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Constraining kinematics during single-leg squats and step-ups can reduce quadratus lumborum activation and facilitate gluteal activation

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Abstract

Increased quadratus lumborum activation and decreased gluteal activation may lead to lateral pelvic drop and increased hip adduction and internal rotation during single-leg exercises. These activation patterns and motions are associated with low back pain or lower extremity injuries. The purpose of this study was to evaluate if mechanically restricting hip adduction and internal rotation of the femur affected muscle activation. Twenty female track and field athletes performed single-leg squats and step-ups, and the quadratus lumborum, gluteus medius and maximus muscles activations were measured with surface electromyography. This study tested the hypothesis that mechanically restricted exercises would decrease quadratus lumborum and increase gluteal muscle activation. Mechanically restricted single-leg squats performed on the left side significantly decreased ipsilateral quadratus lumborum muscle activation. Athletes should focus on maintaining lower extremity alignment in the frontal plane to decrease quadratus lumborum activation. There was some evidence that these athletes have asymmetrical muscle activation patterns.

Keywords

Electromyography, Biomechanics, Quadratus Lumborum Muscle, Step-Ups, Single-Leg Squats, Track and Field Athletes, Female Athletes

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1 Introduction

Athletes often experience lower extremity injuries (Hootman et al., 2007) and low back pain (Bono, 2004), which are detrimental to performance. In fact, when athletes have a lower extremity injury, they are significantly more likely to experience low back pain (Nadler et al., 1998). In runners, weak hip abductor muscles are associated with lower extremity injuries (Ferber et al., 2009; Niemuth et al., 2005) and weak hip extensor muscles are associated with hamstring injuries (Sugiura et al., 2008). These muscle weaknesses are often associated with poor alignment of the pelvis and thigh while running (Ferber et al., 2010). Correct alignment of the lower extremity in the frontal plane is necessary in sport to have efficient movement patterns and reduce the risk of injury. Individuals with low back pain can benefit from neuromuscular training of the muscles surrounding the lumbar spine since it can improve lower extremity alignment in the frontal plane and movement patterns (Corkery et al., 2014). Neuromuscular training has also been shown to decrease the risk of injury (Myer et al., 2005). One goal in track and field is to increase speed while running, jumping or throwing. Increasing speed requires adaptations such as increased strength or range of motion. Athletes often engage in resistance training programs to increase strength and ultimately performance (Delecluse, 1997; Blazevich, 2000). Step-ups and squats are commonly used exercises in resistance training programs. Step-ups are used for increasing unilateral strength of the muscles surrounding hip and knee (McCurdy & Conner, 2003) and maximal squat strength is positively correlated with sprinting speed (Wisloff et al., 2004). When sprinting, compared to running, athletes have a greater stride length with greater lower extremity joint flexion and extension; accordingly, the ground reaction force also increases (Hamill et al., 1983). The risk of lower extremity injuries increases in parallel with the magnitude of the ground reaction force. Modifying lower limb kinematics can change the ground reaction force and indirectly decrease the risk of injury (Prapavessis & McNair, 1999).

1.1 Gluteus Medius Muscle

Single-leg standing has a smaller base of support and doubled ground reaction forces compared to double-leg standing. When transitioning to single-leg standing, the centre of mass must be shifted over the stance foot to maintain postural equilibrium (Santos et al., 2010). The contralateral hip, to the standing leg, may drop laterally so that the centre of mass of the trunk can be positioned over the foot within the new base of support (Tropp & Odenrick, 1988). Accordingly, lateral pelvic drop of the contralateral hip may occur since shifting the centre of mass requires more hip abductor strength. The gluteus medius muscle is a hip abductor and external rotator (Wilson et al., 1976) and keeps the pelvis level (iliac crests at the same height) in closed kinetic chain exercises. The gluteus medius muscle is more active during single-leg standing compared to double-leg standing (Krause et al., 2009) and during single-leg squats compared to double-leg squats (McCurdy et al., 2003). It is also more active during dynamic exercises, such as single-leg squats or step-ups, compared to single-leg standing (Krause et al., 2009). Athletes use single-leg resistance exercises, such as single-leg squats or step-ups, to learn to control the hip through strength and muscle activation patterns, by minimizing excessive hip movements (Blazevich, 2000).

Gluteus medius dysfunction occurs when there is weakness in the muscle or lack of motor control to activate it appropriately. Furthermore, individuals with gluteus medius dysfunction often demonstrate lateral pelvic drop of the contralateral hip (Presswood et al., 2008). The Trendelenburg test assesses the function of the gluteus medius muscle by observing pelvic level and trunk lean while the subject transitions from standing on two legs to one leg. A positive Trendelenburg test, shown in Figure 1, is indicated if the pelvis drops on the contralateral side during weight transfer to one leg. This may indicate weakness of the hip abductor muscles (Kendall et al., 2012). However, a compensated Trendelenburg test involves the participant maintaining a level pelvis by leaning over the stance leg; this may indicate the use of other muscles to maintain stability (Hardcastle & Nade, 1985). The association between lateral pelvic drop and hip abductor strength has been evaluated in individuals with nonspecific low back pain and healthy controls while standing on one leg (Kendall et al., 2010). Interestingly, a three week strengthening program led to an increase in hip abductor strength but no significant difference in the magnitude of pelvic drop (Kendall et al., 2010). Furthermore, Kendall et al. (2012) also studied the association between lateral pelvic drop and hip abductor strength by blocking the superior gluteal nerve to reduce hip abductor strength. They found that there was no difference in lateral pelvic drop measures while standing on one leg (Kendall et al., 2012). This suggests that the strength of the gluteus medius muscle is not solely responsible for reducing lateral pelvic drop. Accordingly, increasing strength in hip abductor muscles is not sufficient to reduce lateral pelvic drop. Thus, the activation pattern of the gluteus medius muscle and recruitment of other muscles may contribute to decreasing lateral pelvic drop. The quadratus lumborum is one muscle that may be recruited to assist the hip abductors to avoid lateral pelvic drop (Hardcastle & Nade, 1985).

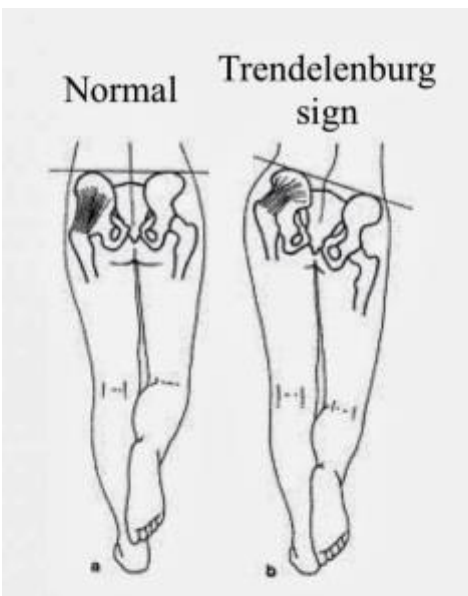

Figure 1: An illustration of a positive Trendelenburg sign.

Adapted from: https://chiropracticforall.wordpress.com/2015/04/22/why-it-is-crucial-to-correct-your-hip-drop-for-runners-athletes-and-even-your-not-so-physically-active-individual/

1.2 Quadratus Lumborum Muscle

The quadratus lumborum muscle is a lateral flexor and extensor of the trunk, (Phillips et al., 2008) and elevator of the hip (Wilson et al., 2005). It also has a spine stabilizing role since it attaches to each lumbar vertebra (McGill et al., 1996). The muscles that help keep the spine stable, including the quadratus lumborum muscle, enable the spine to bear greater force without buckling (Crisco et al., 1992). Akuthota et al. (2008) believe that core strengthening programs improve movement efficiency, decrease compensatory movement patterns and ultimately reduce the occurrence of low back pain. However, these authors state that there is limited evidence to support that core strengthening programs improve athletic performance and reduce risk of injury or low back pain. If the core muscles are weak or have altered firing patterns, then there may be compensatory movement patterns and decreased movement efficiency, which can lead to muscle strain and overuse injuries (Akuthota et al., 2008).

