THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF KINESIOLOGY

A COMPREHENSIVE COMPARISON OF KINEMATIC, EMG, AND GROUND REACTION FORCE ACTIVITY DURING 5 DIFFERENT LUNGING TECHNIQUES

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Summer 2013

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Kinesiology
with honors in Kinesiology

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ABSTRACT

The purpose of this study was to compare muscle EMG activity and ground reaction forces at the patellofemoral joint during different lunge techniques; the dynamic forward stepping and dynamic backward stepping were compared while the basic static lunge, basic static lunge with an external load, and curtsey lunge were compared. It was hypothesized for the dynamic conditions to exhibit similar EMG activity in all of the muscles, while the ground reaction force would be higher in the forward stepping lunge. It was also hypothesized all the static lunge conditions will have not significantly different EMG activity but there will be a significant difference in the ground reaction forces, with the curtsey lunge having the highest force experienced. Eight, four male and four female, active college students completed 5 different lunge techniques (forward stepping, backward stepping, static, static with external load, and static curtsey) with both the right leg and left leg as the lead leg. While this was correct, the ground reaction force data, although higher for forward stepping vs. backward stepping, was not significant. The ground reaction forces experienced in the static lunge conditions were highest for the static plate and lowest for the basic static lunge (Figure 10). Once again although higher, the force exerperinced via the curtsey lunge was not significant in comparison to the basic static lunge (Figure 21). The hypothesis of the similar EMG activities, with the gluteus maximus and rectus femoris being the dominant muscles in each condition as seen in Figures 2, 3, 13, and 14, was confirmed. The VL and ST had consistent EMG activity in each lunge condition, while the BF activity was almost half as low as the RF activities in some cases; this supports previous findings of the BF co-contracting with the RF during the lunge, which is speculated to help stabilize the lower extremities.

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Chapter 1: Introduction

The lunging exercise is one technique used in rehabilitation to prevent lower extremity injuries from occurring by strengthening the leg musculature after injury, after surgery, or even as a tool to prevent injury at the hip or knee. Every year thousands of lower extremity injuries occur, and can be partially attributed to muscle weakness[7,12,13,38]. Lunging, whether it is a dynamic stepping backwards lunge, a dynamic stepping forwards lunge, a static lunge, or most recently a static curtsy lunge – where the non-lead leg is placed behind and to the one side of the lead leg as seen in Figure 1 – are all popular techniques for elite athletes training to build lower extremity muscle endurance. This exercise is also implemented to various rehabilitation programs when the lower extremities are involved. One concern for both athletes and rehabilitation patients alike is safety; the prevention of knee problems is imperative with the amount of stress placed on the patellofemoral joint in both of these environments. Based on the angle and/or phase the knee is at during a specific lunge, there are different forces at the patellofemoral joint and different muscles utilized, which will be explored throughout this chapter.

The Static Lunge

A universal, widely known technique of lunging is the static lunge. The static lunge requires the individual to start with legs shoulder width apart, then step one leg out about two to three feet in front of the other. The back leg's heel will then come off the ground, so that the individual is balancing on his/her posterior leg's toes. Keeping the torso in an upright position, the individual bends both knees, descending the body downward, until the front leg is at a 90 degree angle. The anterior thigh is parallel to the ground, and the posterior shank is parallel to the ground, about 6 inches from the ground (Figure 3). At this point, the individual then pushes up with the leading leg to ascend and return to an extended position[34,35].

The gluteus maximus (GM), bicep femoris (BF), gastrocnemius, and rectus abdominus (RA) have all been shown to be activated during a forward static lunge[2,3,4]. This co-activation of several muscle groups, which is seen in many closed-chained kinetic exercises like the lunge[44], helps to not only strengthen these muscles responsible for the hip and knee joint, but it also helps to improve the balance of the individual[36]. A closed-chained kinetic exercise is when the extremity (like the leg) is in constant contact with an immovable surface, such as the ground, and the extremity is therefore fixed in space. This is seen in the lunge, squat, and deadlift, with co-activation being seen during these exercises as the joint is rotated. Co-activation between the hamstrings and quadriceps has been seen to be at a peak activity level when the lead leg is in a flexed position [38]. Both the GM and the RF have also been shown to have higher activities, especially during the concentric phase of the lunge[47].

While building muscle activity through co-activation is a positive of the lunge exercise, the deterrent of the lunge for some individuals is the loading on the patellofemoral joint. The lunge exercise, in comparison to a power squat and to a front squat, has also been seen to have a higher posterior shear (the tibia force on the femur) and higher extensor moments. This increase in shear in turn can cause an increase in the force experienced at the patellofemoral joint because of how the tissues move in relation to each other during this exercise. The extensor moments were significantly higher when the posterior knee was flexed at 90 degrees during descent in comparison to both exercises, and significantly higher at 60 degrees of descent in comparison to the front squat, showing the extensors are more active at these specific timse[37]. There is also evidence supporting that an increase in muscle moments is also seen with an increase in external load[33].

An increase in joint compression forces at the knee joint are also seen during the static lunge. The quadriceps muscles produce force in order to extend the leg, which in turn causes a compressive force at the patellofemoral joint. This small area (patellofemoral joint) and high force from the contracting muscles during extension causes significant reaction forces at this joint. These compressive forces at the knee joint increase as the knee flexes from 0 degrees to 75 degrees and 90 degrees. For knee extension during a lunge, the peak patellofemoral force was noted between 90-75 degrees during the ascent phase[18].

Lunge Variations

If the static lunge was the only variation for lunging, clinicians and trainers would not have a problem prescribing protocols based on the known research. However, in today's fitness industry, there are several different lunging techniques employed. This study will examine five of the most common types of lunging situations: the static lunge, the forward stepping lunge , the backward stepping lunge, the curtsey lunge, and the static lunge with an external load. The forward and backward stepping lunges are both dynamic lunges (Figure 3 and 4). They require the individual to start with legs shoulder width apart and then step either forward or backwards assuming the same position as the static lunge, lunge down and extend up, then return to the original position. The curtsey lunge, which is a static lunge technique, requires the individual to step his lead leg across the other leg, at the same width (about a stride length) as is described for the static lunge (Figure 1). Once in this position, the participant would lunge down to 90 degrees for the posterior leg, and extend back up then repeat. For all lunges the feet, knees, and torso were instructed to be kept facing forward throughout the lunge. The static lunge with a plate followed the same protocol as described for the static lunge above, except a 10 lb. weight is held at collarbone level, with arms perpendicular to the ground (Figure 5).

This study will investigate which technique of the lunge should be used when working with a specific population. Although it has been observed the overall muscle activity during a static/dynamic forward stepping lunge, it has yet to been seen the different activities during the descent and ascent phase of different lunging techniques. Both the dynamic forward stepping lunge and the static lunge are mostly a hip-extensor dominated exercise in healthy young adults, with little to no kinematic change once an external load is added[2]. The gluteus maximus, gastrocnemius, and rectus abdominus (RA) have all been shown to be activated during a forward static lunge[2,3,4]. Along with the above muscles, the vastus lateralis (VL), vastus medialis (VM), and biceps femoris (BF) are also all activated as a unit throughout the dynamic forward stepping lunge[5].

Another concern of which lunge technique to use with a specific population also arises when it pertains to forces on the patellofemoral joint. Different factors such dynamic or static lunges[17,18], trunk position[19,20], and what plane the lunge is completed in[18] has been shown to effect the forces experienced at the knee joint. Many studies have been done to start employing their findings of the forward, and the less commonly used side lunge in rehabilitation techniques. The static forward lunge has been shown to have the greatest motion at the knee joint, but when external loads are added the greatest kinetic force changes were seen at the hip and ankle joint and not the knee joint[1]; this change is seen in order for the body to keep the trunk upright and keep the body balanced. Similar observations have also been made in regards to what angles are appropriate for least amount of compressive force at the patellofemoral joint. Escamilla et al[21] found that side lunges had a greater compressive force than a forward lunge only at angles 80-90 degrees, showing similar loading at other angles. Escamilla et al.[18] also discovered that in order to minimize stress on the patellofemoral joint it is more beneficial to lunge with a longer step and without a stride (static position), in comparison to a shorter step and with a stride, specifically at 0 – 50 degrees of flexion. It was also seen that the first situation, a longer step without a stride, exhibited a lower joint force and stress magnitude on the knee[18]. In terms of ground reaction forces, the dynamic forward lunge showed a significantly higher peak force during the ascent phase at specifically between 10-40 degrees of flexion when compared to static lunging[17].

Practical Implications

Studies have shown that lower extremity injuries can be attributed to weak hip musculature. This is seen in individuals that have patellofemoral syndrome[7,8,9] and iliotibial band sydrome[10] with hip abductor weakness, and in females that exhibit patellofemoral joint pain with weak hip extensors, hip abductors, and hip external rotators[9,11]. Hip weakness, in some cases, has been seen to cause the gluteus maximus to be recruited to compensate for the weak musculature[7]. Other injuries due to muscle weakness in the lower extremity are hamstring strains due to hamstring weakness[12], and osteoarthritis due to quadriceps weakness[13] and/or excessive loading of the joint[14].

One method to prevent such injuries has been to strengthen lower extremity musculature through close-chained kinetic exercise, in order to help stabilize the core due to the co-activation of these muscle groups[3,15]. Other techniques such as plyometric and/or balance exercises, combined with strength training, have been utilized to help improve knee flexion angles to decrease risk of injury, because a decrease in knee flexion allows for less anterior tibial shear[16], which in turn causes less stress on the patellofemoral joint.

While the available literature is prominent for forward lunging static and dynamic techniques with and without weights, backward static and dynamic lunges along with a newer curtsey lunge are sparse. Logically, weight bearing lunges allow for greater muscle activation, in comparison to non-weight bearing

Figure 1: Curtsey lunge positioning.

exercises[6], in order to control the movement of the body. In regards to the backwards lunge, it has been assumed that it requires less loading on the knee joint, with the same muscular benefit, on the joint since has to decelerate his body weight less than in comparison to a forward lunge[23]. It has also been assumed by trainers that the reverse lunge allows the individual to more easily stack his knee joint above the ankle joint when forming a 90 degree angle so that the knee does not go past the toes. It is also speculated that the backward lunge allows for more stability since all the weight is on the stationary leg[24].

The curtsey lunge, although employed and recommended by trainers and fitness magazines alike, has no concrete evidence for kinematic or kinetic information. This motion has been prompted to help tone the legs as a "ballerina" style workout[26,27]. A look at the angle of the knee in the position of the lead leg (as seen above) though raises a red flag for clinicans[28]. The valgus stress on the knee joint can be speculated to be greater at this angle, in comparison to a straight forward lunge. It has been seen that an increased valgus stress/force can be detrimental to an individual; it can cause strains and tears in the medical collateral ligament[29,30], along with bone bruising and lateral meniscal tears[31].

Both of the above mentioned speculations of the backwards static/dynamic lunge techniques and the poor biomechanical angle speculation of the curtsey lunge technique are what this study will be analyzing through this testing. This study aims to find the best lunge technique that will cause the least amount of stress on the knee, between 5 different static and dynamic lunge techniques, while still allowing beneficial muscular activation. By doing so, the goal is to help clinicians and trainers alike by informing them of the best technique on lunging that decreases the force at the knee joint, while still have the same muscular benefits.

Hypothesis

It is hypothesized that the static lunges and the dynamic backward lunges will allow for smaller patellofemoral joint force, while having the same muscle activity in comparison to the curtsey lunge, the static lunge with a plate, and the dynamic forward lunge respectively. A decrease in ground reaction force, due to a decrease in weight acceptance, will decrease the muscle activity of the quadriceps and decrease the knee joint moment.

For the forward dynamic and the curtsy lunges it is hypothesized that, in comparison, a greater ground reaction force will be seen, but with the same muscle activity. For the forward stepping lunge, I speculate this will be due to the acceptance of weight on the lead leg causing the knee flexors and knee extensors to co-contract in order to control the forward stepping motion. For the curtsey lunge, I speculate the increase in force will be due to the severe angle the lead leg patellofemoral joint is kinematically placed at. This will cause the quadriceps muscles to increase in activity in order to extend during the ascent phase, because the weight of the individual is not evenly balanced throughout the lead leg.

Chapter 2: Materials and Methods

Participants

The participants of this study were eight, 4 male and 4 female, relatively active college students. Relatively active was defined as engaging in medium to high strenuous activity levels at least 3 times a week, and for at least 45 minutes each time. The average age of all the participants was 21 years, with height averaging at 1.74 m ± .072m, and weight averaging 73.7 kg ± 13.1kg. The data collection took place at the Pennsylvania State University's Biomechanics lab. Each participant was also required to sign a constant from consistent with the University's guidelines.

Protocol: Pre-Testing

Fifteen kinematic markers were placed to recreate the person's movement throughout the lunge exercise. This 6 camera kinematic motion analysis system is an Eagle Digital Realtime System. Markers were placed on C7 at the base of the posterior neck, on both the left and right hip at the anterior superior iliac spine, and a larger and raised marker at the sacral crest (due to the battery pack being located by the sacral crest). One was placed the left thigh, on both lateral sides of each knee at the fibular head, on the right shank, on both the left and right ankles, specifically at the lateral malleolus, at the heels, on each big toe (1^{st} phalanx), and on the 4^{th} phalanx of each foot. Larger markers were placed on the pelvic region and sacral crest, while smaller, raised markers were placed on the lower extremities. For recording purposes, the kinematic markers on the pelvic region were placed last. Duck tape was used on the shoes and pelvic region to keep the markers attached. Markers placed on the cutaneous surface were held in place by athletic tape.

A Bortec AMT-8 EMG System was used in order to collect the muscle activity of 8 different muscles specifically on the left leg. The tibialis anterior (TA), vastus lateralis (VL), rectus femoris (RF), rectus abdominus (RA), gluteus maximus (GM), biceps femoris (BF), semitendonosis (ST), and lateral gastrocnemius (LG) were all measured via the EMG recordings. Each muscle belly was found by measuring specific distances from the origin region to the insertion region, by palpating the tendons down to the muscle belly, then by marking the muscle belly where the electrode would be placed.

The TA was found by measuring from the margin of the patella to the lateral malleolus, with the muscle belly being about 1/3 down from the patella. This was found by palpating 1/3 of the way down from the patella until the muscle belly could be felt. The VL was found by measuring 3-5cm superior and lateral to the patella. Starting at the superior iliac spine to the superior board of the patella, then palpating the muscle ½ down this line was where the RF was marked. The RA was simply placed 2-3cm laterally to the right of the naval (the participants left lower abdominal). The location of the GM was found by palpating 2cm inferior and 2cm laterally to the waist band of the participant on the left posterior glut. In order to find the ST, the muscle was measured from the ischial tuberosity to the medial epicondyle of the tibia, and the tendon was palpated from the medial head of the tibia to 1/3/½ of the way up the leg. The BF was found by measuring from the ischial tuberosity to the lateral epicondyle of the femur, and palpating for the muscle belly half way between these distances. The LG was measured from the lateral head of the fibula to the heel, with the location of the muscle belly being located 1/3 from the fibula.

Once each muscle belly was found and marked with the black marker, the area was sanded and swabbed with alcohol, in order to remove any dead skin and lotions that would interfere with the adhesive. Two 2cm bipolar electrodes were then placed on these markings in the direction that the fibers of that particular muscle oriented in respect to the insertion site. A single ground electrode was also placed firmly on the left tibia as well. The lead lines, marked for each specific muscle that correlated with that same muscle on the computer system, were connected to each respected electrode. For organizational purposes, the participant was asked to extend his left arm to drape the lead line over it. Once all the electrodes were attached to the line, all the lead lines were placed together against the subject's left hip. Pre-wrap was wrapped around the waste, while the lines were held tightly against the left hip. This was done in order to prevent too much slack on the lead lines, which could cause the subject to get tangled in the lines. Once pre-wrapped, the EMG battery pack was strapped around the participant's waist and the lines were connected to their respective plugs on the battery pack. Lastly, the pelvic kinematic makers were put in place, and secured with duck tape.

Protocol: Testing

Once the EMG and kinematic markers were firmly in place, the participant was then asked to warm up on a treadmill for duration of five minutes at three miles per hour. Once warm, pre-trail testing was administered to confirm the EMG was being recorded correctly. The battery pack containing the connections to the electrodes on the participant was plugged into the lead line that ran to the computer showing the muscle activities. The TA was tested by having the subject rock back onto his heel, and the LG was tested by then instructing him to rock onto his toes. The subject was then told to bring his left leg up to 90 degrees and extend the knee, testing the RF and VL. The subject then flexed his leg (still at 90 degrees) while being told to resist flexion to test the BF and ST. In order to test the GM the subject was asked to place his/her feet shoulder width apart and squat down and stand back up slowly, overemphasizing flexion of the GM by being asked to squeeze firmly at the top of the squat. The RA was tested by having the subject flex his abdominals, and being asked to tighten/flex his abdominal region. He then would lightly hit the top/middle portion of stomach below his rib cage, but above where the electrode was located. If any of the electrodes had uncharacteristic or no muscle activity, the electrode was checked, re-measured, replaced, and rechecked through the same test until the desired muscle activity was found.

