All conditions were completed on the Power Tower with five repetitions per condition with the subject squatting to 90 degrees of flexion around the knee joint. Each subject was given two minutes rest and recovery time after each condition was completed, and if any subject's EMG data collected during a trial was considered not acceptable by the trained rater, than a potential extra repetition was performed by the subject at the trained rater's discretion and was notated. An unacceptable trial was considered when any additional noise in the EMG signal was observed, or improper squatting technique.

EMG Analysis: EMG data were processed using MyoResearch XP version 1.06 software (Noraxon USA, Inc. Scottsdale, AZ). Raw data were initially preamplified (gain of 500) and filtered with a band pass filter (10-500Hz), and then digitized using a 12-bit A/D converter at a sampling rate of

1500Hz, and with a CMRR > 100dB. An additional gain of 500 was applied to the data and smoothed using the root mean square of the full squat motion (concentric and eccentric phases) of the exercise with a window of 20ms (12, 18, 20). The peak RMS EMG value was determined during a 150ms window of the knee's peak flexion as determined by the electric goniometer. The average RMS EMG value was determined from the average of the full concentric and eccentric squat. Each subject's individual muscle EMG values for peak and average (VLO, VMO, and RF) were normalized to the one legged squat condition EMG value (Figure 5) respectively and expressed as a percentage of the one legged squat condition. Normalizing the EMG based on a percentage of the one-legged conditions allows for comparison of the three different muscles.

Statistical Analysis

Six different repeated measures analyses of variance (RM ANOVA) were run for the average and the peak muscle EMG results comparing a muscle's response over the four different double leg foot conditions. Hence, there were three RM ANOVA for each muscle, testing peak EMG and an additional three RM ANOVA for each muscle testing mean EMG. The repeated measures consisted of the four different foot positions. A base alpha level of 0.05 was set a priori to determine significance. Post hoc Bonferroni tests were used for further analysis due to the test's ability to adjust multiple comparisons and correct the alpha level as needed.

RESULTS

A significant main effect was found for VMO average activity ($F(3, 57) = 24.177, p$

< 0.001, $\eta^2 = .560$). Follow up Bonferroni comparisons revealed that the Staggered foot position yielded significantly greater VMO muscle activity than the neutral position ($p < 0.001$, 95% CI $_{\Delta}$.088 to .272), Internally rotated position ($p < 0.001$, 95% CI $_{\Delta}$.114 to .293), and Externally rotated position ($p < 0.001$, 95% CI $_{\Delta}$.105 to .312) (Figure 6). For VMO peak activity, a significant effect of foot position was also found ($F(2.056, 39.067) = 6.248$, $p < .004$, $\eta^2 = .247$). Follow up Bonferroni comparisons revealed that the Staggered foot position elicited significantly greater muscle activity than the TI position ($p = 0.005$, 95% CI $_{\Delta}$.031 to .212) and the ET position ($p = 0.038$, 95% CI $_{\Delta}$.006 to .271) (Figure 6). No significant differences between the TI, ET, and neutral foot positions were observed for average and peak VMO.

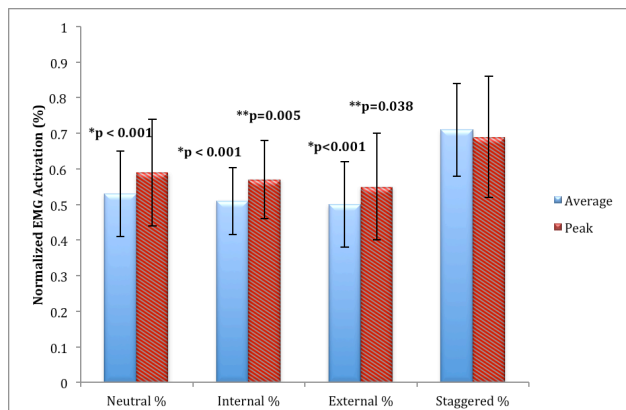


Figure 6. VMO average and peak % one leg muscle activation statistical significance. Note: * = statistical significance from the % staggered position VMO average; ** = statistical significance from the % staggered position VMO peak.