Clinical studies have identified that patients with low back pain often demonstrate excessive activation of the quadratus lumborum muscle as a substitute for gluteus medius activation to maintain a level pelvis (Cynn et al., 2006). Park et al. (2010) studied muscle activation during side lying hip abduction with and without a pelvic compression belt. They found that quadratus lumborum muscle activation decreased and gluteus medius muscle activation increased with the added stability of the pelvic compression belt. Cynn et al., (2006) also studied muscle activation and pelvic tilt during side lying hip abduction with and without a pressure biofeedback unit. They found that the quadratus lumborum muscle activation decreased and the gluteus medius muscle activation increased with the information provided by the pressure biofeedback unit. They also found that the feedback from the pressure biofeedback unit led to decreases in the pelvic tilt angle (Cynn et al., 2006). It appears that if the deep core muscles are unable to provide pelvis stability, then stability may be achieved through an external device and will decrease quadratus lumborum muscle activation, increase gluteus medius muscle activation, and decrease pelvic tilt angle (Cynn et al., 2006). Bewyer & Bewyer (2003) suggest that individuals with altered gluteus medius muscle activation patterns may demonstrate lateral pelvic drop, which can lead to poor mechanics during walking and running. If this lateral pelvic drop occurs during single-leg resistance exercises, then individuals may increase their risk of injury or low back pain (Bewyer & Bewyer, 2003). An example of this muscle relationship is shown in Figure 2.

Figure 2: There is a relationship between activation of the gluteus medius and the quadratus lumborum muscles as they act to help maintain a level pelvis during single-leg stance.

Adapted from: http://sequencewiz.org/2014/05/07/hip-abductors-hip-adductors/

During single-leg resistance or dynamic exercises, the ipsilateral quadratus lumborum muscle, to the standing side, also plays an important role. Since it is a lateral flexor of the trunk (Phillips et al., 2008), it activates to lean the trunk over the stance leg while running or during single-leg resistance exercises. Noehren et al. (2012) found that females that experience patellofemoral pain demonstrated more hip internal rotation and adduction, and had a trend towards greater ipsilateral trunk lean, while running, compared to individuals without patellofemoral pain. They suggest that the runners may have had weak hip abductors leading to increased lateral pelvic drop. Furthermore, to reduce the magnitude of the contralateral pelvic drop, the runners allowed their trunk to lean towards the stance leg (Noehren et al., 2012). Nakagawa et al. (2015) found that individuals that experience patellofemoral pain demonstrated greater ipsilateral trunk lean and hip adduction during single-leg squats. They suggest that ipsilateral trunk lean was a mechanism to reduce contralateral pelvic drop (Nakagawa et al., 2015). Those studies show that increased hip adduction and internal rotation may be associated with increased ipsilateral trunk lean during single-leg exercises and while running. Furthermore, the ipsilateral quadratus lumborum muscle assists in keeping the pelvis level, but should not be excessively activated to lean the trunk over the stance leg to compensate for weak hip abductors, because it is at risk of injury.

1.3 Lower Extremity Alignment in the Frontal Plane during Single-Leg Exercises

Lateral pelvic drop caused by altered muscle activation patterns can lead to poor lower extremity alignment in the frontal plane during single-leg dynamic exercises, such as running or resistance exercises, and it can increase the risk of injury. Running is a dynamic unilateral exercise since there is no double stance phase. It is critical that competitive track and field athletes are able to keep their pelvis level since they sprint at high speeds and poor mechanics can be amplified with speed. This requires greater activation of the hip muscles to avoid lateral pelvic drop. Athletes demonstrating aberrant movement patterns are at a greater risk of developing low back pain (Corkery et al., 2014). Furthermore, imbalances between left and right hip strength are associated with low back pain in athletes (Nadler et al., 1998). Nevison et al. (2015) found that when female track and field athletes run around the corners of the track, they have greater activation in their right gluteus medius muscle in order to produce the lateral force required to run around the corners. However, the athletes did not have strength differences between the right and left sides. These authors speculate that the different muscle activation patterns between sides can be attributed to running around the track in the same direction repetitively (Nevison et al., 2015). That study suggests that female track and field athletes have altered muscle activation patterns between left and right sides which may create an imbalance in muscle activation while running, leading to altered kinematics. These altered kinematics while running may increase the risk of an overuse injury.

During the stance phase of running, the hip is adducted and internally rotated, but to maintain lower extremity alignment in the frontal plane and reduce the risk of injury, the runner needs to reduce further hip adduction and internal rotation as they complete the running stride (Fredericson et al., 2000). Accordingly, the gluteus medius muscle must activate more to control the motion about the hip joint. Inhibition, weakness, or dysfunction of the gluteus medius muscle may reduce its ability to abduct the hip, and it may collapse into an adducted position. Fredericson et al. (2000) believe that athletes with gluteus medius dysfunction will demonstrate more hip adduction and internal rotation than athletes without gluteus medius dysfunction. Runners are prone to lower extremity injuries and often have weaker hip abductors (Bennell & Crossley, 1996) which places them at a higher risk of patellofemoral pain syndrome (Ireland et al., 2003) or iliotibial band syndrome (Fredericson et al., 2000). This may be due to the perception that running is a sagittal plane activity and strength training tends to focus on flexors and extensors (Fredericson et al., 2000). It is essential that athletes have sufficient strength along with proper mechanics to decrease their risk of injury (Ferber et al., 2010). Single-leg resistance exercises such as squats or step-ups can help improve the athletes strength and muscle activation patterns to ultimately decrease lateral pelvic hip drop (Blazevich, 2000).

1.4 Female Athletes

Female athletes participating in competitive sports, including track and field, have higher frequencies of lower extremity injuries than males (Clarke & Buckley, 1980). Alignment of the lower extremity in the frontal plane is a factor that contributes to the increased risk of injuries in females (Dos Reis et al., 2015; Lun et al., 2004). One difference between females and males is that females have a larger quadriceps femoris angle (Q angle)

(Horton & Hall, 1989), which is defined as the angle formed by the combined pull of the quadriceps femoris muscle and the patellar tendon (Hungerford et al., 1979). Accordingly, although females have a greater rate of lower extremity injuries (Clarke & Buckley, 1980) and report more low back pain than males (Nadler et al., 1998), it is not clear whether these occurrences are directly related to their larger Q angles.

Females and males demonstrate different kinematic patterns during single-leg squats. For example, in one study, females started single-leg squats with their knee in a slightly valgus position whereas males started in a neutral position (Zeller et al., 2003). Furthermore, as females went deeper into the squat they moved further into a valgus position whereas males moved into a varus position. The pattern of increasing hip adduction and internal rotation is increasing valgus; during movements it is called dynamic valgus (Munro et al., 2012). Females demonstrate more dynamic valgus than males during single-leg squats (Zeller et al., 2003). Zeller et al. (2003) suggest that these different kinematics between males and females can be attributed to the larger Q angle demonstrated by females and it may predispose females to lower extremity injuries or low back pain. Interestingly, these differences in kinematics are also present in running. Females exhibit greater hip adduction than males throughout the stance phase of running and they require greater activation from the hip abductors to maintain a level pelvis (Ferber et al., 2003). As well, these authors noted that females showed more dynamic valgus at heel strike while running and therefore required greater hip abductor and external rotation activation to maintain a level pelvis. Those differences in kinematics while running (Ferber et al., 2003) and during single-leg squats (Zeller et al., 2003) can also be attributed to the larger Q angle in females. Accordingly, structural alignment plays an important role in the risk of injury in females. Their larger Q angle is associated with altered muscle activation patterns leading to lateral pelvic drop and greater dynamic valgus while running and during single-leg squats.