Five different lunging techniques were observed in this study: Static, forward stepping, backward stepping, static curtsy, and static with a 10 lb. plate. In the following descriptions, the lead leg was defined as the leg that was bent at a 90 degree angle during the lunge, and the non-lead leg was the leg instructed to have the tibial portion parallel to the floor when the subject was in the downward lunge position. For each lunge the participant was instructed to lunge down so the non-lead leg was practically parallel to the floor, and the lead leg was bent at a 90 degree angle. The lunges were demonstrated by the researcher, and then practiced by the participants two to three times in the same order mentioned above. For uniformity all the lunges were done in the same order, with the left leg as the lead leg first in every trial of lunge, and to the beat of a metronome at 60 Hz. For reference purposes the force plate where the lead leg was placed for any static lunge, where the participant stepped onto with the lead leg for the forward lunge, and where the participant started for the backwards lunge will be called the anterior or first force plate. The force plate where the non-lead leg was placed on any static lunge, where the participant started for the forward lunge, and where the participant stepped onto for the backwards lunge with the non-lead leg is called the posterior or second force plate. Both force plates were 90x60cm force plates, one horizontal and at the other vertical in orientation as seen in Figure 4.

In regards to static lunges, the lead leg was always on the first force plate and the non-lead leg was always on the second force plate for every trial. It is also important to note that any instruction given from the researcher were very limited. The only instruction given for the static lunges (not including the curtsy lunges) was to keep the lead leg knee in line with the ankle, and for the lead leg knee not to go past the toe. Once the trial started for the stepping lunges, no instruction was given. The basic protocol for these particular lunges was taken from Adam Campbell's book The Women's Health Big Book of Exercises[39].

Single Left Leg Static Lunge and Single Right Leg Static Lunge

For all static lunges, the starting position required the participant start on the second force plate, about The participant was asked to stand with his heels 15-25cm from the posterior edge depending on height/leg length. The lead leg was placed forward onto the first force plate with the knee bent to 90 degrees. The non-lead leg was placed posterior onto the second force plate, in a comfortable lunge position. Height was the determining factor for how close the participant was to the first force plate when standing on the second force plate. For the first trial, the left leg was considered the lead leg. The non-lead leg, from the patella to toes, was then rested on the ground with the foot in an extended position, so that the dorsal side of the foot was also rested on the ground. This was called the starting position, as seen in Figure 3 below. Once ready the participant was instructed to move from the starting position to the lunge position. To do this, the participant flexed his non-lead leg ankle causing the knee and tibia portion of the lower leg to come off the ground. This put the participant onto his toes, of the non-lead leg, and into the lunge position, with lead knee still flexed at 90 degrees and the non-lead leg parallel to the ground. The metronome then started at 60 Hz. The first sound indicated the participant to push upward and to almost full extension of the lead leg. The second sound

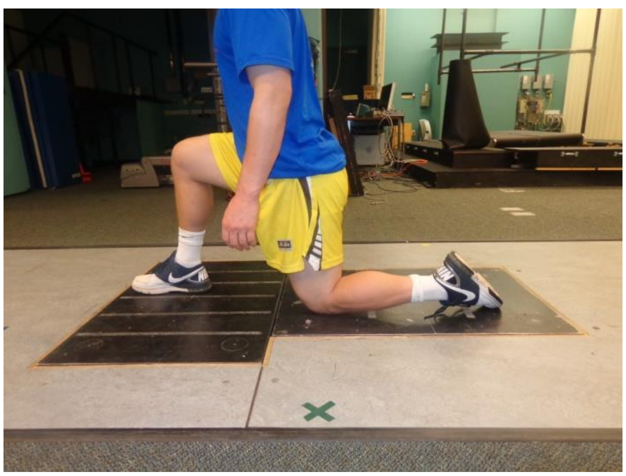

Figure 2: shows the starting position for the static lunge conditions.

indicated the participant to lunge downwards to the 90 degree angle for the lead leg. Kinematic data was recorded via a computer system called Cortex, for 20 seconds (this time duration was also true for the forward stepping and backward stepping lunges). Once the participant matched the beat of the metronome, which took about 2-3 lunges per individual, data began being recorded once the participant reached almost full extension and right before he proceeded to lunge downwards to a 90 degree angle. The participant was instructed to lunge until the researcher said stop, which was after the 20 seconds was complete in order to ensure proper muscle activation recording throughout the lunge. A rest of 2 minutes was given next in order to avoid fatigue or unusual co-contraction of the lower extremity musculature. Once two minutes was complete, the second trial began with the right leg as the lead leg. The same steps as described above, when the left leg was the lead leg, was used in this trial with the right leg as the lead leg.

Forward Stepping Left Leg Lunge and Forward Stepping Right Leg Lunge

The forward stepping lunge trials had the left leg as the lead leg first. The participant was asked to stand with his heels 15-25cm from the posterior edge of the second force plate (depending on height)**.** This was the starting position for the forward stepping lunge(Figure 4). Each beat indicated a different movement of the lead leg in this order: beat 1 – step forward with

Figure 3 shows the starting position of the dynamic forwards lunge, while Figure 5 on the left shows the descent to 90 degrees phase of the dynamic lunge.

lead leg (so the participant is in the lunge position), beat two –proceed downward into the lunge, with the lead leg at 90 degrees and non-lead leg (tibial portion) parallel to the floor, beat three – push upward with both legs into almost full extension, beat four – being lead leg back to starting position. The cycle was the repeated. The participant stepped with the lead leg straight out onto a portion of a long strip of tape to ensure uniformity. Once the metronome started, the participant was asked to start. This particular lunge (along with the backwards stepping lunge) required more time for the participants to acclimate to the 60 Hz beat. Once the beat was matched with the required movement and was a relatively fluid lunge motion, kinematic data and muscle activity was collected for 20 seconds. The start of data collection began once the participant completed beat 4 and was about to proceed to beat 1; in other words, when both feet were in contact with the second plate. The participant continued to lunge even after these 20 seconds was complete to ensure full data collection. As with the static lunges, a 2 minute rest was given, and then the right leg became the leading leg. The same protocol of the left single leg forward stepping lunge stated above was for the next trial, with the right leg as the lead leg.

Single Left Leg Backward Stepping Lunge and Single Right Leg Backward Stepping Lunge

The starting position for the backward stepping lunges consisted of the participant stepping on the center of the first force plate. If the subject was tall or his legs reached too far back, they were moved up a half step from the center of the first force plate. The left leg (as before) was deemed the lead leg and the right leg was deemed the non-lead leg for the first trial of forward stepping lunges. The backward stepping lunges were very similar to the forward stepping lunges in respect that different movements were matched to a beat. Each beat indicated a different movement of the non-lead leg in this order: beat 1 – step backward with non-lead leg (so the participant is in the lunge position), beat two –proceed downward into the lunge; lead leg at 90 degrees and non-lead leg (tibial portion) parallel to the floor, beat three – push upward with both legs into almost full extension, beat four – being non-lead leg back to the starting position. The cycle was the repeated. As with the forward stepping lunge, the metronome was started and the participant began following these instructions. Once the beat matched the movement for the non-lead leg, and was a relatively fluid motion, data began being recorded for 20 seconds. The start of data collection began once the participant completed beat 4 and was about to proceed to beat 1; in other words, when both feet were in contact with the first plate. The participant continued to lunge even after these 20 seconds were complete to ensure full data collection. A 3 minute rest was given, and then the right leg became the leading leg. The same protocol of the left single leg backward stepping lunge was followed for the right leg as the lead leg and the left as the non-lead leg.

Single Left Leg Curtsy Lunge and Single Right Leg Curtsy Lunge

The curtsy lunge starting position was similar to the static lunge starting position. The left leg was the lead leg for the first trial. The participant was asked to stand with his heels 15-25cm from the posterior edge depending on height/leg length. If the subject could not reach the first force plate he was moved up a step. The lead leg was then crossed over the non-lead leg and placed on the first force plate, about the same comfortable distance as one would for a static lunge, but diagonally across the body. Due to height/leg differences, the women placed there lead leg on a strip of 2cm wide tape, 32cm from the right edge (when the left leg was the lead leg; when the right leg was the lead leg, it was the left edge of the first force plate.) of the first force plate. The men placed their lead leg on a strip of tape 16cm from the left edge of the first force plate (when the left leg was the lead leg; when the right leg was the lead leg, it was the right edge of the first force plate.). The location of the tape on the first force plate can be seen in Figure 2 below.

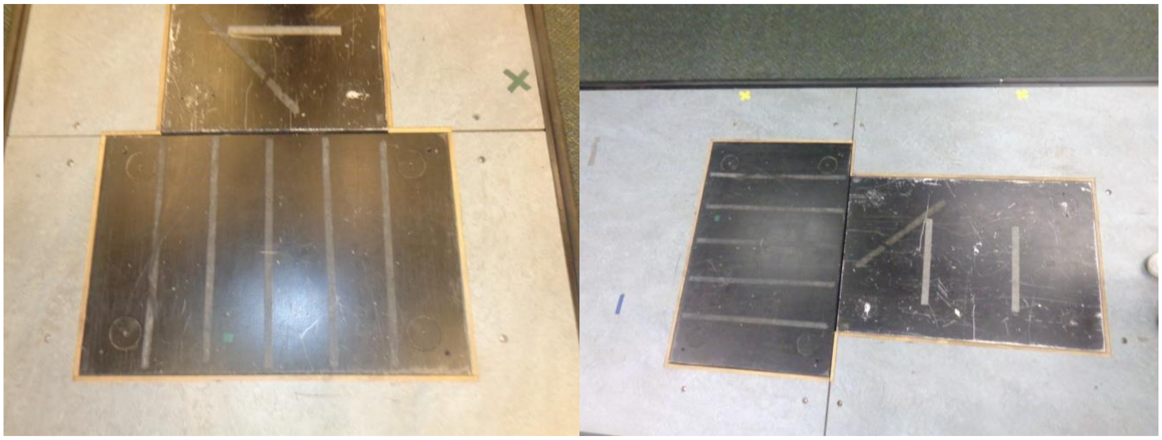

Figure 4 shows the orientation of the two force plates and the tape markers for the curtsey lunge.

Both feet of the participant were instructed to stay facing forward and not to turn towards the angle at which he was lunging, and to keep his torso facing in the forward direction. Figure 2 shows the downward position of the curtsy lunge. He was then asked to place the lower half of the non-lead leg (patella to first phalanx) onto the ground, with his foot in a full extended position so that the top of the foot was also on the ground. Once ready, the participant flexed his ankle joint, so the knee and tibia portion of the lower leg came off the ground and that he was on his toes in the lunge position. In the lunge position the lead leg had the knee joint flexed at 90 degrees and the non-lead leg parallel to the ground. The metronome then started at 60 Hz. The first sound indicated the participant to push upward and to almost full extension of the lead leg. The second sound indicated the participant to lunge downwards to the 90 degree angle. Kinematic data and muscle activity was recorded for a duration of 15 seconds, once the participant had mastered being able to lunge to the beat of the metronome. Recording began once the participant reached almost full extension and right before he proceeded to lunge downwards to a 90 degree angle. As before, the lunging continued after 15 seconds to ensure correct data collection. Once the first trial was finished, and 2 minute rest was given to that participants. The second trial then had the right leg as the left leg, with the same protocol for the curtsy lunge as above.

Single Left Leg Static Lunge and Single Right Leg Static Lunge with 10 lb. Plate

As mentioned before, the starting position for a strictly static normal lunge required the participant to place the lead leg forward onto the second force plate and bend the knee to 90 degrees. The non-lead leg was placed posterior onto the second force plate, in a comfortable lunge position. For the first trial, the left leg was considered the lead leg. The non-lead leg, from the patella to the toes, was then rested on the ground with the foot in an extended position so that the dorsal side of the foot also rested on the ground. Once ready, the participant flexed his ankle so that the knee and tibia portion of the lower leg came off the ground, and he was on his toes in the lunge position. In the lunge position the lead leg's knee was flexed at 90 degrees and the non-lead leg parallel to the ground. The metronome then started at 60 Hz. In this position, the participant held the 10 lb. plate with both hands at clavicle level, making sure to keep his elbows tight by his sides against the rib cage. The first sound indicated the participant to push upward and to almost full extension of the lead leg. The second sound indicated the participant to lunge downwards to the 90 degree angle. Kinematic data and muscle activity was recorded for 15 seconds. Once the participant matched the beat of the metronome, which was about 2-3 lunges per individual, data began being recorded once the participant reached almost full extension and right before he/she proceeded to lunge downwards to a 90 degree angle. The participant was instructed to lunge until the researcher said stop, which was after the 15 seconds was complete in order to ensure proper muscle activation. Once the researcher told the participant to stop the plate was taken from him, and a rest of 2 minutes was given. The second trial had the right leg considered as the lead leg, following the same protocol for data collection as stated above with the lead legs switched.

Chapter 3: Results

The dynamic and static lunge data were compared separately. For the dynamic lunges, the RF and GM exhibited the highest overall activity, especially during the dbr2, while the BF had a lower and more consistent amount of activity. A high mean activity level was also noted for the RA, specifically during the dynamic forward lunge, while the TA and the LG had very similar activities showing co-contraction. Out of all the muscles, the VL and ST showed low activation levels, indicating possible assistance throughout both the dynamic forward and backward lunge. Consistent significance was seen in the LG, RF, and GM, muscle activities with the left leg as the lead leg during descent and ascent (for the LG and RF) and for ascent regardless of the lead leg (for the GM). The RA had the highest activity during the forward stepping lunge in both ascent and descent, regardless of the lead leg. The GRF also increased during the forward stepping lunge when compared to the backwards stepping lunge with the left leg as the lead leg.

Out of all the static lunges, the BF was the only muscle to have the curtsey lunge exhibit a significantly higher muscle activity than the static lunge. The GM, LG, and RF all showed consistent significant values throughout the different lunges. Many significant values were seen when comparing the static lunge to the static plate and static curtsey lunge with the left leg being the non-lead leg; in almost all cases the static lunge had the higher activity level. The RF had the highest activity when it was the non-lead leg, which was also true for the GM. The LG, ST, and VL had very consistent activation throughout each lunge, indicating a possible role in stabilization. The RA also had more consistent activity (than in the dynamic lunge situations), with the highest activation seen during slr1. The GRF activity for the left leg as the lead leg was as follows (from highest to lowest): spl, scl, sll. Although these values were not significant, they follow with the hypotheses formed by the researchers.

Dynamic Lunge EMG

The mean values and standard deviation values for the dynamic lunge conditions were found and graphed to compare activity levels of EMG and GRF. The axes indicate the mean activity vs. the phase of the lunge; descent was assigned a 1 while ascent was assigned a 2. The abbreviations are as follows: dbl – dynamic backwards stepping lunge left leg as lead leg, dbr – dynamic backwards stepping lunge right leg as lead leg, dfl – dynamic forwards stepping lunge left leg as lead leg, , dfr – dynamic forwards stepping lunge right leg as lead leg.

Significant values were found using a one-tailed T-Test comparing dynamic forward lunge and dynamic backward lunge. The statistically significant p- values can be seen below in Figure 1, highlighted in red.

Figure 1.

Muscle	TA	LG	GM	BF	RF	VL	RA	ST
Condition								
dbl1 vs. dfl1	0.20276	0.0407	0.31298	0.21852	0.05667	0.04177	0.0651	0.04088
dbl2 vs. dfl2	0.23469	0.00194	0.01632	0.09746	0.04321	0.2286	0.01861	0.00479

Muscle	TA	LG	GM	BF	RF	VL	RA	ST
Condition								
dbr1 vs. dfr1	0.41874	0.1742	0.16736	0.24255	0.22426	0.1079	0.15682	0.2038
dbr2 vs. dfr2	0.08838	0.03505	0.01335	0.34395	0.42741	0.39672	0.33695	0.2473

Figure 1 shows the significant p-values throughout each dynamic lunge condition for each muscle.

Figure 2.