For VLO average activity, a significant main effect was observed ($F(2.621, 49.794) = 20.248$, $p < 0.001$, $\eta^2 = .516$). Follow up Bonferroni comparisons revealed that the Staggered foot position resulted in significantly greater muscle activity than the neutral position ($p < 0.001$, 95% CI $_{\Delta}$.087

to 2.60), TI position ($p < 0.001$, 95% CI $_{\Delta}$.094 to .289), and ET position ($p < 0.001$, 95% CI $_{\Delta}$.090 to .301) (Figure 7). For VLO peak activity, a significant effect for foot position was revealed ($F(3, 57) = 6.853$, $p < 0.001$, $\eta^2 = .265$). Follow up Bonferroni comparisons revealed that the Staggered foot position provided significantly greater muscle activity than the ET position only ($p = 0.018$, 95% CI $_{\Delta}$.019 to .260) (Figure 7). No significant differences between the TI, ET, and neutral foot positions were observed for average and peak VLO.

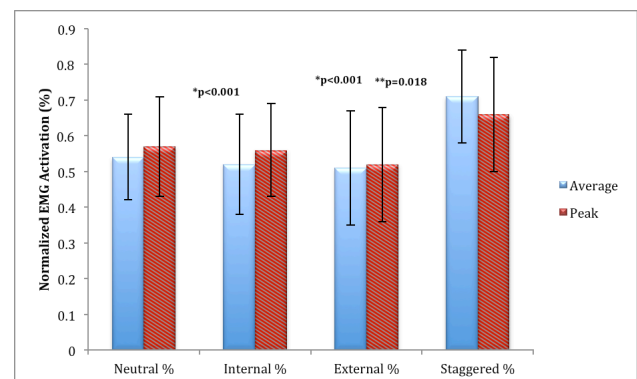


Figure 7. VLO average and peak % one leg muscle activation statistical significance. Note: * = statistical significance from the % staggered position VLO average; ** = statistical significance from the % staggered position VLO peak.

For RF average activity, a significant main effect was revealed ($F(1.762, 33.469) = 9.224$, $p < 0.001$, $\eta^2 = .327$). Follow up Bonferroni comparisons revealed that the Staggered foot position elicited significantly greater muscle activity than the neutral position ($p < 0.001$, 95% CI $_{\Delta}$.132 to .412) and the TI position ($p < 0.001$, 95% CI $_{\Delta}$.161 to .411) (Figure 8). For RF peak activity, a significant effect for position was revealed ($F(1.694, 32.184) = 3.803$, $p = 0.039$, $\eta^2 = .167$). Follow up Bonferroni comparisons revealed that the Staggered foot position yielded significantly greater muscle activity than the neutral position ($p = 0.012$, 95%

CI_Δ .028 to .293) and TI position ($p < 0.001$, 95% CI_Δ .085 to .350) (Figure 8). No significant differences between the Internally, Externally, and neutral foot positions were observed for average and peak RF.

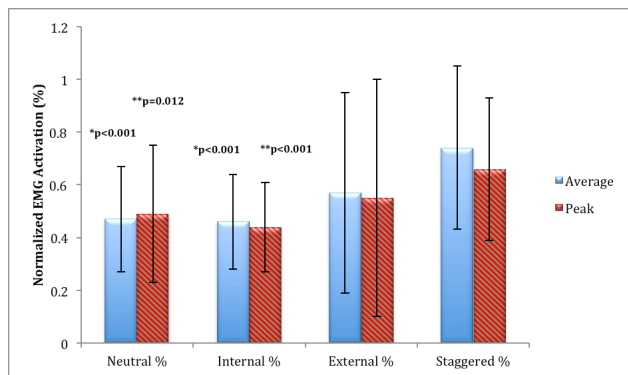


Figure 8. RF average and peak % one leg muscle activation statistical significance. Note: * = statistical significance from the % staggered position RF average; ** = statistical significance from the % staggered position RF peak.