Strength may be another important factor explaining differences between males and females. Leetun et al. (2004) found that females have less hip abduction and external rotation isometric strength, compared to males. This deficit in hip abduction and external rotation strength likely contributes to the inability to keep the pelvis level, especially during dynamic and high speed movements, and may also permit the lower extremity to move into excessive hip adduction or internal rotation positions. These vulnerable positions increase the risk of injury during athletic manoeuvers. Increased isometric hip strength is a strong predictor of reduced low back pain and also reduced risk of lower extremity injury (Leetun et al., 2004). Since the quadratus lumborum muscle can also be activated to maintain a level pelvis during single-leg standing or dynamic exercises, Leetun et al. (2004) also measured side bridge endurance to evaluate quadratus lumborum muscle strength. This was essential because increased side bridge endurance was associated with a lower rate for first time occurrence of low back pain during a one-year prospective study (Biering-Sorensen, 1984). Leetun et al. (2004) found that males demonstrated greater side bridge endurance compared to females. These differences in structural alignment and strength measures indicate that females and males need to be studied independently.

Female athletes are at greater risk of lower extremity injuries (Dos Reis et al., 2015), low back pain (Nadler et al., 1998), and poor kinematics during dynamic exercises (Dos Reis et al., 2015). Zeller et al. (2003) found that females had greater hip adduction and internal rotation during single-leg squats. These authors also found a trend towards less gluteus medius muscle activation in females than males (Zeller et al., 2003). It is essential that females facilitate gluteal activation during resistance exercises to reduce excessive quadratus lumborum muscle activation (Cynn et al., 2006).

1.5 Gluteus Maximus Muscle

The gluteus maximus muscle is a hip extensor and external rotator (Wanson & Caldwell, 2008). However, individuals with altered patterns of gluteus maximus activation during hip extension may experience low back pain (Leinonen et al., 2000) or lower extremity injuries (Sugiura et al., 2008); this may cause other muscles to compensate in order to perform the movement. While running, the gluteus maximus muscle contracts eccentrically to control hip flexion and internal rotation just before heel strike. It also contracts concentrically during toe-off to extend the hip (Wanson & Caldwell, 2008).

Females that experience patellofemoral pain demonstrate less hip extension endurance and greater hip internal rotation while running compared to females without patellofemoral pain (Souza & Powers, 2009). Hip extensor activation is a predictor of hip internal rotation while running (Souza & Powers, 2009). Accordingly, it is essential to have sufficient gluteus maximus muscle strength to decrease hip internal rotation while running and during single-leg exercises. Compared to males, females have less isometric strength in hip abduction and external rotation during single-leg squats (Willson et al., 2006). There is a strong association between hip external rotation strength and lower extremity alignment in the frontal plane throughout single-leg squats. Individuals with less hip external rotation strength are likely to demonstrate poor lower extremity alignment in the frontal plane when they squat; they may demonstrate a more valgus position of the knee as they squat. They will also have greater hip adduction and internal rotation during squats (Willson et al., 2006), reflecting dynamic valgus.

1.6 Single-Leg Squat and Step-Up Exercises

Increases in squat strength are associated with increases in running speed (Wisloff et al., 2004) and accordingly, squats are important to include in resistance training programs. A study evaluating healthy individuals found that the gluteus muscles are recruited more than 50% maximum voluntary contraction (MVC) during squats (Distefano et al., 2009). These authors found that single-leg squats lead to an increase in strength of the gluteus medius (Mean = 64% MVC, SD = 24%) and gluteus maximus (Mean = 59% MVC, SD = 27%) muscles. Other studies have noted that forward step-ups highly activate the gluteus maximus muscle, and single-leg squats highly activate the gluteus medius muscle (Reiman et al., 2012). Athletes generally perform two to five sets of approximately eight repetitions with resistance of approximately 85% of their maximum effort for these types of training regimes (Willardson & Burkett, 2005). Proper mechanics are essential to gain the most benefit by facilitating correct activation of gluteal muscles while reducing the risk of injury. Feedback could be one strategy to decrease excessive quadratus lumborum muscle activation and facilitate gluteal muscle activation. This could be accomplished through the use of mechanical restrictions placed on the medial and lateral sides of the lower extremity, to mechanically restrict hip and knee motion while performing single-leg squats or step-ups. These mechanical restrictions can act as cues to help maintain appropriate alignment of the lower extremity in the frontal plane by reducing hip adduction and internal rotation.

2 Purpose Statements and Hypothesis

Given that the level of the pelvis is controlled through complex contributions of the quadratus lumborum muscle and the gluteal muscles, and that the quadratus lumborum muscle is at risk of injury due to over activation, it is important to evaluate the activation of these muscles during resistance exercises.

2.1 Purpose Statements

The purpose of this study was to compare activations of the quadratus lumborum, gluteus medius and gluteus maximus muscles during resistance exercises with and without mechanical restriction cues. This study evaluated the single-leg squat and step-up exercises.

2.2 Hypothesis

For the purposes of this thesis, the ipsilateral side was considered the supporting or working leg.

1) Mechanical restriction cues for the single-leg squat exercise will decrease ipsilateral and contralateral quadratus lumborum muscle activations and increase ipsilateral gluteus medius and ipsilateral gluteus maximus muscle activations.
2) Mechanical restriction cues for the step-up exercise will decrease ipsilateral and contralateral quadratus lumborum muscle activations and increase ipsilateral gluteus medius and ipsilateral gluteus maximus muscle activations.

3 Methods

3.1 Participants

Twenty track and field female athletes (age = 22.19 ± 2.46 years) participated in the study. Participants that had experienced chronic low back pain that lasted longer than three months, causing absence from work or school in the last two years, were excluded from the study. Participants who could not perform step-ups or single-leg squats without pain were also excluded from this study. Each participant provided informed consent to the protocol that was reviewed and approved by Western University Research Ethics Board (Appendix A).

3.2 Tasks and Equipment Set-up:

All participants completed two step-up tasks and two single-leg squat tasks. All of these tasks were performed using a 42 cm box, and both the step-up and single-leg squat tasks were performed with and without mechanical restriction cues. An example of exercises performed without mechanical restriction cues is shown in Figure 3. For the mechanical restriction condition, the box included two staggered vertical guides to cue participants' hip and knee motions. An example of exercises performed with mechanical restriction is shown in Figure 4. One vertical guide was attached in the middle of the box and positioned against the participant's medial aspect of the knee. The second vertical guide was attached to the outside of the box and positioned against the participant's lateral aspect of the thigh on the ipsilateral or working leg. The purposes of the mechanical restrictions were to cue the participants to reduce their hip adduction and internal rotation. They were positioned to maintain lower extremity alignment in the frontal plane and prevent hip adduction as the participants moved through hip and knee flexion/extension. A metal stand with a handle bar was placed in front of participants at approximately shoulder height (Figures 3 and 4). The participants held onto the stand for balance but were instructed to not use their arms to assist them to complete the step-up or single-leg squat exercises.

All trials were recorded using a video camera placed posterior to the participant. The video recordings were used for qualitative visual assessment.

Figure 3: An example of a single-leg squat performed without mechanical restrictions.