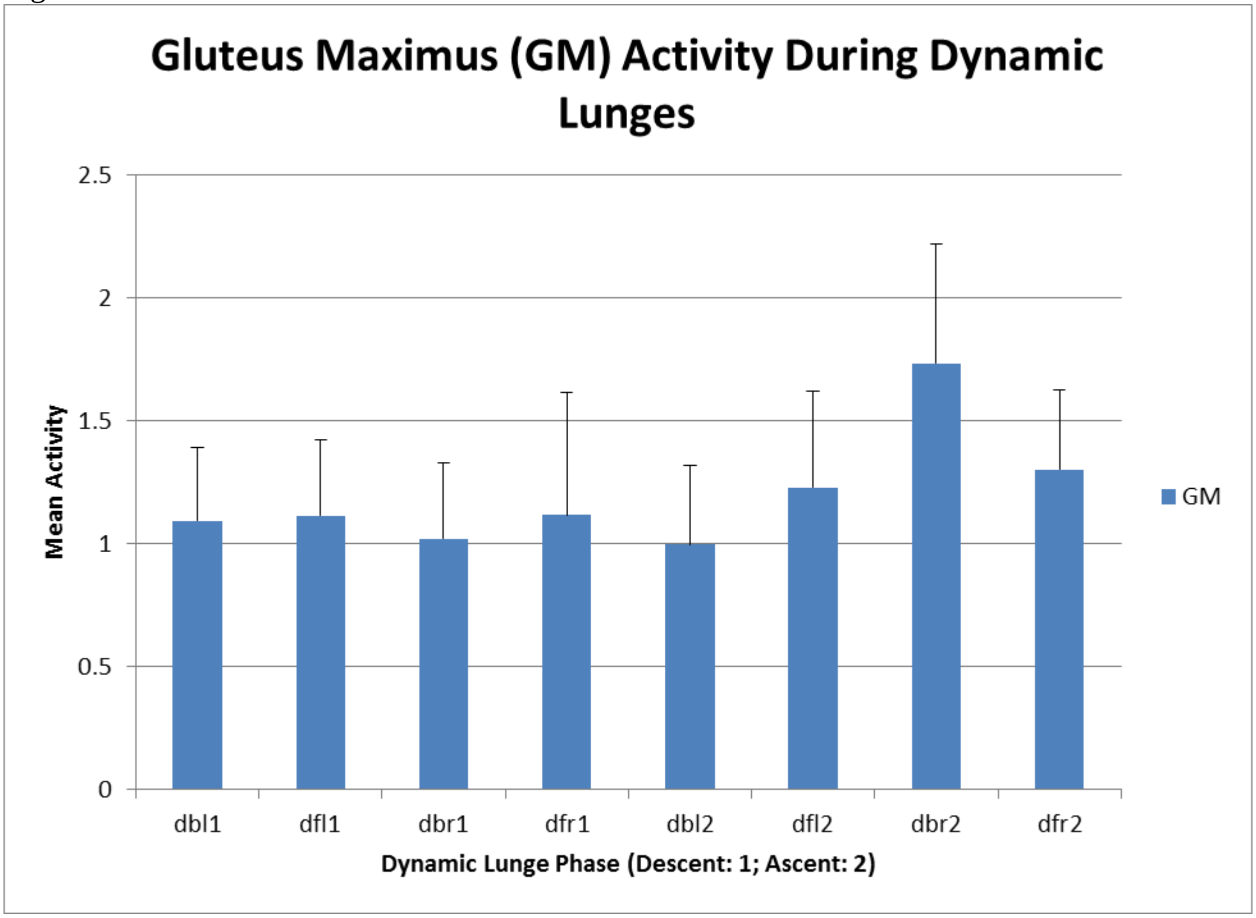

Figure 2 shows the mean EMG activity of the gluteus maximus during descent and ascent for the dynamic lunge conditions.

The highest mean for the GM of 1.73 was recorded when the left leg was the non-lead leg during the ascent phase (dbr2). This correlates with the main function of the GM, which is to extend the hip. We see a significant increase in activity for dfl2's mean activity when compared to dbl2 (p-values=.016), and for dbr2 vs. dfr2 (p-value=.013), indicating the muscle is more activated when it is need to extend the leg and propel the leg back into the starting position.

Figure 3.

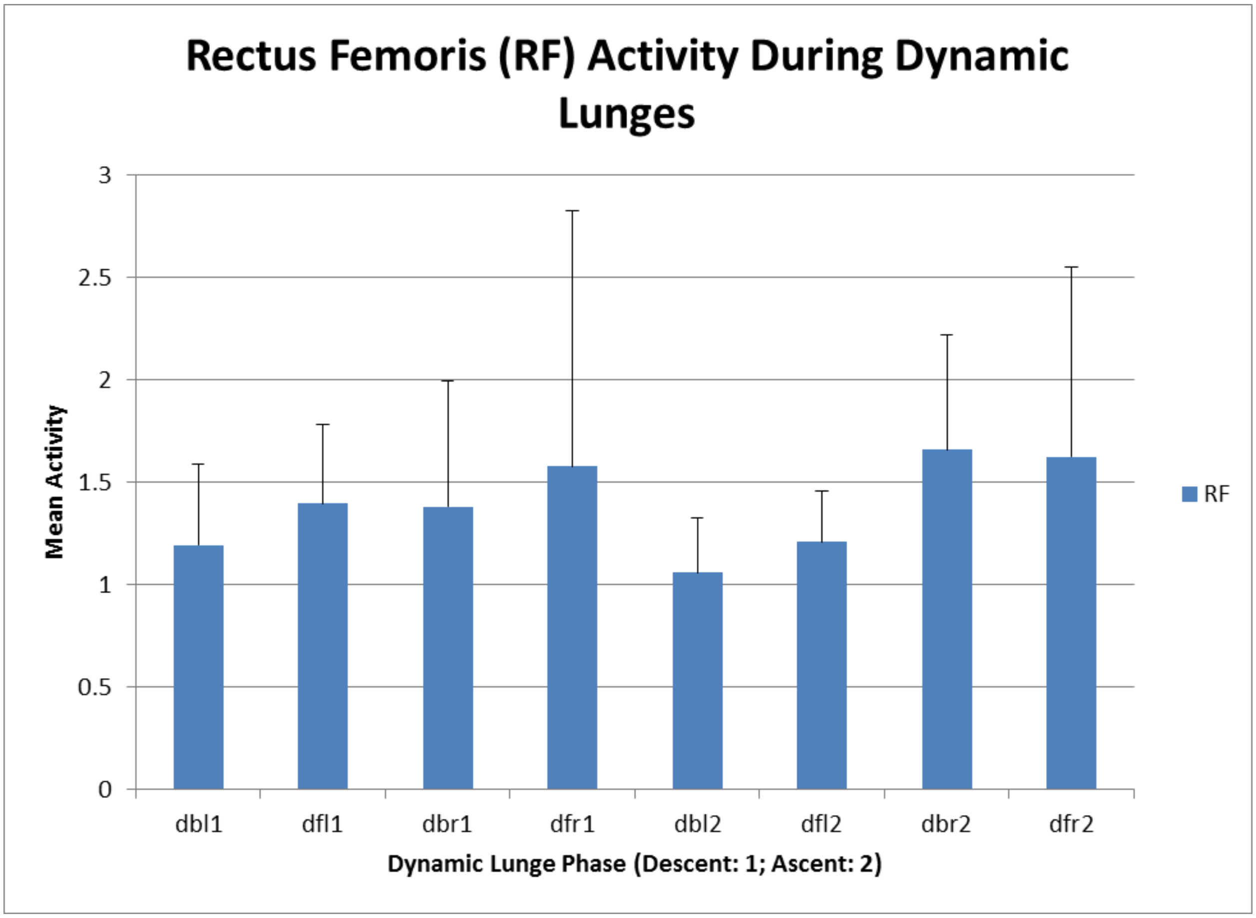

Figure 3 shows the mean EMG activity of the rectus femoris during descent and ascent for the dynamic lunge conditions.

As with the GM, the mean EMG activity for the RF is highest during dbr2. The RF is also similar to the GM in that the forward lunge has a higher activity level in each case, with the exception of the dbr2 vs. dfr2. During the descent phase an increase in the RF activity during the forward lunge is seen. The higher activity when the left leg is the lead leg in the dynamic forward situations may indicate stabilization of the leg during descent and ascent respectively (p-value=.057;p-value=.043).

Figure 4.

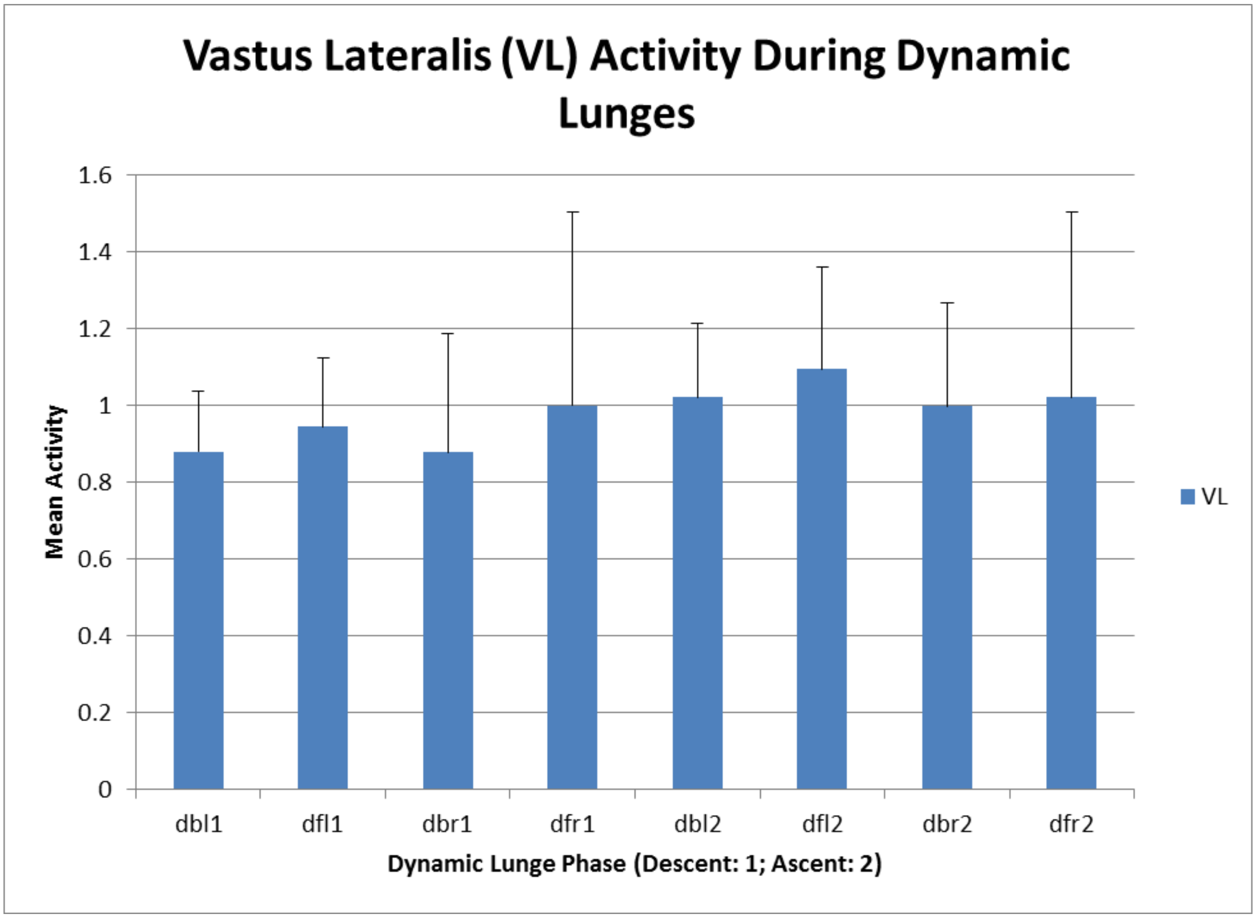

Figure 4 shows the mean EMG activity of the vastus lateralis during descent and ascent for the dynamic lunge conditions.

The VL's mean activity is higher (although not significantly in all cases) in the forward lunge condition no matter the phase. However, the dfl2 has the highest overall activity, with a mean value of 1.0938. The activity level of the VL is also relatively consistent throughout each phase, ranging from .08 to a little above 1. There is significance though when comparing dbl1 vs. dfl1 (p-value=.041). The VL's mean activity is also relatively and consistently lower than in the other above graphs.

Figure 5.

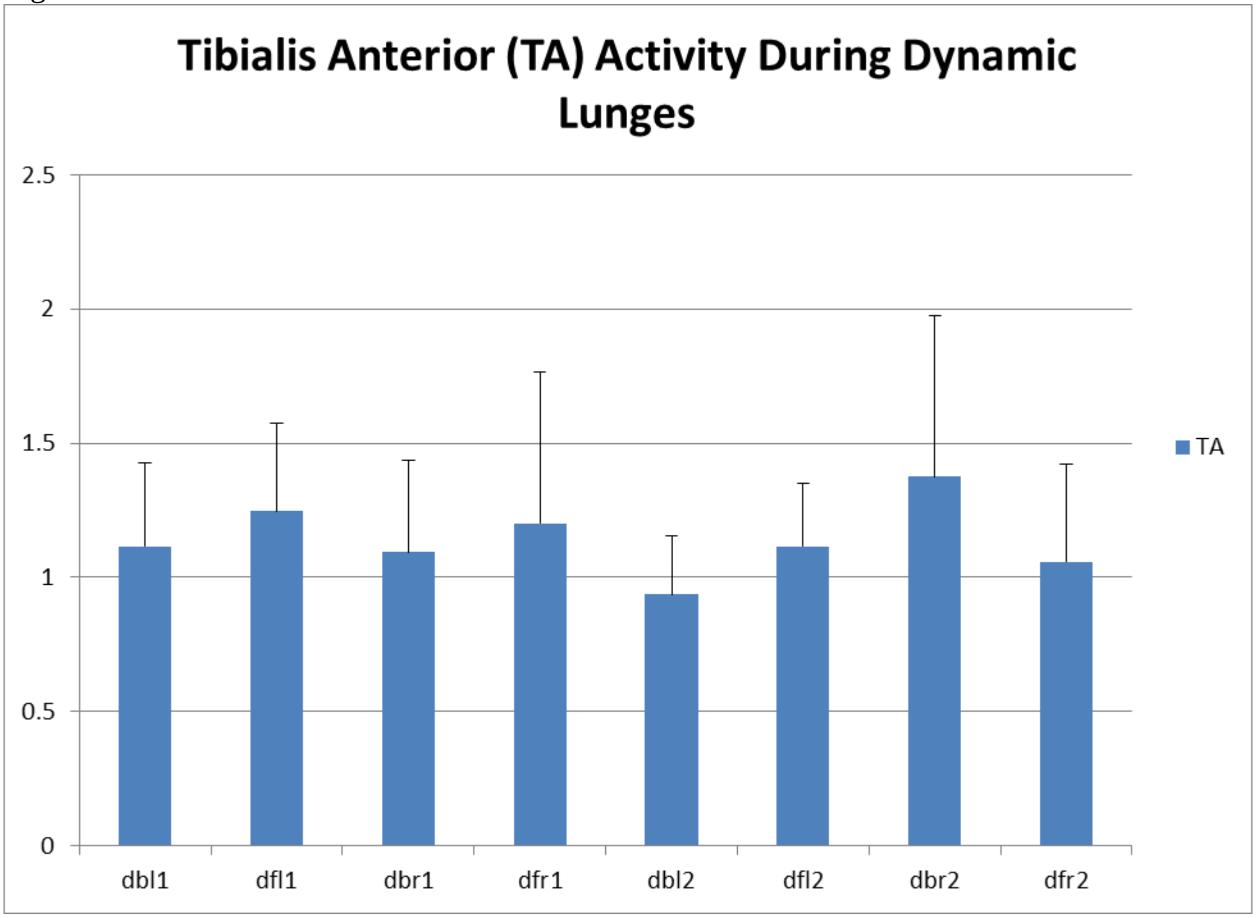

Figure 5 shows the mean EMG activity of the tibialis anterior during descent and ascent for the dynamic lunge conditions.

The highest mean activity level for the TA, like the GM and RF, was during the ascent phase of the backwards dynamic lunge with the left leg as the non lead leg (dbr2). Again, the pattern of the forward lunge conditions having the highest activity level is seen, with the exception for dbr2, but with no significant values. This increase in activity can be attributed to the flexion of the foot when the leg needs to be swung forward or backward. However, the highest activity level is during dbr2 because the left leg must be propelled forward for the foot to come off the ground, and be placed back into the starting position.

Figure 6.