DISCUSSION

The purpose of this study was to determine the effect of foot position on muscle activation of the superficial quadriceps as measured by electromyography (EMG) during a functional squatting movement in asymptomatic healthy male and female adults. The results suggest that altering foot position, to a Staggered foot position, during a partial weight squat on a Power Tower has an effect on the EMG amplitudes of the quadriceps. For all muscles measured the Staggered position was the only position determined to have significantly greater muscle activity from neutral in both average and peak RMS magnitude. Greater muscle activity during a Staggered squat was expected as the foot position during Staggered stance should activate the quadriceps femoris similar to a single leg squat. This is due to the high amount of weight applied upon the back leg (support

leg) of the Staggered position. Therefore, the amount of muscle activation from the support leg should increase when compared to a symmetrical double leg squat.

We hypothesized that the VMO would demonstrate the highest muscle activation in the Externally rotated position. When the foot was Externally rotated, the VMO should be at an optimal length tension relationship and therefore produce the highest activation magnitude (19). However, we did not observe this; instead we found that only the Staggered foot position resulted in significantly greater VMO activity when compared to a neutral foot position. Therefore, our hypothesis was not supported. These results also do not support prior research that the neutral foot position produces the greatest amount of muscle activity in the VMO (18, 20). One possible explanation of this unexpected result is that an over elongation of the VMO in the external rotation position occurred which could lead to less force coupling reactions inside the sarcomere (1). If the Staggered position is not considered, the neutral foot position responded similarly to prior research in regards to the VMO (18), however no statistical significance was determined to support this claim. It is unclear to the researchers why this occurred but a random error within the measure could have attributed to this effect or a decrease of the amplitude due to the inclusion of the concentric and eccentric phases of the squat. Furthermore, significance could have been nullified by the combination of the concentric and eccentric phases of the squat (see Figure 6).

The VLO average reached significance for the Internally, neutral, and Externally foot

positions when compared to the Staggered foot position. This average muscle activation is similar to the VMO average data. Due to the similarities between the VMO and VLO muscles, comparable results for the VLO average muscle activation were expected. Surprisingly, no significance was achieved between the Internally rotated foot position and the neutral or external foot positions given prior research findings (18, 20). Prior research suggested that in the Internally rotated position, the VLO activated the highest and reached statistical significance from the other positions. The researcher's speculation is that VLO and VMO were elongated beyond the optimal length tension relationship (1). Therefore, the muscle activation was considerably lower across the foot conditions (Figure 7).

The VLO peak muscle activation achieved significance when in the external foot position compared to the Staggered foot position. The muscle activation is explained by the higher amount of tension in the VLO muscle group due to the VLO fiber orientation laterally to medially in an oblique pattern. However, no significance was determined when comparing the Internally rotated position and other foot positions, therefore not supporting prior claims and our hypothesis. Exaggerated Q-angles could have contributed to the change and the observed reduced muscle activation due a potential over elongation of the muscle fibers.

Alternatively, examining prior research, both Signorile et al. (18) and Stoutenberg et al. (20) performed open kinematic chain exercises. In an open kinematic chain leg extension the distal portion of the leg is free to move in space and causing the tibia to move superiorly in relation to the femur.

When the distal segment is not fixed, greater tibial rotation occurs in full extension when compared to the distal segment being fixed, and thus the musculature activation could have been altered. Our subjects performed a closed kinematic chain squat were the distal portion of the leg was fixed and the femur moved inferiorly in relation to the tibia. Due to the knee joint's complex convex-concave relationship the muscle activation of the quadriceps femoris could have been affected. The researchers support this finding that muscular contractions and activity change given if the motion is an open or closed kinematic chain movement.