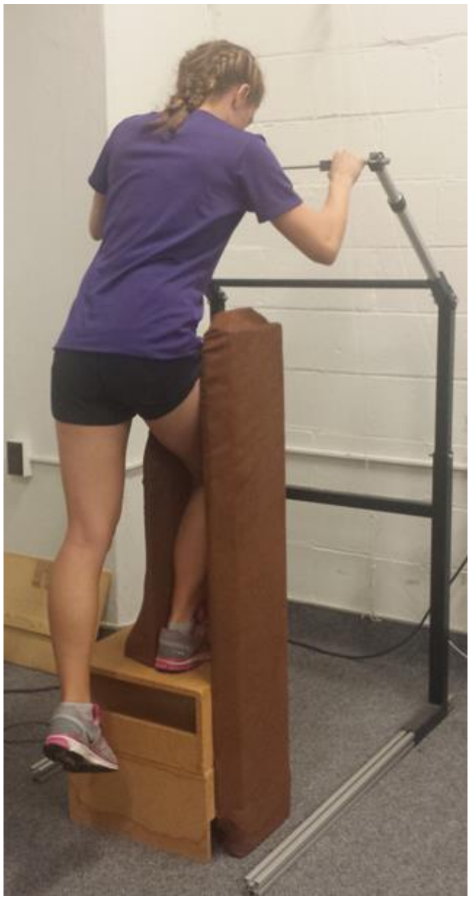

Figure 4: An example of a single-leg squat performed with mechanical restriction.

3.3 Surface Electromyography:

Electromyographic (EMG) activity was recorded bilaterally from the quadratus lumborum, ipsilateral gluteus maximus and ipsilateral gluteus medius muscles using wireless surface electrodes on each muscle (Trigno, Delsys Boston, MA). Electrode sites were cleaned with alcohol, and electrodes were placed over the muscle belly along the direction of the muscle fibres. The electrode for the quadratus lumborum muscle was placed on the lateral portion of the muscle at the midpoint of the line between the 12th rib and the iliac crest (Park et al., 2010). The electrode was affixed while the participant stood and leaned laterally away from the side that the electrode was being placed on. The electrode locations for the gluteus maximus and medius muscles were provided by the

SENIAM project (SENIAM, 2016). The electrode for the gluteus maximus muscle was placed on the skin at the midpoint of the line between the sacral vertebra and greater trochanter (SENIAM, 2016). The electrodes were placed on the skin overlying the muscle while the participant was lying in a prone position. The electrode for the gluteus medius muscle was placed on the skin at the midpoint of the line from the iliac crest to the greater trochanter (SENIAM, 2016) which is the most superficial portion of this muscle and no other muscles overly it. The electrodes were placed on the participant while they were lying on their side. All electrodes were placed bilaterally for each participant.

3.4 Maximum Voluntary Contractions:

Participants performed maximum voluntary contractions for the gluteus medius, gluteus maximus and quadratus lumborum muscles. These reference trials were performed two times for each muscle with at least five minutes rest between each maximum effort (Soderberg & Knutson, 2000). Each maximum voluntary contraction was held for three seconds.

To generate a maximum voluntary contraction for the gluteus maximus muscle, the participant was lying in prone position with their knee flexed. Manual resistance was applied downward to the distal portion of the posterior thigh while the participant was instructed to extend their hip with maximum effort. This protocol is similar to previous researchers (Souza & Powers, 2009). Studies have noted that gluteus muscle activation varies with positioning (Ng et al., 2002), and accordingly, a second maximum voluntary contraction test was done while the participant was standing. The participant stood on one leg while extending their non-supporting leg against a chain, which was tightly fit around their ankle and attached firmly to the ground. The participants held on to the metal stand for balance. The participants were instructed to extend their hip with maximum effort.

The maximum voluntary contraction for the gluteus medius muscle was generated while the participant was lying on their side and abducted their top hip such that the top leg lifted laterally, while downward manual resistance was applied to the distal portion of their lateral thigh. This approach is similar to previous studies (Souza & Powers, 2009; Nevison et al., 2015). Similarly to the above approach for the gluteus maximus, a second maximum voluntary contraction test was done while the participant was standing. The participant stood on one leg while abducting their non-supporting leg against a chain, which tightly fit was around their ankle and attached firmly to the ground. The participants held on to the metal stand for balance. The participants were instructed to abduct their hip with maximum effort.

The maximum voluntary contraction protocol for the quadratus lumborum muscle is not well documented in previous studies (McGill et al., 1996; Park et al., 2010; Cynn et al., 2006). In the current study, it was generated through a restricted hip hike. The participant stood on a box on one extended leg, while the non-supporting leg was also in knee and hip extension with a dorsiflexed foot that hung off of the box. The non-supporting leg had a constraining chain attached around the ankle to apply downward resistance. The participant was instructed to maintain an extended non-supporting leg and elevate their hip upwards against the chain.

3.5 Procedures:

The total time for each participant to complete the study was approximately 60 minutes. The participants filled out the informed consent and questionnaire. They performed the maximum voluntary contractions as described above. The participants were then allowed up to three practice trials with and without the mechanical restrictions to become accustomed to the experimental set up. The participants did not receive coaching on the exercises. Each participant then performed the experimental trials of the single-leg squat and step-up tasks with and without mechanical restriction.

For the step-up exercises, participants started with one foot on the box and one foot on the ground. The participants stepped-up onto the box while keeping their non-supporting leg extended without it touching the box and stepped back onto the ground to complete the repetition. The supporting leg remained on the box throughout the entire movement. Participants completed five consecutive repetitions on each side.

The single-leg squat began by standing on the box on one extended leg while the non-supportive leg hung off of the box. The participants flexed their ankle, knee and hip as much as they could without letting their non-supporting leg touch the ground or box, and then extended their ankle, knee and hip to return to the start position. Participants completed five consecutive repetitions on each side.

Due to the arrangement of the test setup, all of the tasks were performed in the same order for all participants: step-ups without mechanical restriction, single-leg squats without mechanical restriction, step-ups with mechanical restriction, and then single-leg squats with mechanical restriction. Each task was performed on the right side and then they were performed on the left side.

3.6 Data Analysis:

The raw EMG voltages were collected at a sampling rate of 2000 Hz and then full wave rectified and low-pass filtered using a Butterworth filter with a cut off frequency of 3 Hz, similarly to other researchers (Winter & Yack, 1987). The muscle activations for all six electrodes were collected continuously for all the maximum contraction exercises as one trial. The peak muscle activation for each muscle was determined by its absolute maximum contraction voltage during the maximum voluntary contraction trial. This approach is consistent with observation that gluteal muscle activation is sensitive to positioning of the hip and accordingly different activation can be found for various positions (Sidorkewicz et al., 2014).

In each trial, five repetitions of either single-leg squats or step-ups were collected for the bilateral quadratus lumborum, ipsilateral gluteus medius and ipsilateral gluteus maximus muscles. These raw EMG voltages were processed as described for the maximal voluntary contractions. The peak muscle activation of each of the five repetitions from both the step-up and single-leg squat trials were extracted and then averaged to give one value for each muscle for each trial. These average peak values were expressed as a percent of each muscle's maximum voluntary contraction. The data was processed similarly for both with mechanical restriction and without mechanical restriction conditions.

3.7 Statistical Analysis:

I formed *a priori* directional hypotheses that there would be increased gluteal muscle activation, and decreased quadratus lumborum muscle activation, in the mechanical restriction condition. Accordingly, eight paired t-tests were performed to evaluate if there was a statistically significant difference in peak muscle activations for the individual muscles during single-leg squats between the mechanical restriction and no mechanical restriction conditions. These comparisons were performed separately for the right and left sides, and for four muscles: bilateral quadratus lumborum, ipsilateral gluteus medius and ipsilateral gluteus maximus. Eight more paired t-tests were used similarly for the step-up exercise. Statistical significance was determined by comparing α to a one-tailed critical p value.