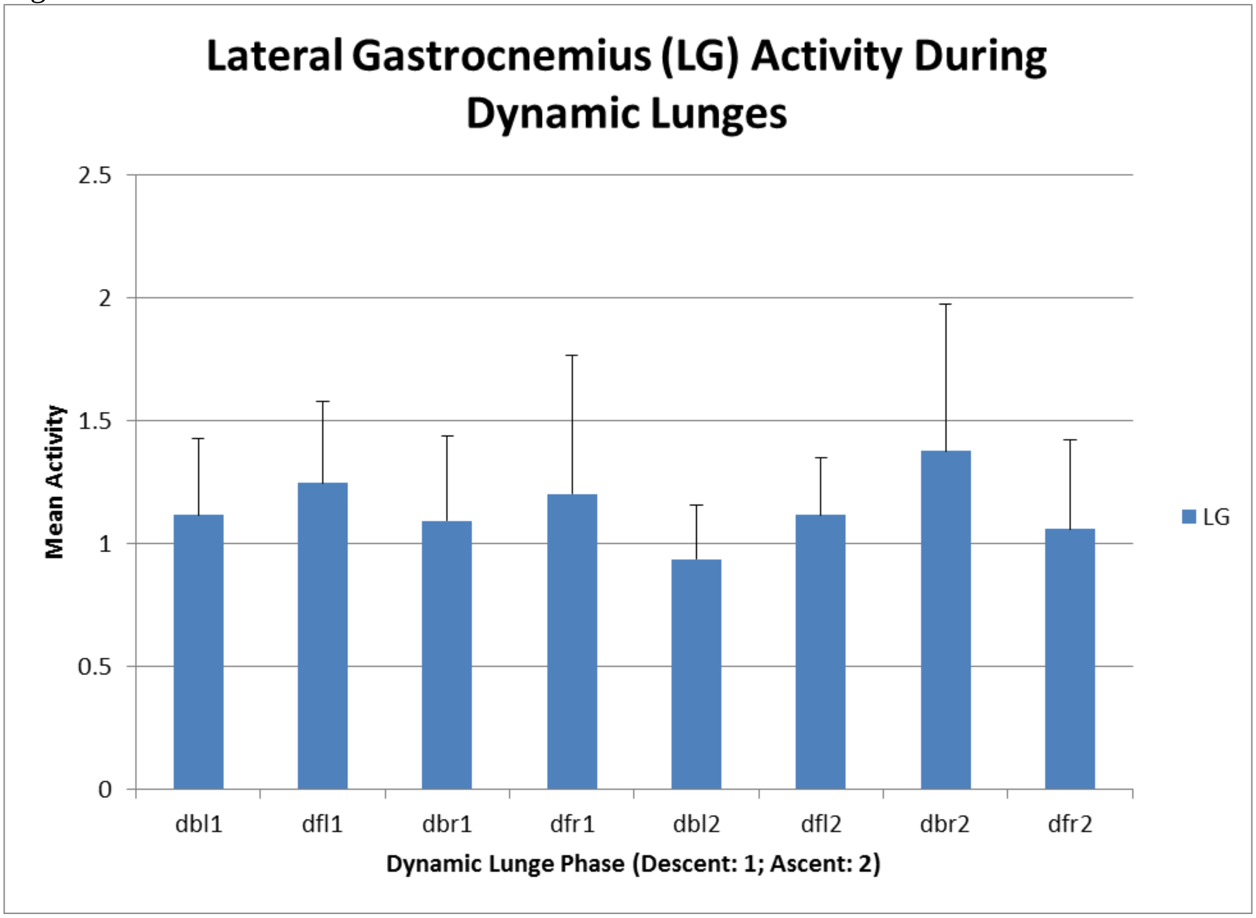

Figure 6 shows the mean EMG activity of the lateral gastrocnemius during descent and ascent for the dynamic lunge conditions.

The highest mean activity for the LG is noted when the left leg is the non-lead leg during the ascent phase (dbr2), which is similar to the TA'S activity. This is expected due to the LG's main role in extending the foot which was previously in a flexed state. The increased activity during the descent phase in the forward lunge (no matter the lead leg) could possibly indicate contraction due to stabilization of the lead leg during the forward dynamic lunge motion, because of the weight transferring to the left leg. Once again the pattern of the forward lunge having a higher muscle activity is shown above, with the exception of dbr2. Dbl1 vs. dfl1 and dbl2 vs. dfl2 showed significant differences (p-value=.041; p-value=.002) with dfl having the higher activity in both cases. Also significant was dbr2 vs. dfr2 (ascent) (p-value= .035).

Figure 7.

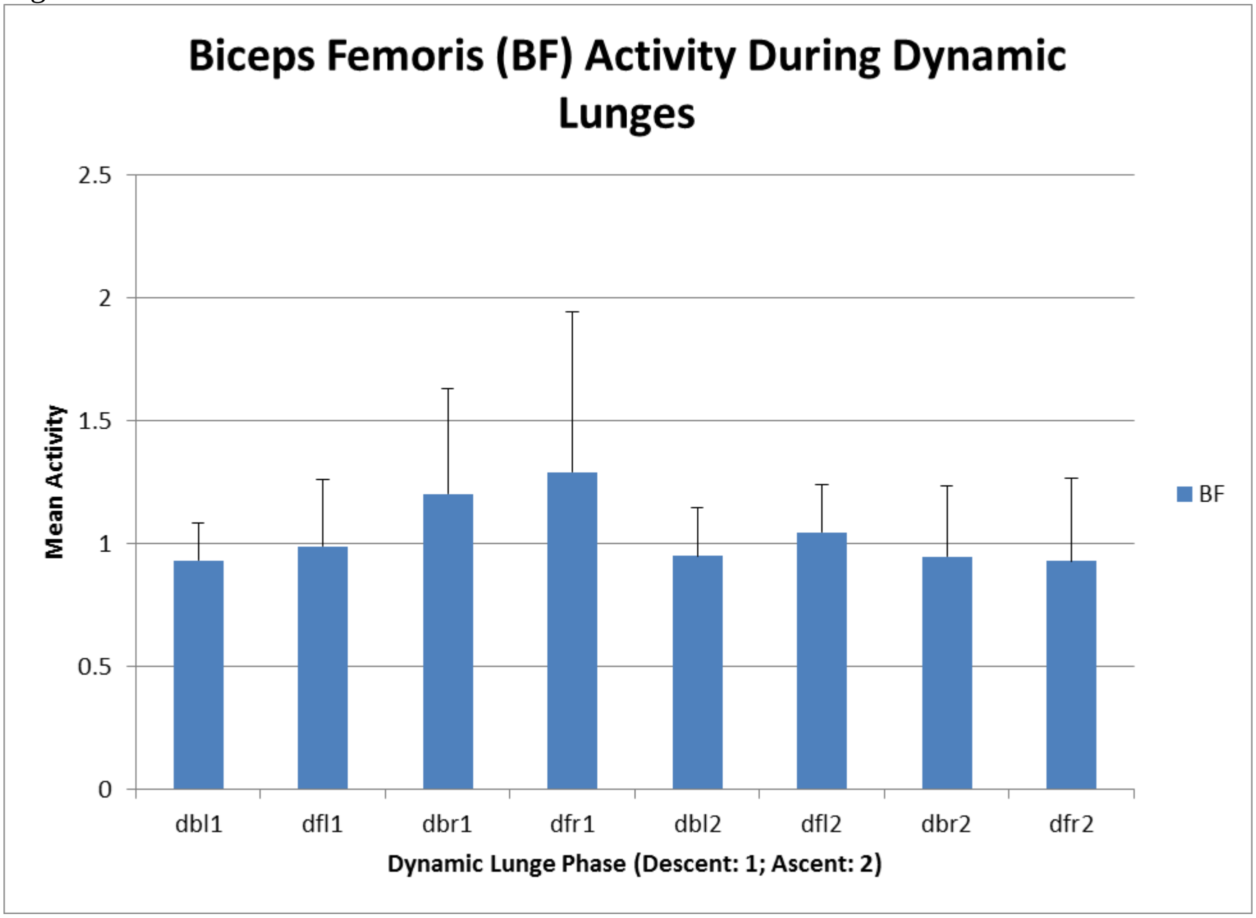

Figure 7 shows the mean EMG activity of the biceps femoris during descent and ascent for the dynamic lunge conditions.

The highest activity level is seen when both the descent phase of the right leg being the lead leg in the forward and dynamic lunges; the dfr1 has the highest activity, with a mean value of 1.29. These high levels for dbr1 and dfr1 could be due to the fact that the BF is co-contracting to help stabilize the non-lead leg at a 90 degree angle. The similar activation in all ascent cases may prove that the BF is co-contracting with other musculature during this phase to help stabilize when accelerating upward. No significant differences are noted for the BF mean activity, although the closest significant p-value of .098 is noted for dfl2 vs. dbl2.

Figure 8.

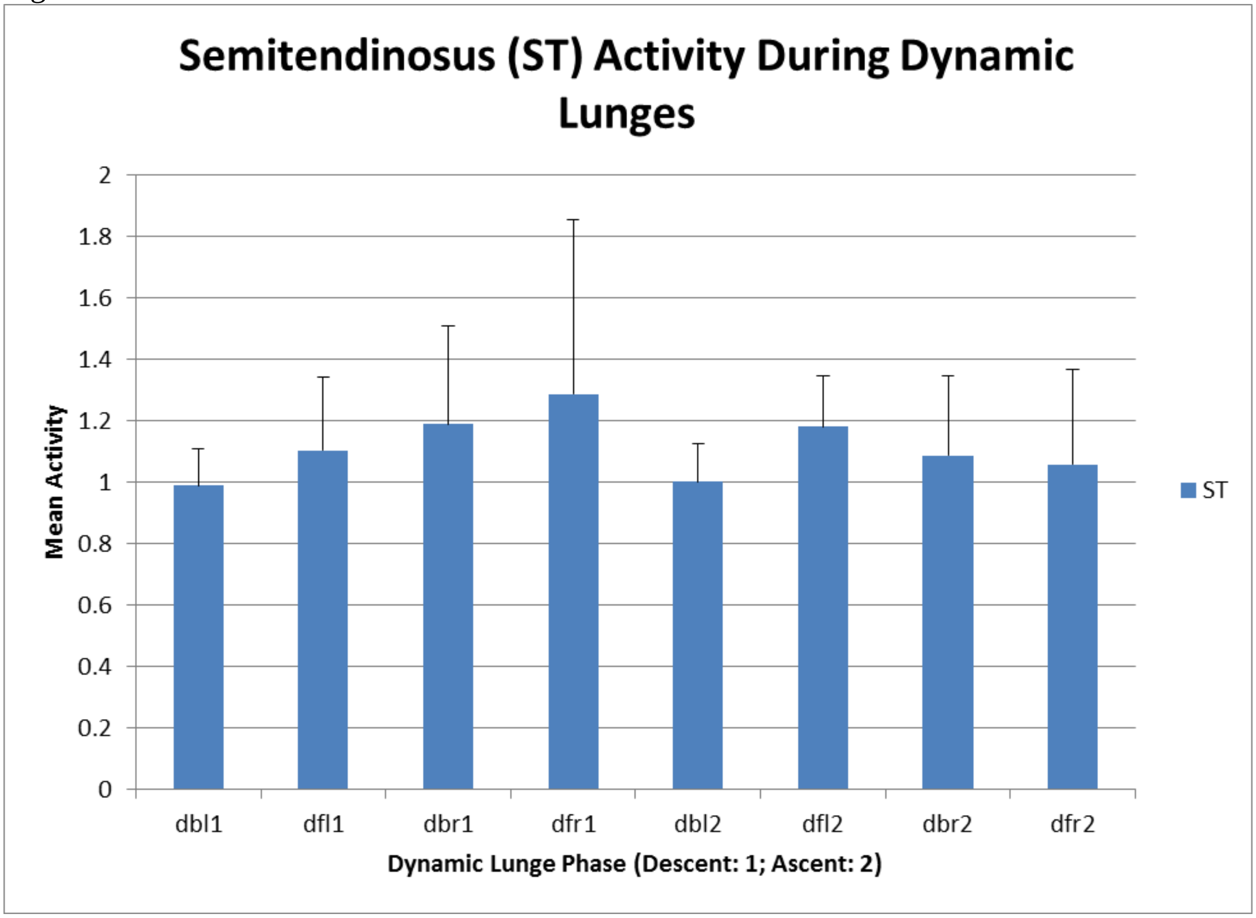

Figure 8 shows the mean EMG activity of the semitendonosis during descent and ascent for the dynamic lunge conditions.

The ST's mean activity level is like the BF's mean activity because it also has a higher activity for dbr1 and dfr1, with dfr1 having the highest mean value of 1.28. The highest activity seen in dfr1 and dbr1 is possibly from playing a greater role in flexing the knee of the non lead leg, and controlling knee stability when descending. Statistically significant values are seen for dbl1 vs. dfl1 and dbl2 vs. dfl2 (left leg as lead leg) (p-values=.041 and p-value=.004 respectively). Overall, the values seem to be relatively consistent for the activity, ranging from .98 to 1.28.

Figure 9.

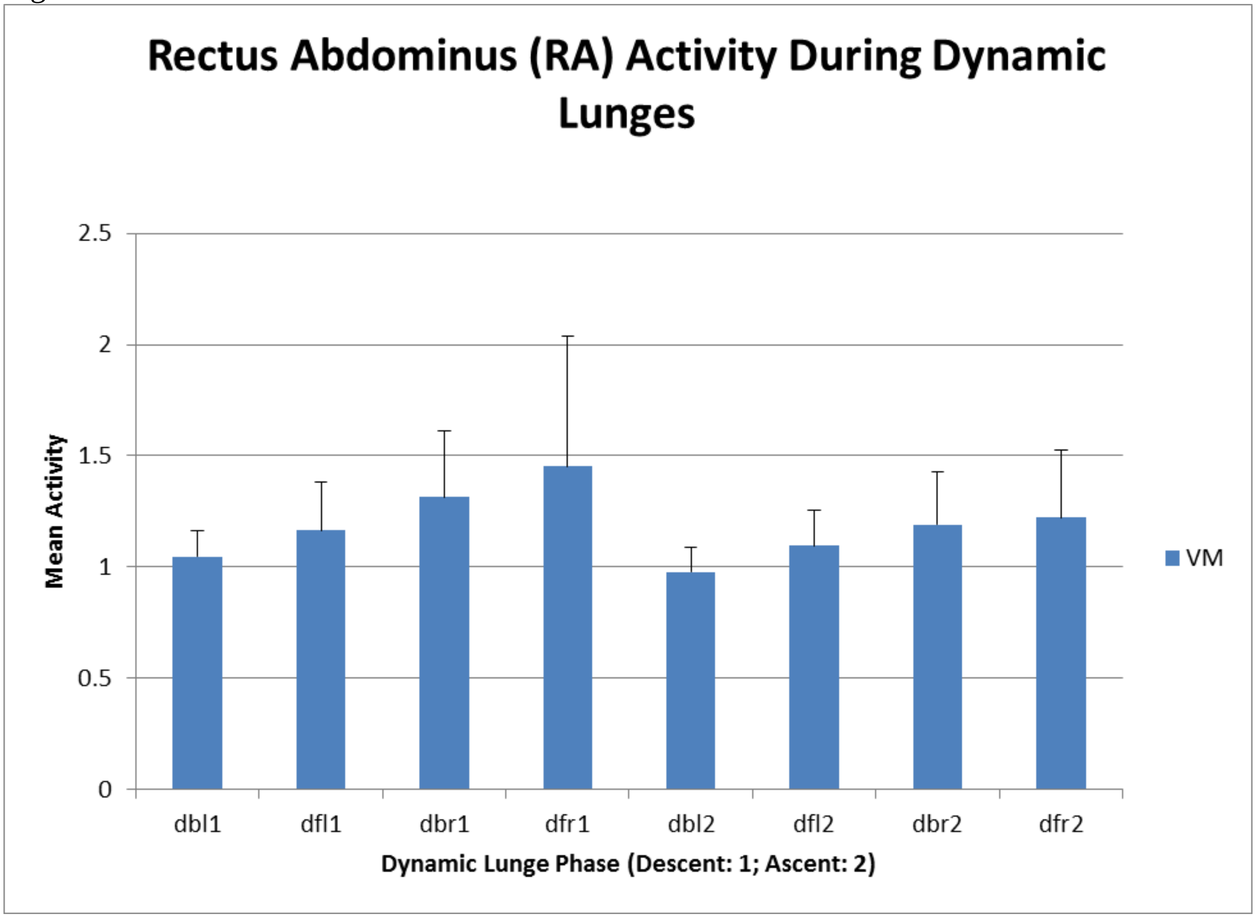

Figure 9 shows the mean EMG activity of the rectus abdominus during descent and ascent for the dynamic lunge conditions.

The mean EMG activity for the RA tends to increase more during the descent phase of the forward and backward, most likely for stabilization purposes of the lower extremities through contraction of the core. The same could be said for the descent phase when the left leg was the lead leg. Another important observation is the activity was highest when the left leg was the non-lead leg; this could lead us to speculate that the abdominals assist in stabilizing the non-lead leg in any dynamic lunge situation. The highest overall value of 1.45 was seen during dfr1. Significant p-values for the ascent phase of dbl2 vs. dfl2 and dbr2 vs. dfr2 were observed (p-value=.016 and p-value=.013 respectively).

Forces for Dynamic Lunges

Figure 10.