The RF average and peak data displayed similar results. Significance was reached when comparing the neutral and Internally rotated foot position to the Staggered position. Thus, our hypothesis was partially met when the foot was in an external rotation, the average and peak results had no significance across all conditions. Additionally, Signorlie et al. (18) suggested that the RF activates the greatest in the Internally rotated foot position and Stoutenberg et al. (20) suggested that the RF activates the greatest in the external foot position. However our study demonstrates that no statistical significance was found to support either trend in the prior research (18, 20). Due to the RF being the only biarticulate muscle of the quadriceps femoris, when the foot was Externally rotated the hip was placed in an Externally rotated position and potentially activating the RF maximally, yet no significance was determined. Additionally due to the high standard deviations reported for the RF averages and peaks, error can be a factor in the results determined (Figure 8). It is the suggestion of the authors that if the

standard deviations or potential error caused by the variability between subjects was decreased, or increased power of the sample size, significance could be determined in the Externally rotated foot position when compared to the Internally rotated and neutral foot positions.

From the data presented, it can be suggested that during a partial weight bearing squat with alternating foot positions, maximal muscle average and peak activation for the quadriceps femoris occurs in a Staggered position. Altering the foot position (Internally or Externally rotation) demonstrated little to no effect upon the quadriceps femoris. When the foot is in a displaced position (Staggered), a higher amount of muscle activation occurs. The higher muscle activation is likely due to the increased weight placed upon the back leg or support leg. Even though, no statistical significance was found when comparing the alternate foot positions (neutral, TI, ET) for each muscle group, this does not discount training in these positions. When a person is training during the early stages of rehabilitation it is good to mimic functional movements; training the body while in different foot positions could potentially prepare the LE to support the body while moving in unpredictable manners.

Squatting in a Staggered position could be a possible modality to train a single limb of the LE before the more progressive single leg squat are performed. Adding to the body of literature in rehabilitation, if one trains in a Staggered squatting motion, it could help reduce muscular imbalances, promote symmetry, and to strengthen the quadriceps femoris (1, 5, 6, 18). However, findings of this study suggest that one

cannot train in a squatting motion with an Internally or Externally rotated foot position to increase muscle activation in the VMO to decrease imbalances when compared to the VLO.

A study is only as strong as its limitations and errors. In this study multiple factors could have contributed to mixed results. The subjects in the study could have participated in the study after an exercise workout and did not report this to the researcher. Additionally, the Q-angle of the subjects was not measured. If exaggerated Q-angles were present in the subjects, muscle activation could have been altered for the subjects, specifically in the VLO, which would lead to a change in the overall group mean muscle activation. Lastly from the different squatting exercises performed in the study, a fatigue effect could have been introduced and could potentially inflate the muscle activation.

This study was considerably limited, but further research could expand the methods of this study to potentially observe different results. If the EMG muscle activation was examined in the concentric and eccentric phases of the squat motion separately, potential differences could emerge. Additionally, the squat technique was a partial weight bearing activity. By allowing the subject to bear full weight or additional weight during the squatting exercises, other findings could be expressed. Another expansion of this study could be to rotate the foot position Internally and Externally while in a Staggered position and observe any differences. Lastly, the specific muscles of the quadriceps femoris have been observed in previous literature to have different onset timings while performing motion. Further research could examine

this relationship and suggest possible onset muscle activation differences.

Overall, there was no difference in muscle activation of the quadriceps femoris when the foot is in a neutral, Internally, or Externally rotated positions. Only in a Staggered foot position can muscle activation increase due to the highest amount of EMG muscle activation of the quadriceps femoris. Therefore training in a Staggered foot position could impact muscle activation. The hypotheses were not met for this study, but alternate effects were determined. This research suggests that closed and open kinematic chain movements activate the quadriceps femoris differently given the differing results by prior researchers (18, 20), and further investigation is needed to support which style of exercise is best suited for rehabilitation purposes to reduce muscular imbalances that lead to PFPS. Limited generalizations can be made due to the limited sample size and population that was used in our study. Future research is warranted to extrapolate further the significance found in our study.

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