In this study the critical p value was 0.05, and there were 16 comparisons. A modified Bonferroni adjustment was used in the current study because it increases power by sequential comparison values without increasing the overall risk of a type 1 error (Olejnik et al., 1997). Specifically, the Holm procedure was used. The 16 comparisons were ranked from the smallest effect to the largest effect and the critical p value was calculated sequentially and compared to one-tail p values to determine significant results (Holm, 1979). All statistical tests were performed using Microsoft Excel 2010 (Microsoft Corporation, Santa Rosa, California).

Effect sizes were calculated to quantify the strength of the relationship between two tasks while taking into account the sample size (Vacha-Haase & Thompson, 2004). Cohen's d was used in the current study as a measure of the standardized difference between means and was used to describe the difference of an effect (Lakens, 2013). In the current study effect sizes were interpreted as small if Cohen's d was greater than 0.2, medium if greater than 0.5, and large if greater than 0.8 (Vacha-Haase & Thompson, 2004).

4 Results

4.1 T-test Findings

The ipsilateral quadratus lumborum muscle activation significantly decreased during single-leg squats performed on the left side with mechanical restrictions compared to without ($t=0.0012$, $p<0.05$). This was the only statistically significant finding in the current study.

In addition, there were five comparisons that satisfied the $p <0.05$ threshold, but did not satisfy the critical t after the modified Bonferroni correction was performed; these comparisons are referred to as trends. The contralateral quadratus lumborum muscle had a trend towards decreased activation with mechanical restrictions during single-leg squats performed on the left side with a small effect size, step-ups performed on the left side with a medium effect size, and step-ups performed on the right side with a small effect size. The ipsilateral quadratus lumborum muscle had a trend towards increased activation with mechanical restrictions during step-ups performed on the left side with a small effect size, and single-leg squats performed on the right side with a small effect size.

The remaining ten comparisons did not satisfy the $p <0.05$ threshold. These comparisons are as follows. The gluteus medius muscle did not significantly decrease activation during any exercise performed on either side. There were negligible effect sizes for comparisons of activation of the gluteus medius muscle during single-leg squats performed on the left side, and step-ups performed on the left and right sides. There was a small effect size for the gluteus medius muscle in the mechanical restriction compared to no mechanical restriction condition during single-leg squats performed on the right side. Furthermore, with mechanical restrictions, the gluteus maximus muscle did not significantly decrease in activation during right single-leg squats performed on the right side, or step-ups performed on the right or left sides. These three gluteus maximus muscle activation comparisons had negligible effect sizes. With mechanical restrictions, the ipsilateral quadratus lumborum muscle did not significantly decrease during step-ups performed on the right side, although, the effect size was negligible. Similarly, with mechanical restrictions, the contralateral quadratus lumborum did not significantly decrease during single-leg squats performed on the right side, although, the effect size was negligible.

4.2 Average Activation Changes for Single-Leg Squats

The directional changes in muscle activations during single-leg squats were similar for the right and left sides in the mechanical restriction condition compared to without. Table 1 shows the means and standard deviations of these muscle activations. With mechanical restriction the average activation of the ipsilateral quadratus lumborum muscle decreased by 6% during single-leg squats performed on both the right and the left sides, both with small effect sizes. Similarly, the contralateral quadratus lumborum muscle activation decreased on average by 3% during single-leg squats performed on the right side, although the effect size was negligible, and it decreased on average by 9% during single-leg squats performed on the left side, with a small effect size. The gluteus medius muscle also had decreases in average activation; it decreased on average by 3% during single-leg squats performed on the right side with a small effect size, and it decreased by 9% during single-leg squats performed on the left side, although this response varied considerably between participants and the effect size was negligible. Similarly, the gluteus maximus muscle activation decreased on average by 2% during single-leg squats performed on the right side, and 3% during single-leg squats performed on the left, with negligible effect sizes for both.

4.3 Average Activation Changes for Step-Ups

The directional changes in muscle activations were similar during step-ups performed on the right and left sides in the mechanical restriction condition compared to without. With mechanical restriction, on average, the ipsilateral quadratus lumborum muscle activation increased by 6% during step-ups performed on the right side, although with a negligible effect size, and increased by 6% during step-ups performed on the left side, with a small effect size. Similarly, the contralateral quadratus lumborum muscle activation decreased by 3% during step-ups performed on the right side and 10% during step-ups performed on the left side, both with small effect sizes. The gluteus medius muscle had very small activation changes of 1% average increase during step-ups performed on the right side and 0.25% average increase during step-ups performed on the left side, although both had negligible effect sizes.

Table 1: Mean and standard deviation (SD) reported in percentage of maximum voluntary contraction (%MVC) for the peak activation of various muscles (ipsilateral (Ipsi) and contralateral (Contra) quadratus lumborum (QL), gluteus medius (Glute Med) and gluteus maximus (Glute Max)) while performing the exercises (step-ups and single-leg squats (Squat)). Statistical significance and effect size for comparisons of mechanical restriction cues (Guide) to without mechanical restriction cues (No Guide). The one-tailed t was compared to the p value of the modified Bonferroni adjustment. Cohen's d was calculated to determine the effect size of each comparison. The statistically significant finding is denoted by '*'.

Leg	Muscle	Exercise	Guide		No Guide		One-Tailed t	Cohen's d
			Mean (%MVC)	SD	Mean (%MVC)	SD		
Left	Ipsi QL	Step-Up	31.69	21.14	26.01	15.02	0.01	0.31
Left	Ipsi QL	Squat	27.92	16.95	34.83	19.93	0.00*	0.37
Left	Contra QL	Step-Up	19.27	12.51	28.75	21.04	0.02	0.57
Left	Contra QL	Squat	22.96	14.10	31.57	24.75	0.02	0.44
Left	Ipsi Glute Med	Step-Up	25.47	10.64	25.23	11.50	0.44	0.02
Left	Ipsi Glute Med	Squat	25.74	14.64	25.82	12.39	0.48	0.01
Left	Ipsi Glute Max	Step-Up	30.79	15.59	32.07	17.28	0.18	0.08
Left	Ipsi Glute Max	Squat	29.22	17.11	32.19	17.69	0.04	0.17
Right	Ipsi QL	Step-Up	35.23	16.55	32.28	16.12	0.07	0.18
Right	Ipsi QL	Squat	35.09	18.35	41.49	16.86	0.01	0.36
Right	Contra QL	Step-Up	22.04	15.55	27.64	17.48	0.03	0.34
Right	Contra QL	Squat	26.04	13.35	28.89	18.48	0.20	0.18
Right	Ipsi Glute Med	Step-Up	23.46	9.35	22.47	8.78	0.29	0.11
Right	Ipsi Glute Med	Squat	21.21	9.46	24.10	9.36	0.05	0.31
Right	Ipsi Glute Max	Step-Up	36.74	12.76	38.99	18.07	0.22	0.15
Right	Ipsi Glute Max	Squat	37.08	13.44	38.72	13.98	0.23	0.12

5 Discussion

The purpose of this study was to compare peak activations of the bilateral quadratus lumborum, ipsilateral gluteus medius and ipsilateral gluteus maximus muscles during resistance exercises with and without mechanical restrictions guiding the motion. The current study evaluated single-leg squat and step-up exercises. I hypothesized that there would be decreased ipsilateral and contralateral quadratus lumborum muscle activation and increased gluteal muscle activation for both of these exercises performed with mechanical restriction. The results of this study did not fully support this hypothesis for either the step-up or the single-leg squat exercises. In the current study, the ipsilateral quadratus lumborum muscle had significantly decreased activation during the single-leg squats performed on the left side with the mechanical restrictions, compared to without. Although not significant, the average changes of muscle activation partially supported the hypotheses. Also, consistent directional changes of average muscle activation were found between the right and left sides during both the single-leg squat and step-up exercises. Interestingly, exercises that were performed on the left side had greater changes in muscle activation compared to exercises performed on the right side.