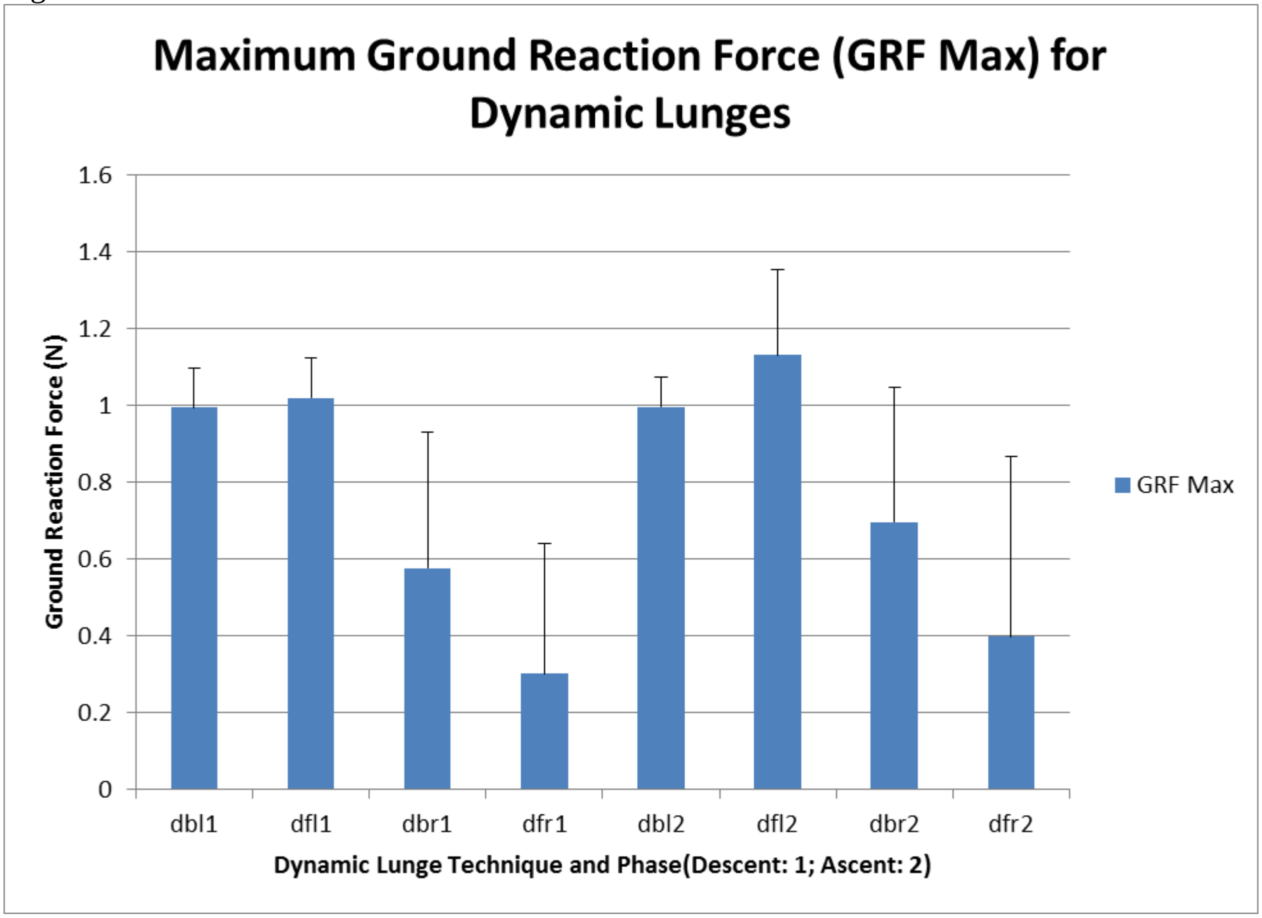

Figure 10 shows us the maximum ground reaction force during the descent and ascent phase during the dynamic lunge conditions.

Although forces experienced were higher with the left leg as the lead leg, the maximum force is almost halved when the left leg was the non lead leg. In this situation, the non lead leg has a higher force exerted on the knee in the dynamic backwards lunge condition; however, these forces are much smaller than when the left leg is the lead leg. The dynamic backward lunges for the left leg being the lead leg (dbl1 and dbl2) show a consistent force value of .993 and .996 respectively. During the forward lunge, the lead leg is observed to have a higher maximum force experienced, as seen in dfl1 and dfl2. Significant p-values for the ground reaction forces are shown in Table 1 below.

Figure 11.

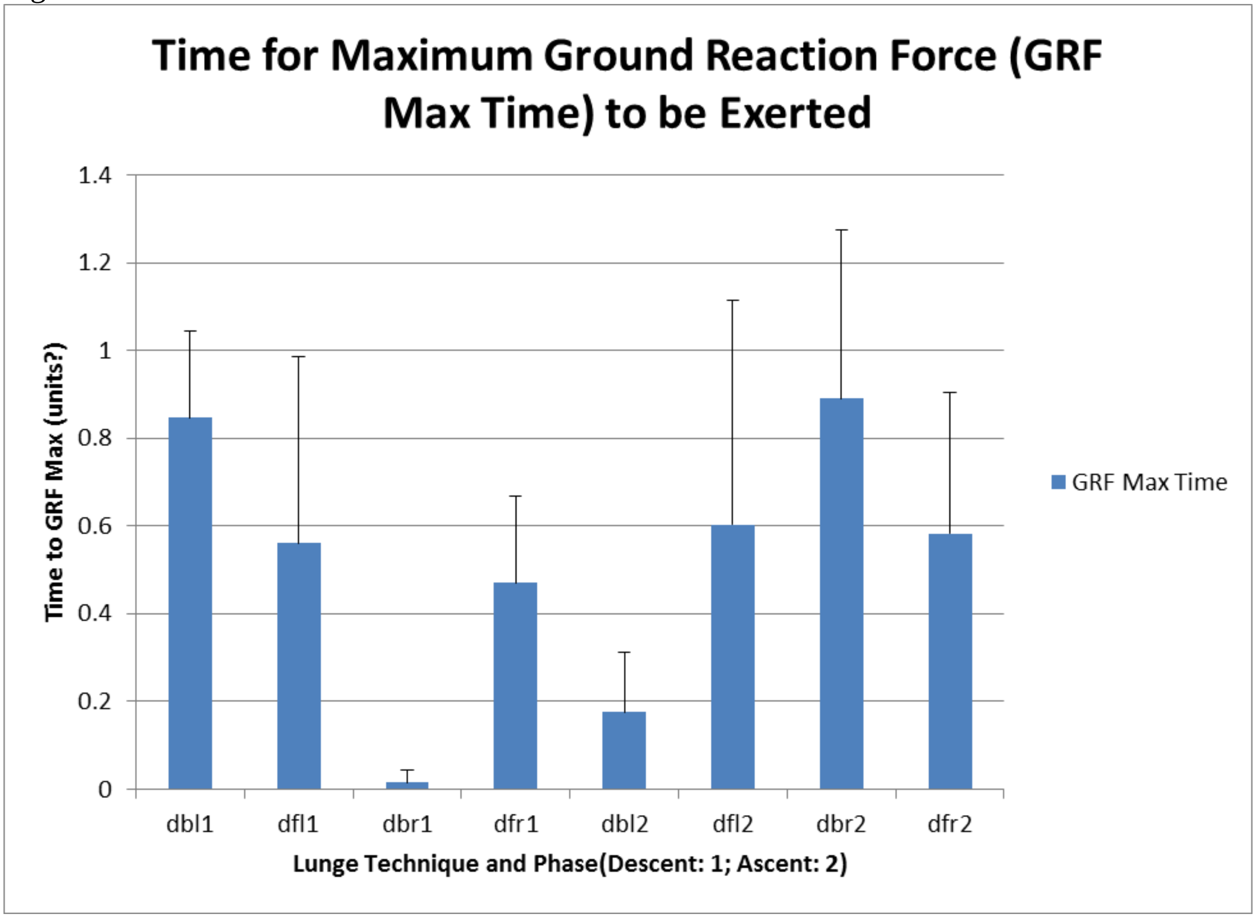

Figure 11 shows the time to which the maximum ground reaction force was achieved during the descent and ascent phase of the dynamic lunge conditions.

The overall time to maximum GRF varied greatly throughout each condition. In descent, dbl1 had a longer time to reach almost the same force in comparison to dfl1. However, there was a very large time difference during the ascent phase for the dbl even though there is also a high variance. Dbr2 also took a longer time than dfr2, even when a higher force was experienced on the non-lead leg in dbr. Statistically significant p-values are shown in Table 1 below.

Table 1: Significance Values of GFR Max and Time to GRF Max for Dynamic Lunges

Condition	Ground Reaction Force (GRF) Max P-Value	Ground Reaction Force Time to Max P-Value
Dfl1 vsDbl1	0.306645	0.031437
Dfl2 vsDbl2	.07103	.02801
Dfr1 vs. Dbr1	.00048	.00017
Dfr2 vsDbr2	.00358	.01873

Table 1 compares the significant p-values throughout the different dynamic lunge conditions for maximum ground reaction forces, and time to these maximum ground reaction forces.

There is significance in every time to maximum ground reaction force situation. However, the maximum ground reaction force is significant in the condition of the left leg being the non lead leg.

Static Lunge EMG

The mean values and standard deviation values for the dynamic lunge conditions were found and graphed to compare activity levels of EMG and GRF. The axes indicate the mean activity vs. the phase of the lunge; descent was assigned a 1 while ascent was assigned a 2. The abbreviations are as follows: scl – static curtsey lunge left leg as lead leg, scr – static curtsey lunge right leg as lead leg, sll – static lunge left leg as lead leg, slr – static lunge right leg as lead leg, spl – static plate lunge left leg lead leg, spr – static plate lunge right leg lead leg.

Significant values were found using a one-tailed T-Test comparing dynamic forward lunge and dynamic backward lunge. The statistically significant p- values can be seen below in Figure 1, highlighted in red.

Figure 12.

Muscle Condition	TA	LG	GM	BF	RF	VL	RA	ST
Sll1 vs. spl1	0.381436	0.047168	0.113917	0.398493	0.330513	0.437648	0.125977	0.239406
sll1 vs. scl1	0.025185	0.004655	0.44939	0.018531	0.17649	0.400917	0.134756	0.355925

Muscle Condition	TA	LG	GM	BF	RF	VL	RA	ST
Sll2 vs. spl2	0.171905	0.020839	0.268612	0.144536	0.149253	0.026979	0.226263	0.076971

Sll2 vs. scl2	0.464074	0.008753	0.041949	0.228423	0.394504	0.469538	0.047398	.193851

Muscle	TA	LG	GM	BF	RF	VL	RA	ST
Condition								
Slr1 vs. spr1	0.334711	0.076178	0.159687	0.279762	0.386127	0.269157	0.346853	0.225263
slr1 vs. scr1	0.040034	0.049717	0.093808	0.100976	0.19192	0.031661	0.142032	0.076224

Muscle	TA	LG	GM	BF	RF	VL	RA	ST
Condition								
Slr2 vs. spr2	0.175165	0.151357	0.002889	0.016005	0.000998	0.040847	0.132528	0.163618
Slr2 vs. scr2	0.006475	0.062125	0.054283	0.032597	0.002735	0.071909	0.028242	0.011975

Figure 13.

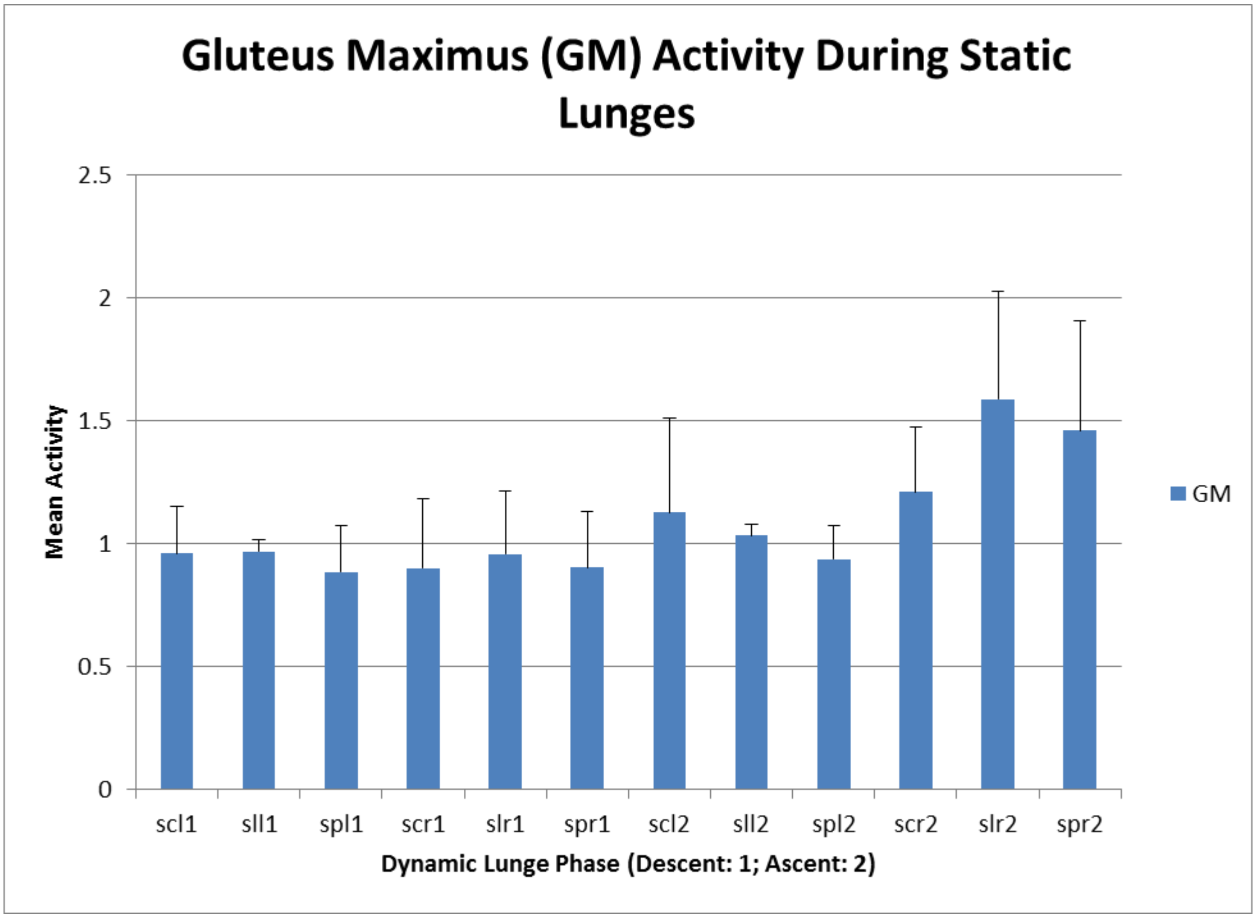

Figure 13 shows the three different static lunge conditions for both the descent and ascent phase.

For both descent conditions, the muscle of the GM seems relatively consistent for each lunge no matter which leg was the lead leg. The ascent phase, specifically when the left leg is the non-lead leg, has the highest increase in activity; Slr2 has the highest activity overall, and scr2 has the lowest amount of activity. The static curtsey lunge has relatively the same activity when comparing the left and right leg as the lead leg in the descent phase. In the ascent phase, the static curtsey lunge has a significantly higher mean activity level than the static lunge (p-value=.041); this shows the GM helping to extend the lead leg in the curtsey lunge. This is the only case in which the static curtsey lunge exhibits a higher activation for the GM. However, when the left leg is the non-lead leg, a significant p-values when comparing slr2 vs. scr2 (p-value=.054) and slr2 vs. spr2 (p-value=.002) is seen.

Figure 14.

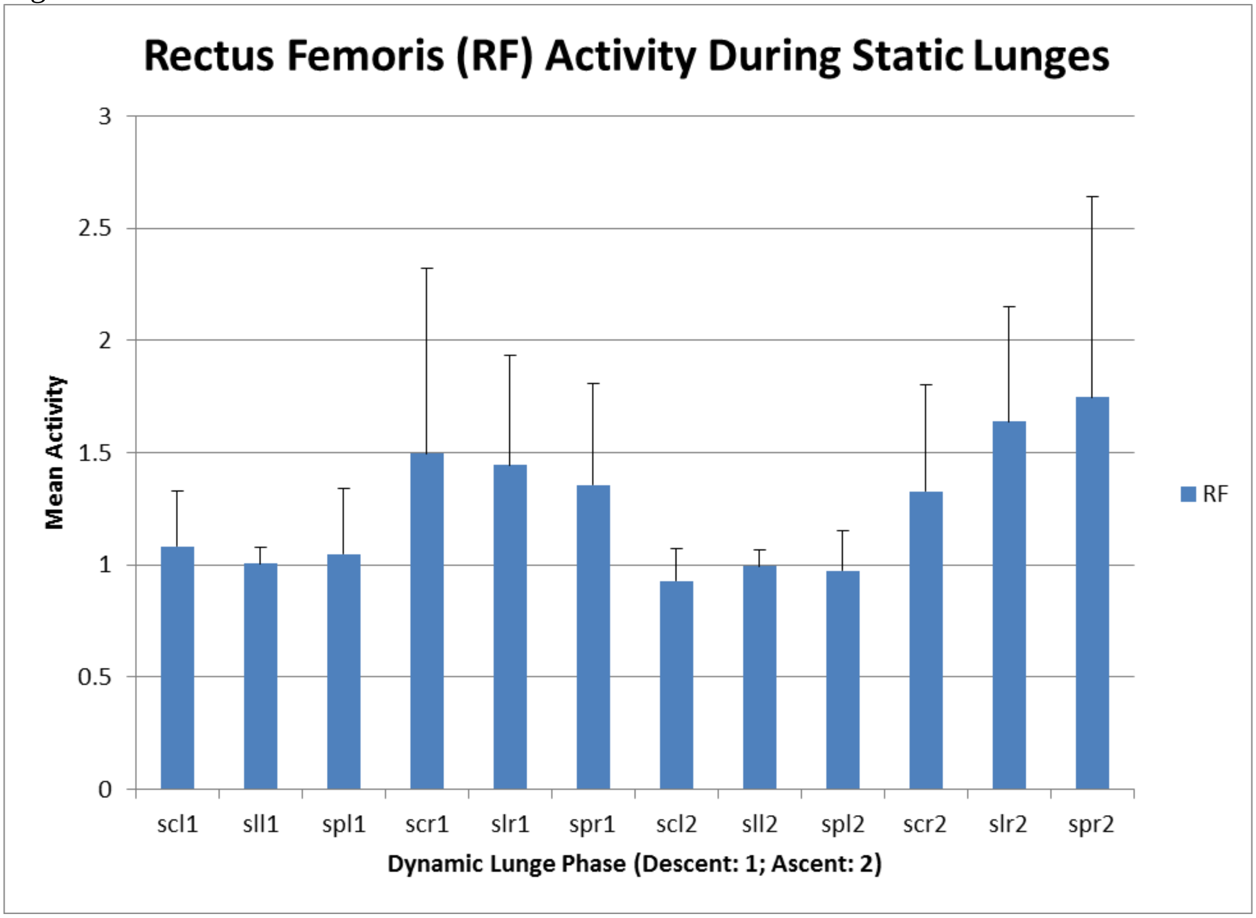

Figure 14 shows the three different static lunge conditions for both the descent and ascent phase.