5.1 Interpretation of Muscle Activation

5.1.1 Ipsilateral Quadratus Lumborum Muscle

In the current study, the ipsilateral quadratus lumborum muscle activation significantly decreased during the single-leg squats performed on the left side with mechanical restrictions, compared to without. The quadratus lumborum muscle is a lateral flexor of the trunk (Phillips et al., 2008) and it causes the trunk to lean over the stance leg while running (Noehren et al., 2012) and during single-leg resistance exercises (Nakagawa et al., 2015). In the current study, the ipsilateral quadratus lumborum muscle activation significantly decreased with mechanical restrictions and qualitiative visual assessment of video images revealed that some participants demonstrated more ipsilateral trunk lean during exercises performed without mechanical restrictions, which may be related to the increased ipsilateral quadratus lumborum muscle activation found in the current study

(Figure 5). A compensated Trendelenberg test occurs when a participant maintains a level pelvis by leaning over the stance leg and activating their quadratus lumborum muscle. The current study found less ipsilateral quadratus lumborum muscle activation during single-leg squats performed on the left side. This may indicate that during single-leg squats without mechanical restrictions, some participants had a trunk lean, like in the compensated Trendelenberg test. In contrast, during the mechanical restriction condition, these participants did not use this strategy.

Individuals with patellofemoral pain syndrome experience anterior knee pain while activating their quadriceps muscle, and it is partially the result of an increased load on the patellofemoral joint associated with abnormal patellofemoral mechanics (Hvid et al., 1981). Patellofemoral pain syndrome may occur if individuals demonstrate excessive knee dynamic valgus and increased dynamic quadriceps angles (Nakagawa et al., 2015). Noehren et al. (2012) found that females that experience patellofemoral pain demonstrated more hip internal rotation and adduction, as well as a trend towards greater ipsilateral trunk lean, while running, compared to those without patellofemoral pain. They suggest that runners may have weak hip abductors, and instead of dropping their pelvis laterally, they lean their trunk towards their stance leg (Noehren et al., 2012). In addition, studies examining single-leg hopping have found that individuals that experience patellofemoral pain have weaker hip abductors than individuals that do not experience patellofemoral pain (Dierks et al., 2008). Also, individuals that experience patellofemoral pain demonstrate greater ipsilateral trunk lean while single-leg hopping compared to individuals without patellofemoral pain (Dos Reis et al., 2015). These findings have also been observed in individuals that experience patellofemoral pain during single-leg squats (Nakagawa et al., 2015). These authors suggest that ipsilateral trunk lean was a mechanism to compensate for poor hip control as a means to avoid excessive contralateral pelvis drop (Nakagawa et al., 2015). In summary, individuals that excessively adduct and internally rotate their hips, during single-leg squats or while running, also tend to have greater ipsilateral trunk lean. Presumably, individuals that have greater ipsilateral trunk lean, may have greater activation of their ipsilateral quadratus lumborum muscle to maintain a level pelvis, as observed anecdotally in the current study and as reported in previous studies (Andersson et al., 1996). In the current study, the mechanical restrictions were designed to reduce the participant's hip adduction and internal rotation. Previous studies have shown that these alterations in hip kinematics are associated with less ipsilateral trunk lean in order to maintain a level pelvis. Instead, individuals in previous studies and in the current study would activate their gluteal muscles more to maintain a level pelvis; this would enable them to perform the movement without the compensation of leaning over the stance leg. Although the gluteal muscle activations were not statistically significant in the current study, this could explain the significant decrease in ipsilateral quadratus lumborum muscle activation during single-leg squats with the mechanical restrictions. In summary, the current study found that single-leg squats performed on the left side, with mechanical restrictions, had significantly less quadratus lumborum muscle activation and according to qualtitiative video assessment, some participants appear to have had less ipsilateral trunk lean with mechanical restrictions.

Figure 5: Illustrations of postures adopted by one participant during single-leg squats performed on the left side without mechanical restrictions (left) and with mechanical restrictions (right). These photographs qualitatively illustrate that this participant had decreased ipsilateral trunk lean with mechanical restrictions. Trunk lean is defined as the difference in inclination between the pelvis and the shoulders, as illustrated by the red lines superimposed on the figure. The findings identified that there was significantly less ipsilateral quadratus lumborum muscle activation during single-leg squats performed on the left side with mechanical restrictions, and this may lead to decreased ipsilateral trunk lean.

5.1.2 Contralateral Quadratus Lumborum and Ipsilateral Gluteus Medius Muscles

Previous studies have reported that the contralateral quadratus lumborum muscle had decreased activation, and the ipsilateral gluteus medius muscles had increased activation, with external devices, such as a biofeedback unit (Cynn et al., 2006) or a pelvic compression belt (Park et al., 2010). The mechanical restrictions in the current study acted as an external device by constraining the position of the participant's femur to alter hip kinematics, such as restricting hip internal rotation and adduction. Although the results of the current study for the step-up exercise were not statistically significant, the changes in average activation were consistent with previous studies. For example, in the current study, during the mechanical restriction condition the contralateral quadratus lumborum muscle activation decreased during step-ups performed on the left side with a medium effect size and decreased during step-ups performed the right side, with a small effect size. The average activation of the ipsilateral gluteus medius muscle increased with mechanical restrictions, however, the effect sizes were negigible on both sides. Although the findings from the current study during the step-up exercise were not statistically significant, there were meaningful differences since some of the comparisons had small or medium effect sizes. Accordingly, these comparisons may have practical significance (Kirk, 1996). Furthermore, the average activation changes were consistent with previous studies, as well as the theoretical framework for the complementary action of the quadratus lumborum and gluteus medius muscles to avoid lateral pelvic drop.

During the single-leg squats, the changes in the muscle activations in the current study were only partially consistent with previous studies (Park et al., 2010; Cynn et al., 2006). In the current study, with the mechanical restrictions, the average contralateral quadratus lumborum muscle activation decreased during single-leg squats performed on the left side with a small effect size, and decreased during single-leg squats performed on the right side, although with a negligible effect size. This decrease in the contralateral quadratus lumborum muscle activation is consistent with previous studies (Park et al., 2010; Cynn et al., 2006). However, in constrast with these previous studies, the current study found that the average gluteus medius muscle activation decreased in the mechanical restriction condition during single-leg squats performed on the right side with a small effect size and decreased during single-leg squats performed on the left side, although the effect size was negligible. In summary, the current study has average activation changes of the contralateral quadratus lumborum muscle during single-leg squats that is consistent with previous studies, but the average activation changes of the gluteal muscles are not.

Previous studies suggest that excessive quadratus lumborum muscle activation is associated with low back pain and altered movement patterns (Akuthota et al., 2008; McGregor & Hukins, 2009). These studies show that external mechanisms can decrease quadratus lumborum muscle activation (Akuthota et al., 2008; Cynn et al., 2006; McGregor & Hukins, 2009; Park et al., 2010). The current study found that the contralateral quadratus lumborum muscle activation decreased during both the step-up and single-leg squat exercises in the mechanical restriction condition. The mechanical restrictions were designed to decrease hip adduction and internal rotation. The contralateral quadratus lumborum muscle decreased with mechanical restrictions during step-ups performed on the left side, with a medium effect size, decreased during step-ups performed on the right side with a small effect size, and decreased during single-leg squats performed on both the right and left sides, both with small effect sizes. In summary, during both the step-up and single-leg squat exercises in the mechanical restriction condition, for both the right and left sides, the contralateral quadratus lumborum muscle activation decreased. Previous studies suggest the importance of decreasing the activation of the contralateral quadratus lumborum muscle to reduce the risk of injury (Cynn et al., 2006; Park et al., 2010). In the current study, participants demonstrated a trend towards decreased average activation of the contralateral quadratus lumborum muscle during the exercises performed with the mechanical restrictions, with small or medium effect sizes.

5.1.3 Differences between the Right and Left Gluteus Medius and Quadratus Lumborum Muscles

Activation of the gluteus medius muscle keeps the pelvis level during single-leg exercises (Krause et al., 2009). In the current study, there were differences in muscle activation during single-leg squats performed on the left side compared to the right side. For example, on average there was a larger change of muscle activation during exercises performed on the left side compared to the right side. The exercises performed with mechanical restriction had decreased gluteus medius muscle average activation by 3% during single-leg squats performed on the right side and 9% during single-leg squats performed on the left side, compared to without mechanical restriction. Similarly, the mechanical restriction condition had average decreases in contralateral quadratus lumborum muscle activation by 3% during single-leg squats performed on the right side and 9% during single-leg squats performed on the left side. Since there was more change in activation during single-leg squats performed on the left side for both of the muscles, it appears that these participants had differences in muscle activation patterns between sides. Athletes engage in resistance training to increase strength (Delecluse, 1997) since maximal strength in squats is associated with sprinting speed (Wisloff et al., 2004). If athletes have different activation patterns between their right and left sides during single-leg squats, then those patterns may also be present while running. One study found that female track and field athletes had significantly increased gluteus medius muscle activation on the right side while running around the curve compared to the straightaway, while the left side showed a trend towards decreased activation (Nevison et al., 2015). These authors suggest that female track and field athletes may have asymmetrical muscle activation patterns by running around the curve of the track in the same direction (Nevison et al., 2015). Their study showed that track and field athletes have the same strength on their right and left sides, but that they activate their left and right gluteus medius' muscles differently depending on the biomechanical demands, such as a curve or straightaway. In the current study, the athletes performed the same exercises on both the right and left sides; however, exercises performed with the mechanical restrictions showed a greater change in muscle activation during single-leg squats performed on the left side. These track and field athletes may have conditioned muscle activation patterns due to specificity and consistency of their training, and the differences observed in the current experiment may reflect these conditioned patterns.

Nevison et al. (2015) only studied long distance runners, and these individuals typically train by running around the track the same direction. The inclusion criteria for the current study only required participants to be competitive track and field athletes and in turn, the participants were from a variety of track and field event groups including running, sprinting, hurdling, and jumping. The participants that were distance runners run multiple laps around the oval track each practice; however, most athletes regardless of event group still perform warm-up laps or recovery workouts that involve running around the track repetitively in the same direction. Also, athletes that jump or hurdle have functional asymmetries (Gasilewski et al., 2014), and this may affect their muscle activation patterns between the right and left sides. In the current study, there were larger muscle activation changes on the left side compared to the right side. This may reflect that individuals who sprint, hurdle or jump may also have asymmetrical muscle activation patterns, analogous to the changes observed in long distance runners (Nevison et al., 2015).

It is appropriate to consider whether athletes should focus on balancing their activation patterns through resistance exercises, or if it may be advantageous to have asymmetries. For example, sprint hurdlers generally use the same leg to run over each hurdle (Iskra & Coh, 2003). Accordingly, it may be that the asymmetries that were observed in the current study may reflect positive adaptations to their racing requirements. Furthermore, elite athletes are unlike the general population and asymmetries in muscle activation patterns may be the key for their success. For example, sprint hurdlers may be successful because their muscle activation patterns are specifically trained, and may be different on their hurdling compared to their non-hurdling leg (Iskra & Coh, 2003). In summary, in the current study there were larger changes in muscle activation during single-leg squats performed on the left side compared to the right side which may be because track and field athletes have adaptive asymmetries. This could be explained because each track and field event requires a primary leg, whether their competitive sport involves running continuously in the same direction around an oval track, sprint hurdling, or jumping. Future studies should evaluate the importance of resistance training to determine if it should focus on balancing muscle activation patterns or acknowledge the importance of functionally appropriate asymmetries.

5.1.4 Gluteus Maximus Muscle

The current study observed minimal changes in gluteus maximus muscle activity for the exercises performed in the mechanical restriction condition, compared to without. The gluteus maximus muscle average activation decreased by 2% during the single-leg squat performed on the right side, 3% during the single-leg squat performed on the left side, 2% during the step-up exercise performed on the right side and 1% during the step-up exercise performed on the left side. However, the effect sizes for all comparisons were negligible. The hip can internally rotate when the gluteus maximus muscle is not activated sufficiently (Souza & Powers, 2009). Accordingly, the lack of change in gluteus maximus muscle activation in the current study may be because the participants were not internally rotating. The gluteus maximus muscle is a hip extensor and is not activated very strongly in slow movements, such as walking, but it is more active as speed increases (Lieberman et al., 2006). The change in gluteus maximus muscle activation during the mechanical restriction condition, compared to without, may have been minimal because of the amount of hip flexion performed by the participants. More activation is required from the gluteus maximus muscle as the knees are flexed more than 90 degrees (Caterisano et al., 2002). The box that was used in the current study was 42 cm high and allowed the participants to reach approximately 90 degrees of hip flexion during both the single-leg squat and step-up exercises. The participants were instructed to have as much ankle, knee and hip flexion as they could during the exercises, however, if the participants did not attain 90 degrees of hip flexion, then this may provide reasoning for the minimal gluteus maximus muscle activation.

5.2 Observations

There was one statistically significant difference in muscle activations in the mechanical restriction condition compared to without. One reason for the lack of statistically significant findings may be because the inclusion criteria favoured strong and healthy competitive track and field athletes. The participants were likely experienced with the single-leg squat and step-up exercises and have been coached on proper form during resistance exercises. Also, they generally have strong lower extremity and gluteal muscles (Nevison et al., 2015). The participants may have been performing the exercises with proper form, whether they were performing exercises with the mechanical restrictions or without. Thus, the mechanical restrictions may not have altered their kinematics, and may not have required substantial changes in muscle activations. It may be useful to evaluate individuals that do not have experience with resistance exercises, as perhaps they would perform the exercises with poor form without mechanical restrictions, but then have improved form with mechanical restrictions.

In the current study, the mechanical restrictions were designed to decrease hip adduction and internal rotation by restricting the femur, since decreasing hip internal rotation and adduction may result in decreased quadratus lumborum muscle activation. The mechanical restrictions were positioned to maintain lower extremity alignment and prevent hip adduction as the participants moved through hip and knee flexion/extension. Qualitative visual observation of the task performances revealed that the mechanical restrictions seemed to maintain the alignment of the stance foot, knee and hip. However, the mechanical restrictions did not overly control for the position of the pelvis. This allowed the hip to adduct by moving the pelvis towards the fixed standing leg. This is consistent with the observation that some participants appeared to adduct their hip by rotating their pelvis towards the stance leg despite the mechanical restrictions. When individuals transition from double-leg to single-leg standing their center of mass is shifted to stay within the smaller base of support (McCurdy et al., 2010). Also, when individuals perform single-leg exercises they exhibit hip adduction and internal rotation in order to maintain their centre of mass over their standing leg. In the current study, the mechanical restrictions were designed to prevent hip adduction and internal rotation, and compensation was required to maintain their centre of mass within their base of support. In the current study, qualitative visual observation showed that the participants rotated their pelvis towards their standing leg, perhaps reflecting this type of compensation. It may be that the mechanical restrictions used in the current study did not effectively reduce hip adduction and internal rotation. It may be useful to measure hip kinematics or to provide a different form of mechanical restriction to maintain proper lower limb alignment.