Overall, the values are relatively similar in descent and ascent when the left leg is the lead leg. The RF has the highest activity when the left leg is the non lead leg. This shows that the static lunge (no matter the type of lunge) activates the RF more on the non-lead leg. The only significant p-values are seen when comparing the slr2 vs. spr2 (p-value = .001) and slr2 vs. scr2 (p-value = .002); this correlates with the RF main function of extending the knee.

Figure 15.

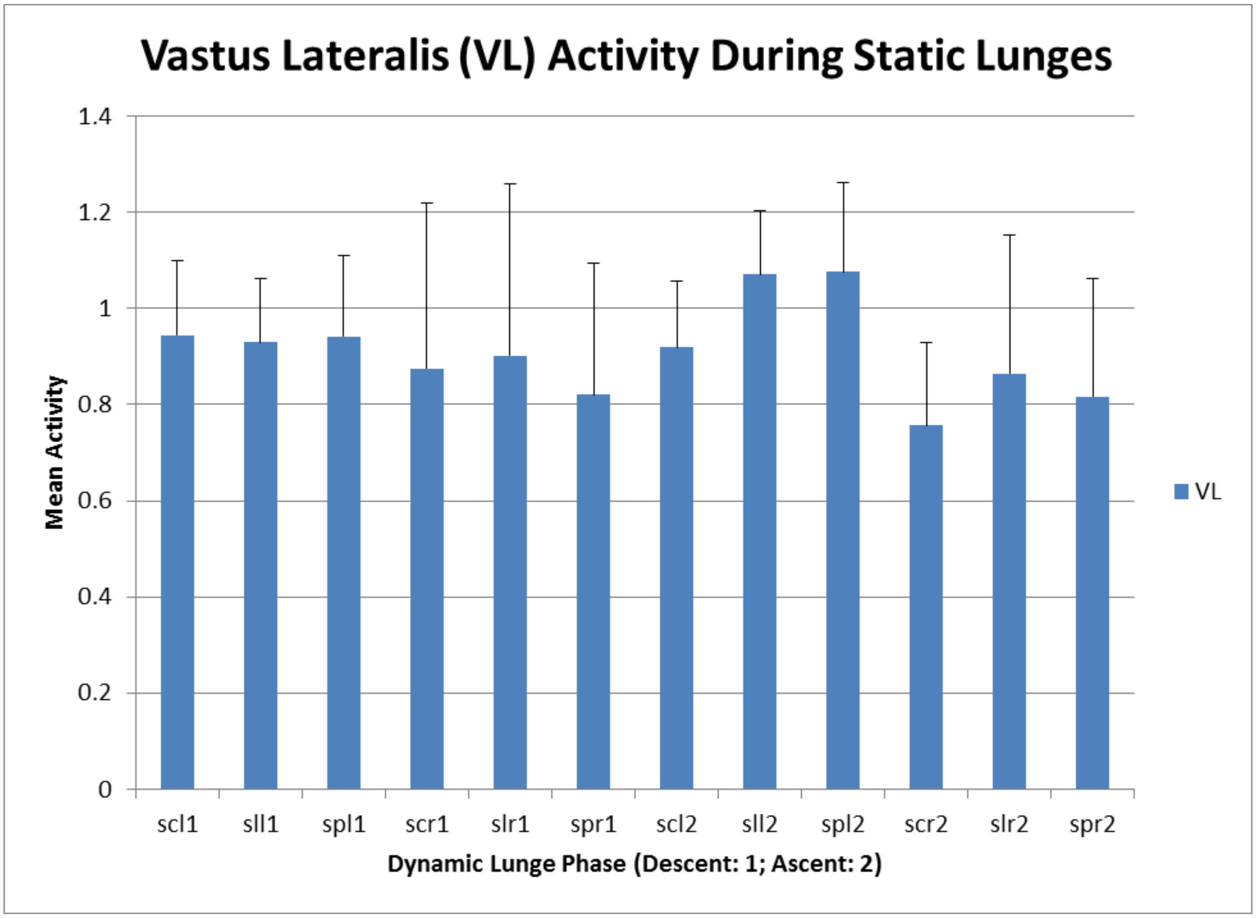

Figure 15 shows the three different static lunge conditions for both the descent and ascent phase.

Overall, when comparing each lunge in each situation, the values of the VL are relatively consistent, and have a lower activation level than the RF. The highest overall activity appears during spl2, although sll2 shows a very similar high activation level. These high activation levels are opposite of the RF; the higher mean activity is seen when the left leg is the lead leg. When compared, significant p-values for sll2 vs. spl2 (p-value=.002), slr1 vs. scr1 (p-value=.031), and slr2 vs. spr2 (p-value=.041) are seen. With the exception of the static plate lunge in the ascent phase, the control static lunge has a higher activation in each condition, or relatively the same activation of the other two lunge conditions.

Figure 16.

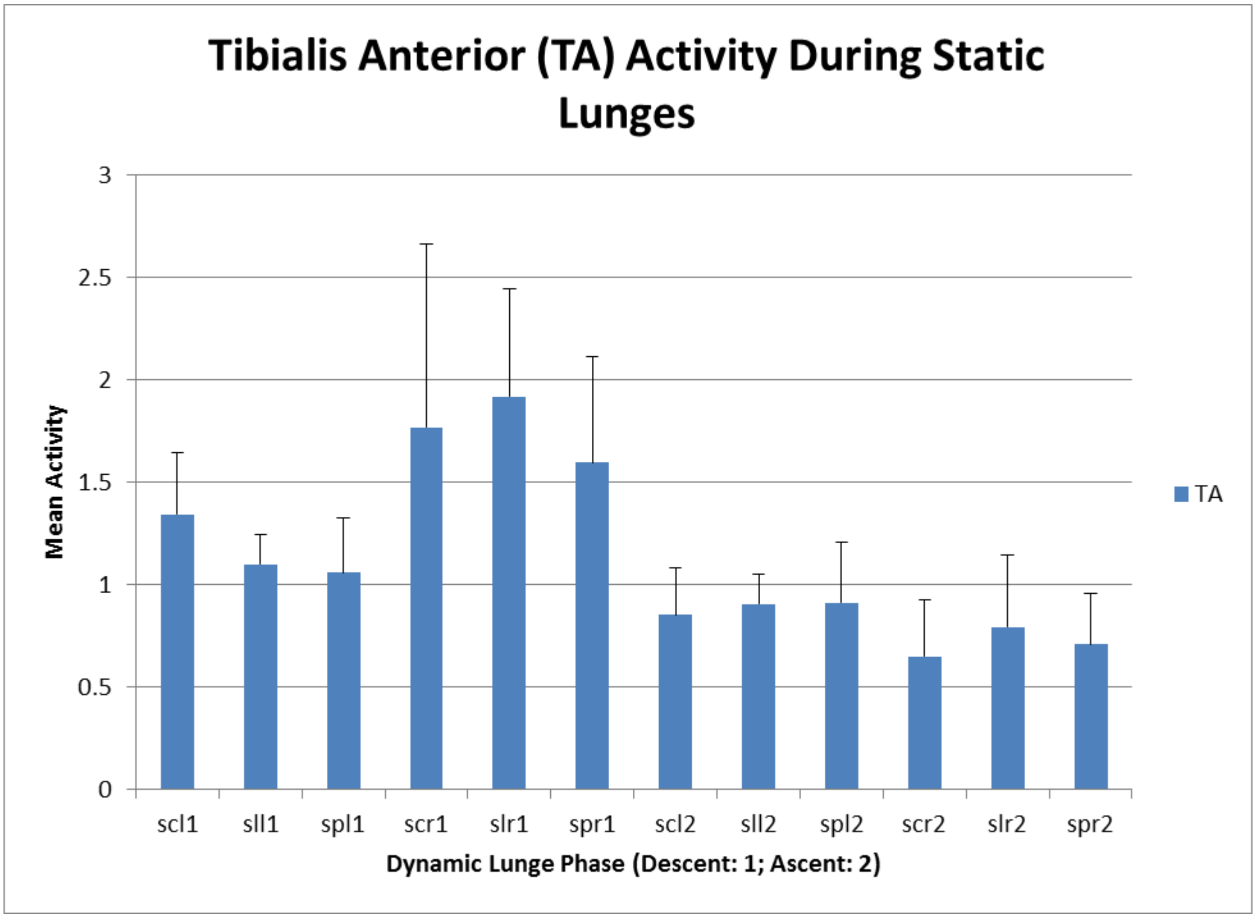

Figure 16 shows the three different static lunge conditions for both the descent and ascent phase.

When comparing all the lunge situations, the TA's highest mean activity level is when the left leg is the non-lead leg during descent. This corresponds with the TA's main function of flexing the foot, allowing the non-lead leg to be lowered to 90 degrees. All other activities seem relatively consistent for the TA in the given situations. Scl1 showed a significantly higher level of activity than sll1(p-value=.025); Slr1 and slr2 also showed significantly higher levels of activity than scr1 and scr2 (p-values=.04 and p-value=.006 respectively). This shows that the TA works harder in the control static lunge condition when it is the non-lead leg.

Figure 17.

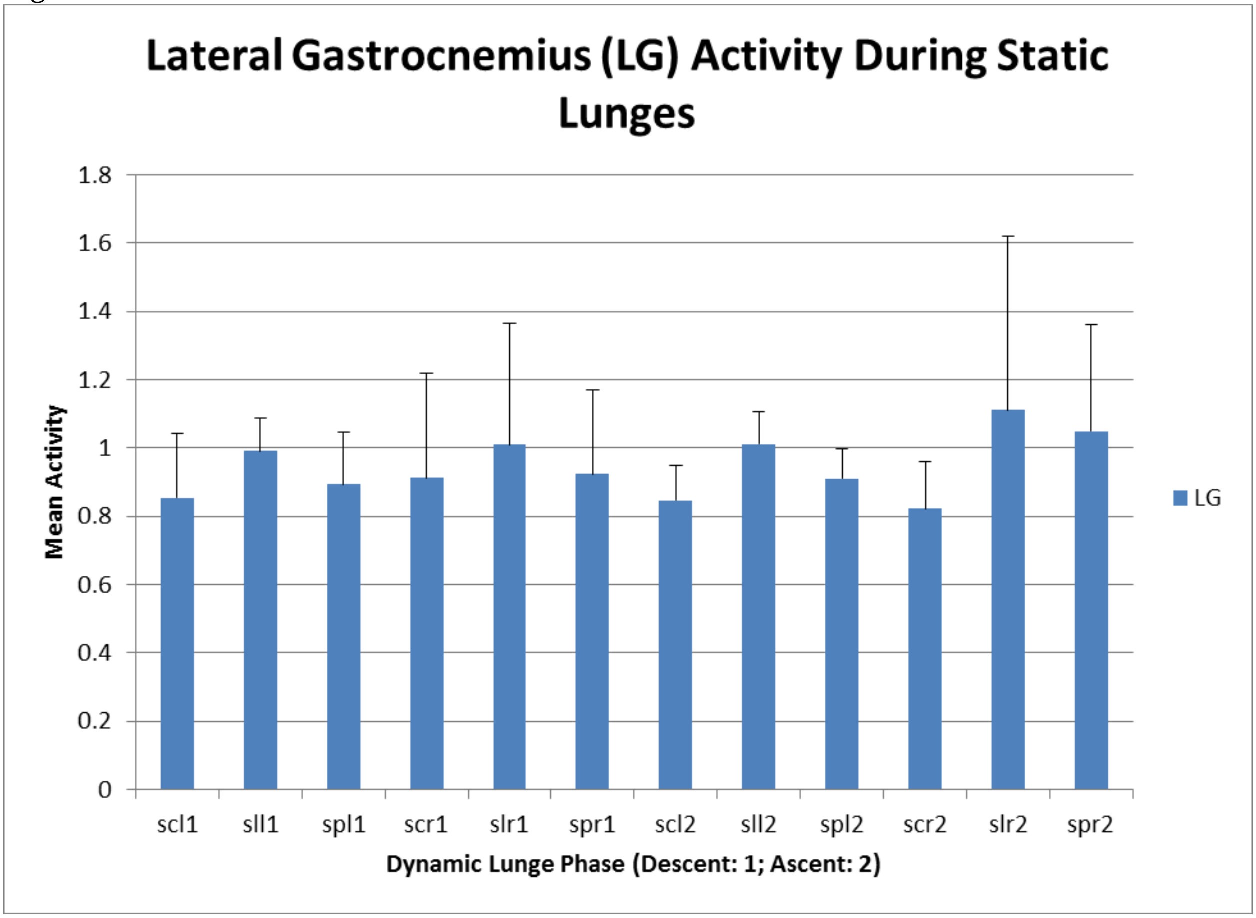

Figure 17 shows the three different static lunge conditions for both the descent and ascent phase.

Unlike the TA, the LG has a lower activation level throughout each lunge condition. The highest activity is seen when the left leg is the non lead, and is need to accelerate the body upward, with the slr2 and spr2 (1.110305 and 1.048657) having similar mean values, and the scr2 (0.846524) having very a smaller mean value. For all situations the static lunge has the highest activity in comparison to the static lunge with the plate or the curtsey lunge, regardless of the lead leg. The static lunge shows significantly higher activity when compared to both the scl and spl in the descent phase (p-value=.025 and p-value=.047 respectively) and ascent phase (p-value=.008 and p-value=.0208 respectively). The static lunge is also significantly higher during the descent phase when the left leg is the non-lead leg in comparison to the curtsey lunge (p-value =.0497). Overall, more activity in the LG is observed when doing the static lunge without a plate.

Figure 18.

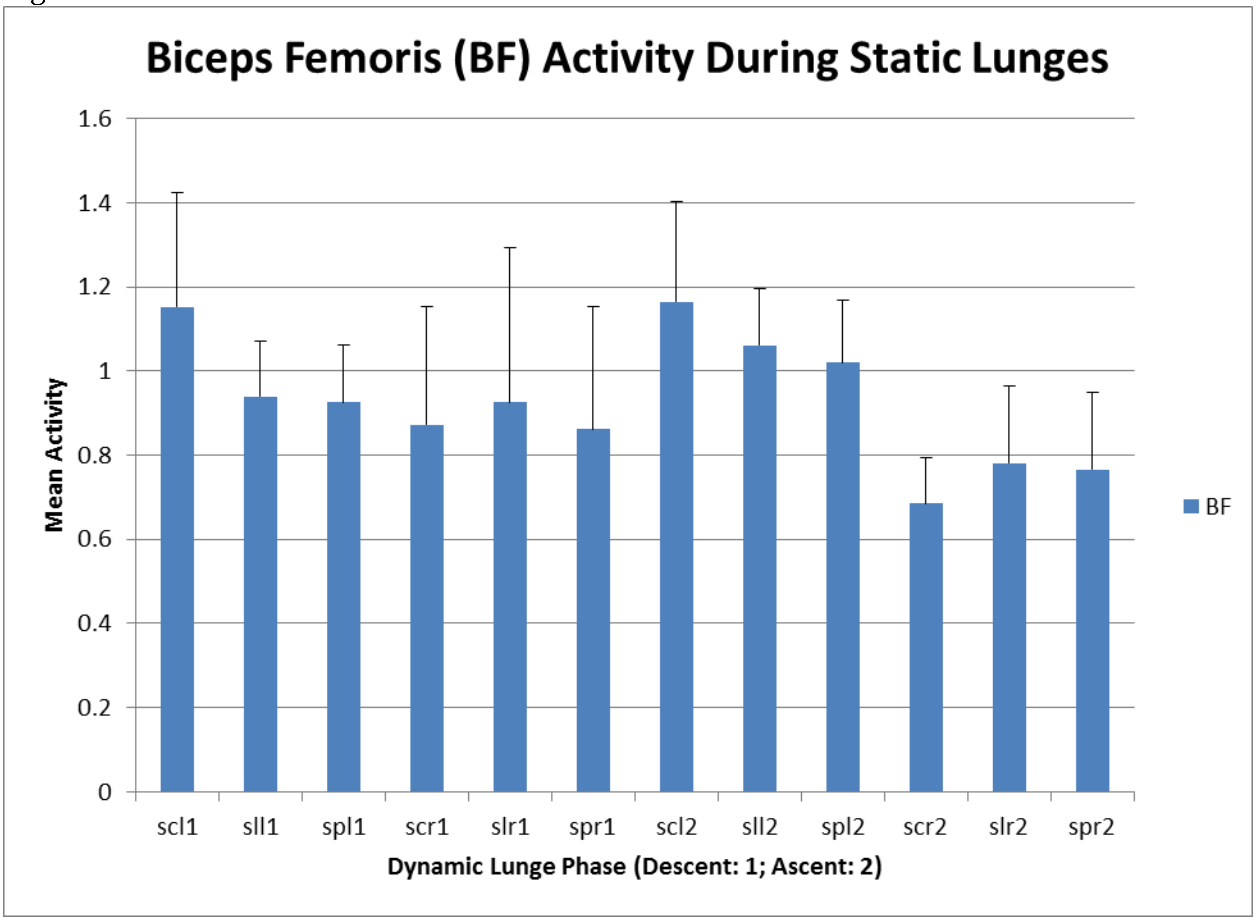

Figure 18 shows the three different static lunge conditions for both the descent and ascent phase.

The BF has the highest mean activity levels when the left leg is the lead leg. The highest activity is seen in the curtsey lunge for scl1 and scl2, however there is only a significant difference in the descent phase for this condition (p-value=.018). Significant values are also seen for the slr2 compared to the scl2 (p-value = .035) and spr2 (p-value = .016); these three conditions show the lowest activity for the BF.

Figure 19.

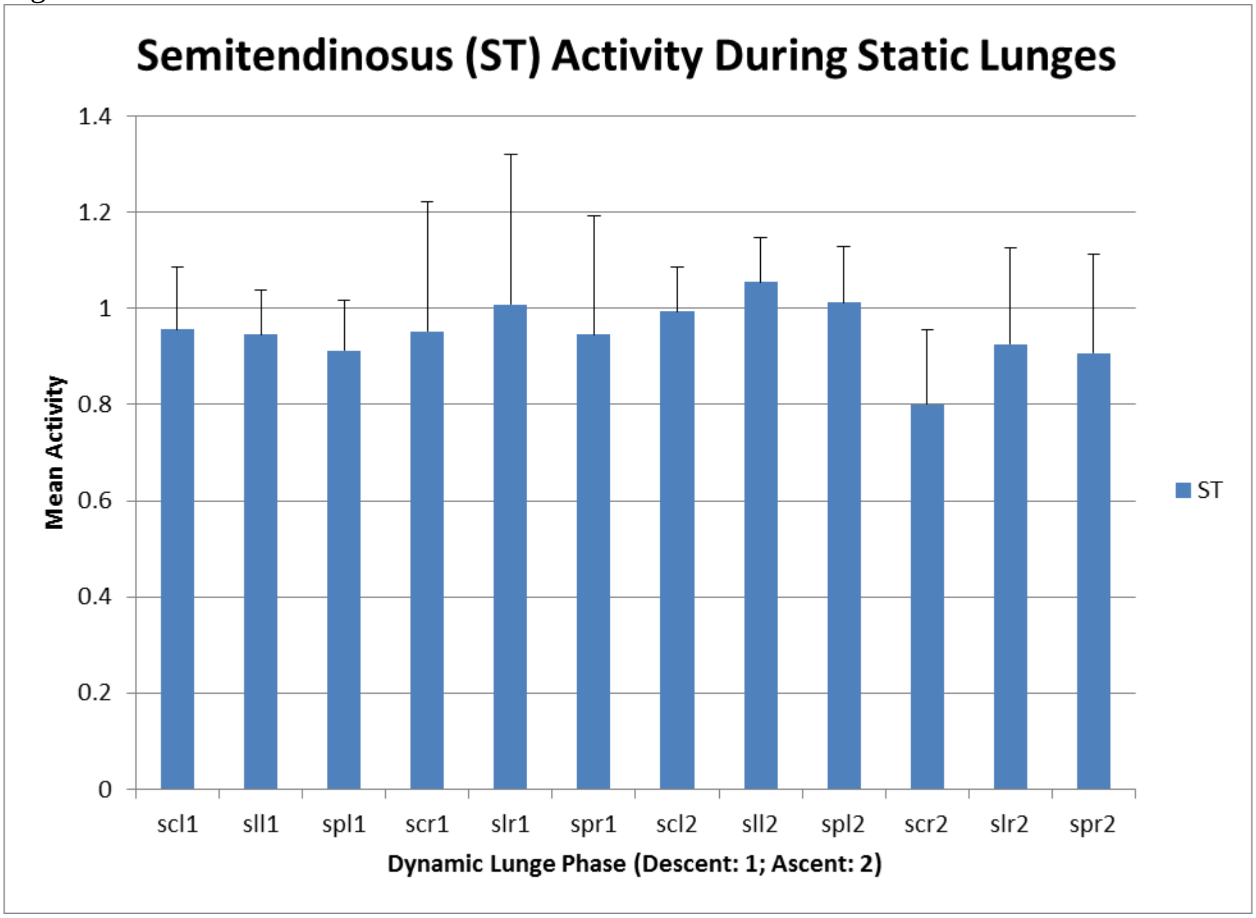

Figure 19 shows the three different static lunge conditions for both the descent and ascent phase.

The mean activity for the ST is relatively consistent throughout each condition. The highest activation in each condition is when the static lunge is performed. The only exception to this is the very similar mean values of the scl1 and sll1 (0.956425 and 0.945762). A significant difference was noted in comparing the static lunge to the curtsey lunge in the ascent phase with the right leg as the lead leg (p-value = .011). Other close significant values were observed when comparing slr1 vs. scr1 (p-value = .076) and sll2 vs. spl2 (p-value = .076); in both these instances the static lunge was observed to have the higher activity level.

Figure 20.

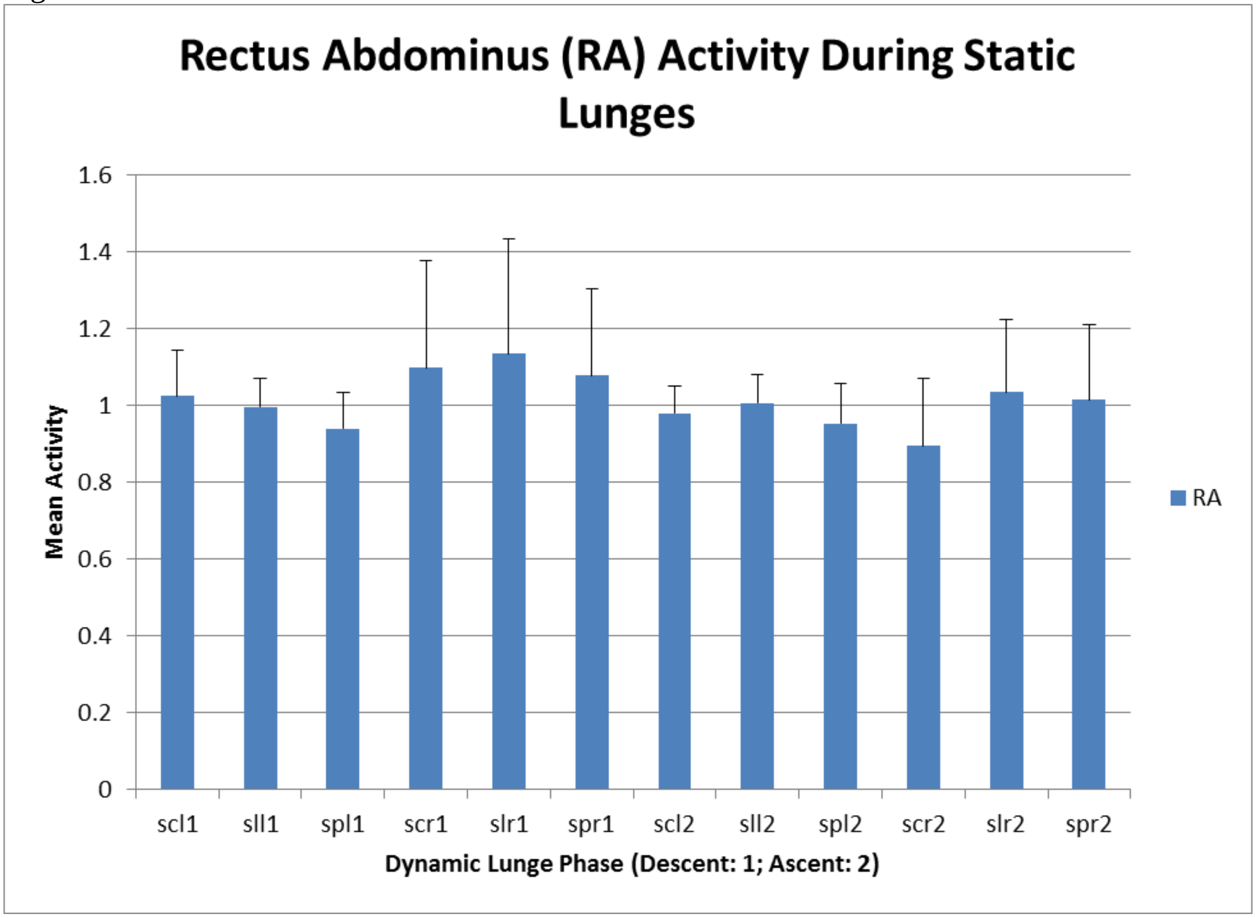

Figure 20 shows the three different static lunge conditions for both the descent and ascent phase.

The highest mean activity levels for the RA were seen during descent when the left leg was the non lead leg, the highest being during the static control lunge. This could possibly indicate the core activating to stabilize the non lead leg while descending. Significant p-values were noted in the ascent phase for comparing the static lunge to the curtsey lunge for ascent with the left leg as the lead leg (p-value = .047), and for ascent when the right leg was the lead leg (p-value = .028). In both conditions, the static lunge has more of an increase in activation which is interesting considering the static lunge, with the tibia directly in line with both the knee and the ankle joint, seems more kinematically stable than the curtsey lunge.

Static Lunge GRF

Figure 21

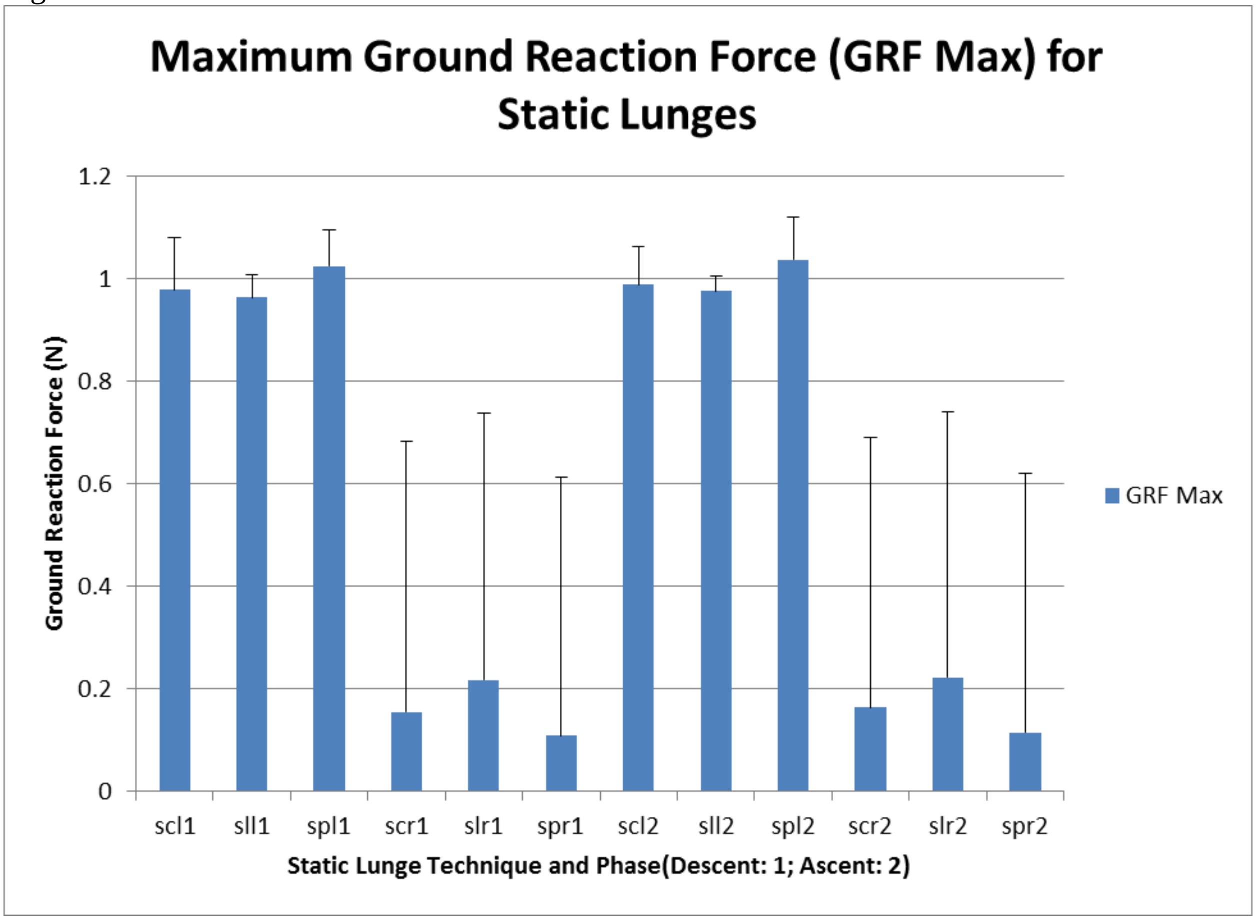

Figure 21 exhibits the maximum ground reaction force felt in all the static lunge conditions.

The highest forces were seen when the static lunge with an external load with the left leg as the lead leg in both ascent and descent phases. The static lunges had the lowest GRF when the left leg was the lead leg in comparison to the other conditions. In comparison, the static lunge when the left leg was the non-lead leg had the highest GRF experienced in descent and ascent. However, the high variances indicate a variety of means for this particular condition, possibly due to the population observed. The static lunges were only significant when compared to the static lunge with the plates, as seen in Table 3 below.

Figure 22.

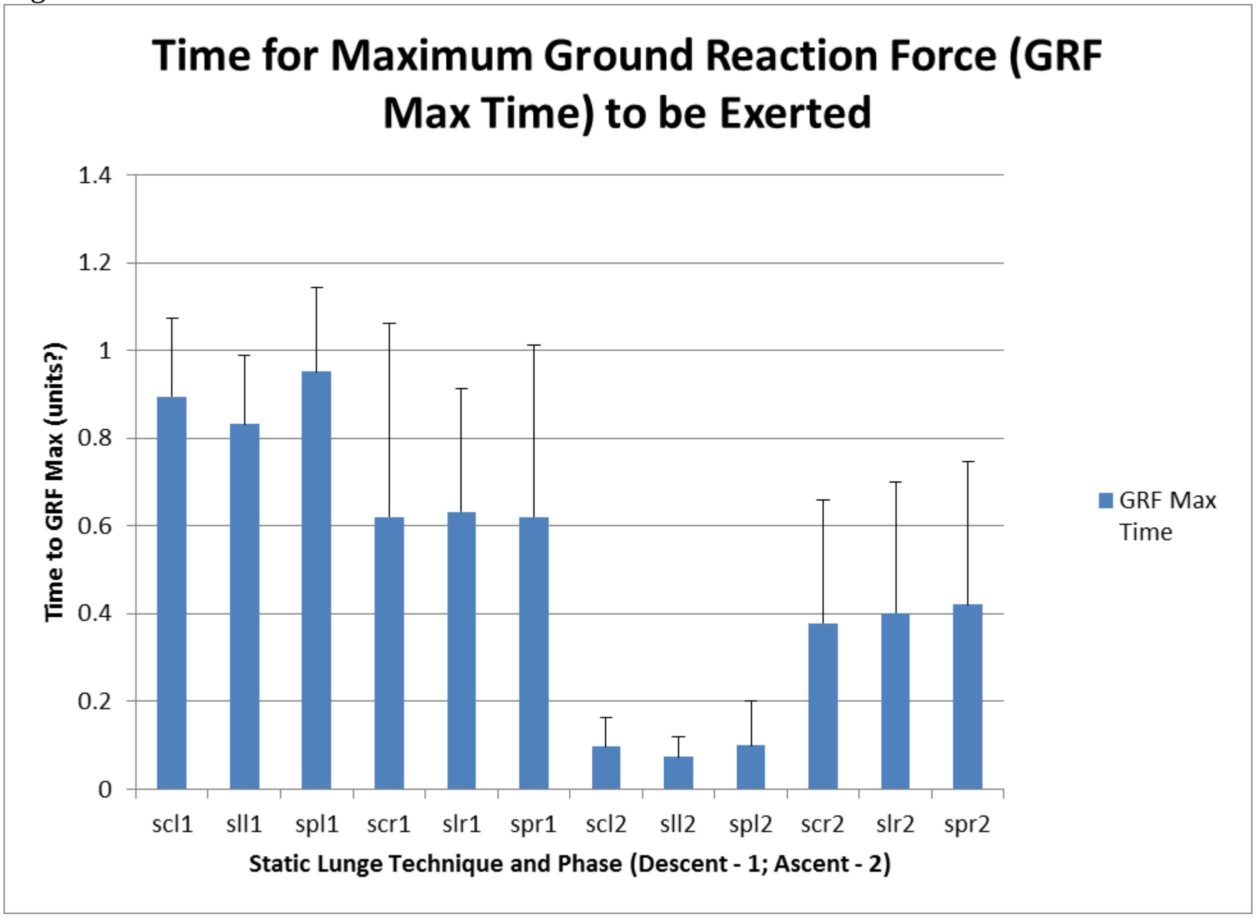

Figure 22 shows the time it took for the ground reaction force to reach its maximum in all static lunge conditions.

The shortest times were noted during ascent phase, but the only significant differences were seen when comparing the static lunge and the static lunge with a plate in the descent phase. Sll1 had a shorter time compared to spl1 (p-value=.048), while the slr2 also had a shorter time compared to spr2 (p-value=.0108). These shorter times could also be attributed to the fact that the force was less for the static lunge without a plate.

Table 3: Significance Values of GFR Max and Time to GRF Max for Static Lunges

Condition	Ground Reaction Force (GRF) Max P-Value	Ground Reaction Force Time to Max P-Value
Sll1 vsSpl1	0.0124	0.048328
Sll1 vsScl1	.3178	.171208
Sll2 vs. Spl1	.0349	.24528

Sll2 vsScl2	.3506	.16924
Slr1 vs. Spr1	.0064	.4583
Slr2 vs. Spr2	.0014	.0108
Slr1 vs. Scr1	.0064	.4583
Slr2 vs. Scr2	.015	.3884

Table 3 shows the significant differences in maximum ground reaction force experienced, and the statistical significance of the time to this maximum experienced.

Chapter 4: Discussion

The purpose of this study was to compare the different lunging techniques in terms of EMG activity and ground reaction forces experienced. Our findings indicate that the lunge activates the GM, RF, and LG in both the dynamic and static lunge conditions the most, while having a smaller activity from the BF. The relatively consistent conditions of the TA, RA, VL, and ST follow our hypothesis (for both the static and dynamic lunges) of similar muscle activations throughout each lunge. Overall, the muscle activities in both conditions were relatively the same and even with an added weight, the static lunge had the higher overall activity majority of the time, proving our hypothesis on muscle activities during the static lunge. The BF was the only lunge significantly activated more during the curtsey lunge, disproving our hypothesis in regards to the curtsey lunge; instead of the knee extensors being more activated in the lead leg, the knee flexors were more activated. Our hypothesis was disproved for both GRF in the dynamic and static lunges; although the forward stepping lunge and curtsey lunge did have higher forces than the backward stepping lunge and static lunge, respectively, the data was not significant. However, the lack in significance could possibly be due to the small population size.

Dynamic Lunge EMG

The overall activity of the 8 muscles measured, the gluteus maximus and rectus femoris were activated the most throughout each lunge condition, with the mean range of the GM being 1.73 and of the RF being 1.63. The high mean activity values for the GM follow Riemann et al. al. (2012) findings of the forward stepping lunge being a hip extensor dominate exercise; this study focused on more of the kinematic aspect of the lunge, rather than the EMG activity levels. Our study shows the hip-extensor, specifically the GM, is activated more when it is the non-lead leg as opposed to the lead leg. Interestingly, the RF showed higher levels of activation than the

BF, while the BF activation means were more consistent throughout each condition than the RF and had no significant differences. Thus, the dynamic lunge conditions may also be a more knee extensor dominant exercise as well, while the BF's consistent co-activating activity may indicate a role in stabilizing the leg throughout the lunge supporting prior research of the hamstrings role in stabilization[43].

The LG and TA had the next highest mean activity values. Both the higher activation levels of the LG and the RF during the dynamic exercises correlate with Jönhagen et al. al (2009) observations of a longer contraction during the dynamic forward walking lunge for both of these muscles. Although both muscles exhibited high activation, there was only significant differences seen in the LG; the dynamic forward lunge for both the descent and ascent phases caused more activation of the LG. This increase in activity for the descent phase could be due to the swing of the leg forward and transfer weight onto the whole left foot, while in the dynamic backwards lunge the weight is transferred to just the distal 1/3 of the posterior foot. The motion of the forward lunge is similar to the gait cycle, in which the LG contracts right before heel strike in order to control the foot(44). However, the significantly higher mean activity seen in dbr2 (p-value=.035) shows that the LG is activated more when propelling the non-lead leg forward and back into the starting position than when the heel strikes the ground.

Similar to the LG's activation levels are the activation levels of the TA. The highest activation for the TA was observed during dbr2 like the LG. This could also possibly be mimicking the TA's increase in activity at the end of stance/beginning of swing during the gait cycle (44); it shows the importance of the TA in contracting in order to help push the non-lead leg back into a starting position. The other three conditions had a higher mean activity during the forward lunge rather than the backward lunge. This observation could possibly indicate the TA's role of co-contraction in order to control foot strike and toe off at the beginning and end of the dynamic forward lunge.

The RA's mean activity levels were consistent in a different way compared to the other muscle activities. As seen in Figure 9, there was an almost step-wise increase with each condition: the lowest being the dbl1 and dbl2, and the highest being the dfr1 and dbr2. The overall highest mean activity (1.45) was seen during dfr1. The higher activity levels during descent show the possible function of the RA in stabilizing the torso during the lunge. Drawing the leg upward during the forward stepping lunge could also be a possible explanation for the higher recruitment of RA fibers. During closed chained kinetic exercises, such as the squat and lunge, it is important to keep a specific upright posture in order to execute the exercise correctly. The high activation levels of the RA show the recruitment of these fibers in order to dynamically stabilize the trunk, and keep the necessary posture throughout the compound movement[46]. The less activity level for the backwards lunge, as compared to the forwards lunge for the RA, could be due to that fact that the individual's center of mass is more stable when one leg does not have to accelerate forward and then decelerate once the lead foot strikes the ground. Instead, the weight is kept stable over the lead leg that is not moved during the backwards lunge.

In contrast, the BF, ST, and VL all had the lowest activation levels. Similarly, the BF and the ST had the highest activity during the dfr1 and dbr1. While none of the BF activity mean values were significant, the ST had significant differences in all the forward lunge conditions, as seen in Figure 1. The consistent activity of the BF and VL, along with the limited activity of ST, can be attributed to the co-contraction in order to control the leg throughout the lunge cycle. This enhances Pincivero et al. al. Findings that the BF and VL contract as a unit during eccentric and concentric contracts of the lunge cycle. This observation further supports that the hip extensors are activated more throughout the lunge cycle, and that even the RA is recruited more in order for stabilization.

As seen in our study, GM, RF, TA, and LG all assumed the similar pattern of the dynamic forward lunge having a slightly higher activity level for each muscle, no matter which leg was the lead leg. However, the exception for all of these muscles was seen in the DBR2 (dynamic backward lunge with the right leg forward during ascent). In each activity level, this specific condition had the highest overall activity for each muscle. The only significant p-values for this condition was seen in the GM (p-value=.01) and LG (p-value=.03).

When comparing these muscle activities in the different dynamic lunges, there are very small significant differences between the forward and the backwards lunge, proving our hypothesis that the muscle activity is relatively the same; the only dramatic exception to this is seen in the LG, which activated significantly higher in the forward lunge (as the lead leg) for ascent and descent, and in the backwards lunge for ascent (as the non-lead leg).

Although our hypothesis was not proven true since the ground reaction forces are not significant, our information does show a higher force is experienced with the dynamic forward lunge. The ground reaction forces for the dynamic forward lunge with the left leg as the lead leg does, in both cases, experience a higher ground reaction force. The difference in forces is more noticeable, and close to significant with a p-value of .07, during the ascent phase of the lunge. The backwards dynamic lunge with the left leg as the lead leg experiences a force almost the same in value for the descent (.993) and ascent phase (.996). The higher forces experienced during the ascent phase are consistent with Escamilla et al.'s research into the side and forward dynamic lunges. He found that the peak flexion during ascent in the dynamic forward lunge was when the highest ground reaction force was experienced[17]. Our research helps support this data, and show that ascent phase is when the highest force is experienced at the knee joint during ascent, because the knee is flexed at 90 degrees[37,18]; during ascent the body is working against gravity and has no momentum, explaining with the GRF is higher during ascent.

Static Lunge EMG

The overall muscles with the highest activation during the static lunges were the GM and the RF. The GM had the highest activity during slr2; the ascent phase of the left leg as the non-lead leg in general exhibited higher activation while the other three conditions had relatively consistent values. As with the dynamic lunges, this data shows that the static lunges also activate the hip-extensor muscle group. Interestingly, the only significant values of the GM show that the static lunge caused more muscle activation than the static plate or curtsey lunge, as seen in Figure 12. The only exception to this was that scl2 was higher than sll2, however there was no significant difference here.

The RF also showed the highest activity when the left leg was the non-lead leg during the ascent phase. Unlike the GM, the RF highest activation was seen during the spr2 phase. This condition was significantly different than both the slr2 and the scr2. This is interesting because, logically, one would assume the RF to have the highest activity in the weight bearing leg during ascent (extension). The activity level seen could perhaps indicate a balance deficiency of the individual, or even muscle weakness.

A slight increase in activation of the RF was seen during the curtsey lunge in comparison to the static lunge during the descent phase (no matter the lead leg), but neither of these conditions were significant. The possible increase in activity could be due to the RF having to compensate for the added weight while extending the posterior leg during ascent. As seen in Sorenson et al.'s study on lunges with different external loads, there is an increase in hip extensor moments but no significant increase in EMG activity. While the lack of significant EMG activity with an added load is also seen throughout the rest of the muscles measured, the RF is the exception and is activated more during this condition.

What is also interesting is the increase in RF activity during the descent phase when the left leg is the non-lead leg. Here, the static lunge with the plate is observed to actually have the lowest activity, while the curtsey lunge has the highest activity; that being slightly higher than the static lunge. The overall activity increase for this condition could possibly be due to co-contraction of the quadriceps in order to control the leg bending downward to a 90 degree angle, and to prevent hyper flexion of the knee.

While the GM and RF both had the highest activity level, like the dynamic lunges, the LG and TA activity levels were much smaller. In each condition, no matter the lead leg, the LG's activity was always highest during the static lunge. This significance of the static lunge having a higher activity was seen in every condition, except with the highest value observed overall during slr2. The highest overall value shows the propulsion necessary to return the non-lead leg back to starting position. Unlike the dynamic lunge conditions, the LG is relatively consistent throughout each condition and lunge, showing its importance in controlling the leg throughout the whole static lunge.

As with the LG, the TA's activity levels were also smaller. However, there was a spike in activity for all lunge conditions during the descent phase with the left leg as the non-lead leg. Due to the increase in ankle flexion and the change in weight distribution onto the toes during this phased it is necessary for the TA to contract, allowing the ankle to flex and the leg to lower downward to a 90 degree angle. The smaller activity levels for the lead leg show possible contraction of the TA in order to stabilize the leg and keep it in a stationary position throughout descent and ascent. The only significance worth noting is a higher activation during scl1 than sll1. This possible increase could be due to the TA needing to contract to help balance the leg and keep the foot facing forward, since the leg is placed at a severe angle during this specific lunge, and also to help stabilize the tibia when weight baring[37,45].

Like the LG and TA, the BF has a decrease in activity in the static lunges when compared to the dynamic lunges; the activity level is also still lower than that of the GM and the ST. Unlike many of the other muscles, the BF shows the highest activity levels during the curtsey lunge when the left leg is the lead leg. In the non-lead leg condition, the higher activity levels are seen in the static lunge for both the descent and ascent phase. The highest overall activity of the BF was seen during scl2, although scl1 was also very close in value (1.16 and 1.15 respectively). This increase in activity could be attributed to the position of the lead leg, specifically the ankle of the tibia, causing a more demand on the co-contracting musculature to help stabilize the leg. In all other lunging instances, the hamstrings and quadriceps are said to be more for co-contraction during the lunge[38], while the focus of the lunge is on strengthening the hip extensors, like the GM, and quadriceps[43]. Previous research has shown that closed chained exercise result in co-contraction of the quadriceps and hamstring muscles. This occurs because of the different moment arms occurring at the knee and the hip joint; The quadriceps contract to counteract the flexor moment at the knee joint, while the hamstrings contract to counter act the flexor moment at the hip joint[40, 41, 42].

The curtsey lunge offers an interesting increase in activity for the BF, but this increase in activity is only seen in the lead leg. The only significant difference though is in the descent phase during this condition, which also follows with Hefzy et al. (1997) observations of a maximum co-contraction of the BF and RF during the peak flexion of the knee. Another significant difference is seen when comparing slr2 to scr2 and spr2 (with slr2 having the highest activity level). While these values are significant, this condition exhibited the lowest amount of activity for the BF.

Also like the LG and TA, the RA's EMG activity was relatively consistent for each condition. The highest level of activity was seen during descent with the left leg as the non-lead leg, which was also the same for the dynamic lunge conditions. We speculate this to be due to stabilizing the pelvic region of the non-lead leg in order to ensure proper form of the lunge is executed. Since the entire static lunge conditions are a non-compound movement, the RA is not activated as much as it was in the dynamic lunge to ensure stabilization.

Similar to the dynamic lunges, the ST and VL have consistent and lower activity levels throughout each lunge condition. In almost all cases, the static lunge for both of these muscles has a higher activity in comparison to the other two lunges. Both the ST and the VL also have the highest activation in the sll2, consistent with the VL's main function of extending the knee; the ST may have a higher activation during this phase to counter act the increase in activity of the VL, and to also prevent hyperextension of the knee. This small activity level of the ST enhances the speculation the lunge being a hip extensor and quadriceps oriented exercise, causing the hamstrings to co-contract with the quadriceps to control the leg during the lunge cycle; this further enhances the idea of the VL and ST being recruited to stabilize the leg.

GRF

Our hypothesis was proven incorrect in terms of the static lunge having a significantly lower ground reaction force than the static curtsey lunge; the static lunge did however have a significantly lower ground reaction force than the static lunge with the added load. When comparing the values, although not significant, the static lunge did experience a lower force than the curtsey lunge. The reason the forces of the two lunges may not be so different is because the static lunge constitutes the same motion of ascending and descending in the same plane. Although the force does not differ significantly, further research should be done regarding the angle of the curtsey lunge on the impact of the knee joint.

What is interesting of the static lunge conditions is how many muscle activities are significant when the left leg is the non-lead leg during ascent in Figure 1. The GM, BF, and RF are significant for comparing the static lunge to the other two conditions, with the static lunge having the higher activity level. The RA, ST, and TA also show significance of the static lunge having a higher activity level here than the curtsey lunge. This data helps show that the non-lead leg is in fact worked more than the lead leg during the static lunge. In terms of our hypothesis regarding similar muscle activity for the lunges, our hypothesis proven correct. Almost all the muscle activities were not statistically significant, and the curtsey lunge only increased the activity of the BF, with no other noticeable differences in the other EMG activity levels.

Like the curtsey lunge, the added 10 lbs to the static lunge did not have a dramatic impact when compared to the regular static lunge overall. This may be because each of the subjects was a relatively active individual, and his/her resistance training more than likely exceeded that of 10 lbs. In turn, more muscle fibers were not recruited to achieve the same results of lunging without the weight. Future studies with different grades of weight resistance during lunging would be necessary to find a specific value in which the EMG activity is significantly different.

Limitations

Many steps and procedures were followed consistently to ensure reliable data such as the number of females and males, the activity level and age of the participants, and order in which the lunges were executed, but like other studies, there were some limitations.

The small pool of participants only allowed us to look at very small population and draw conclusions based on this population. A larger pool of participants with a wider age range would help decrease the variance found in our study, and allow a stronger statistical significance base in order to detect differences.

Future Research

Our study enhances data on both the well studied forward stepping lunge and static lunge, and sparsely studied backwards stepping lunge and curtsey lunge. Future research into the curtsey lunge regarding possible detrimental effects the knee is placed at, or in specific regards to the BF activation would be beneficial to the rehabilitation and exercise communities. Studies that also cause the participant to lunge for a more extended period of time may be able to find differences in the EMG activity of the muscles tested, or perhaps offer more insight into the GRF experienced throughout these lunges. In general, repeating this study with a larger age range and a larger amount of participants will help increase the reliability of this study, specifically with a population who have a good control over his/her balance and stability such as dancers, yoga instructors, and gymnasts.

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Undergraduate Teacher's Assistant **Spring 2012**
Coordinated review sessions for students before each exam
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Biomechanics Laboratory **Fall 2011**
Analyzed and edited data regarding kinematic activity during down hill running

Orthopedic and Rehabilitation Laboratory **Spring 2011**
Assisted thesis research regarding ACL injuries in female athletes

Kinesiology Peer Mentor **Spring 2011 – Summer 2012**
Assisted students in the kinesiology major career related functions and academics.
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Center County Caterer **Spring 2011 – Present**

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Assisted patients with exercises
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Coached ages 6 to 10 twice a week to improve physical fitness.

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Assisted Penn State employees in stretching to prevent injury.
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