5.3 Recommendations for Athletes

Athletes need to maintain the alignment of their lower extremity in the frontal plane as well as a level pelvis while running and during single-leg exercises to reduce the risk of injury (Myer et al., 2005). Poor lower extremity alignment in the frontal plane may involve lateral pelvic drop, which may be associated with increased quadratus lumborum muscle activation (Hardcastle & Nade, 1985). The mechanical restrictions used in the current study did not result in significant decreases in quadratus lumborum muscle activation during both of the resistance exercises on both sides. Athletes may need more effective mechanical restrictions or alternative solutions to enable a reduction in quadratus lumborum muscle activation. One way that athletes can improve their kinematics is with visual feedback. Running with real-time visual feedback has been shown to reduce the risks associated with excessive lower extremity loading (Crowell et al., 2010). Similarly, verbal feedback can augment visual feedback to improve kinematics. For example, real-time visual and verbal feedback reduced the knee external adduction moment through a gait retraining intervention with hip kinematic modifications (Barrios et al., 2010). Visual feedback through the use of a mirror or instrumentation with real-time values of hip motion on a computer screen in front of the participants, along with the mechanical cues, may help athletes improve their lower extremity alignment in the frontal plane. Verbal feedback on proper hip kinematics or facilitating gluteal activation along with the mechanical restrictions could also help athletes improve their lower extremity alignment in the frontal plane. Another way that athletes can improve their kinematics is through neuromuscular training. Proprioception plays an important role in injury reduction (Mandelbaum et al., 2005). A neuromuscular training intervention focused on avoiding excessive dynamic valgus knee movement and improving gluteal muscle activation patterns during plyometric and sport-specific agility drills, is associated with decreased risk of lower extremity injuries (Mandelbaum et al., 2005). Neuromuscular training is associated with reduced risk of injury by improving lower extremity alignment in the frontal plane and movement patterns during single-leg dynamic movements (Myer et al., 2005). The participants in the current study performed few practice trials and were not given feedback on proper alignment or muscle activation patterns. With neuromuscular training, the athletes may be able to maintain their lower extremity alignment in the frontal plane, as well as a level pelvis without the use of mechanical restrictions. A third way to improve kinematics is through strength training. Leetun et al. (2004) found that females have less hip abduction and external rotation strength, and lower quadratus lumborum muscle endurance than males. Also, females have a larger Q angle than males (Horton & Hall, 1989) and they demonstrate different kinematics, such as greater hip adduction and internal rotation while running (Ferber et al., 2003) and single-leg squats (Zeller et al., 2003). If females had more strength in hip abduction and external rotation, then they may not demonstrate excessive hip adduction and internal rotation during these activities. If mechanically restricted exercises were used in combination with feedback, neuromuscular training, or specific strength training, then they may exhibit improved hip kinematics and ultimately the quadratus lumborum muscle activation may decrease.

5.4 Limitations

A limitation of this study was that the participants' hip kinematics were not quantified. During pilot testing, two Penny and Giles electrogoniometers (SG150, Biometrics Limited, Gwent, UK) were placed on the lateral aspect of the thigh and pelvis to quantify hip adduction/abduction, flexion/extension, and internal/external rotation. However, we observed that the electrogoniometers did not accurately measure hip abduction/adduction and internal/external rotation when the hip flexion approached 90 degrees. We believe that this occurred because the thigh attachment shifted as the hip flexed due to the contour of the thigh. Accordingly, the electrogoniometers could not be used to accurately quantify the motion of the hip. It would have been useful to associate the changes in hip adduction and internal rotation motion with the change of muscle activations in the quadratus lumborum and gluteal muscles, as performed in other studies (Cynn et al., 2006).

A limitation of the equipment set-up was that the participants could have used their arm strength on the metal stand to pull themselves up. The protocol for the current study required the participants to only use the metal stand for balance, but we did not measure the forces on the stand. It is unlikely that the participants pulled on the stand since it was not bolted down and therefore could not have supported large forces.

Surface EMG also has limitations such as cross talk. The quadratus lumborum muscle is only partially superficial and the deep portion is covered by the erector spinae muscle. Also, the transverse abdominals, internal and external obliques, rectus abdominals, psoas and iliacus muscles are near and could contribute to the signals to the quadratus lumborum electrode. Although the electrode was placed directly over the superficial part of the quadratus lumborum muscles, it may have also collected signals from other muscles. Thus, the EMG signal from these other muscles may have been contributing to the recordings from the quadratus lumborum muscle. However, the electrode was placed on the skin overlying the quadratus lumborum muscle similarly to previous studies (Noh et al., 2012; Cynn et al., 2006). Also, previous studies have shown that this placement of surface electrodes adequately represents quadratus lumborum muscle activation compared to fine-wire EMG (McGill et al., 1996). Another limitation of surface EMG is the requirement for maximum voluntary contractions in order to compare activations across participants (Soderberg & Knutson, 2000). Each participant was required to contract each muscle to their maximum while a force was being applied, but it can be difficult to achieve reliable maximum efforts (Soderberg & Knutson, 2000). For example, the participant may not trust the individual applying the force, the participant may not know how to give their maximum effort, or the participant may be compensating with other muscles against the applied force. However, maximum voluntary contraction normalization provides better reliability for evaluating the muscle’s maximum ability in healthy, pain-free participants compared to dynamic methods (Bolgla & Uhl, 2007). Some evidence suggests that it is important to perform trials at different joint angles to get the greatest maximum voluntary contraction (Ng et al., 2002). The current study performed maximum voluntary contractions in prone and standing positions for the gluteus maximus muscle, and side lying and standing positions the gluteus medius muscle in an attempt to measure the greatest maximum voluntary contraction.

The highly trained nature of the participants in the current study may be another limitation. The participants in this study were all female track and field athletes and previous research reported that this group has strong gluteal muscles (Nevison et al., 2015). As well, the participants had experience with squats and step-ups, and had well trained muscle activation patterns. Although female athletes are prone to lower extremity injuries and low back pain compared to males (Clarke & Buckley, 1980), the participants in the current study may already be experts at performing single-leg squat and step-up exercises without excessive hip adduction and internal rotation, and accordingly may not have been strongly affected by the mechanical restrictions.

This study did not randomize the order of performance of the exercises because of equipment set-up. One box was used for exercises with mechanical restriction and another box was used for exercises without mechanical restriction and accordingly it was convenient to perform the exercises in a standardized order. However, this protocol was not expected to lead to fatigue since athletes generally perform multiple sets of approximately eight repetitions of squats or step-ups with resistance of 85% of their maximal effort during one resistance training session (Willardson & Burkett, 2005). Accordingly, since one trial had five repetitions, it is unlikely that one trial would affect the following trials, and thus it is not expected that any order effects would have confounded this experiment.

This study also did not randomize which side that the exercise was performed on first. All tasks were performed on the right side and then the left side. Accordingly, there may have been some motor learning such that initial performances with the right limb may have influenced subsequent performances with the left limb; a similar phenomenon has been documented in individuals undergoing rehabilitation following rupture of their anterior cruciate ligament (Urbach & Awiszus, 2002). This may be a reason for the larger changes of muscle activation found during exercises performed on the left side compared to the right side.

5.5 Future Research

Females were used in this study because they demonstrate different kinematics during single-leg exercises and have different isometric strength measures compared to males. For example, females demonstrate more hip adduction and internal rotation during single-leg squats (Zeller et al., 2003) and while running (Ferber et al., 2003), as well as greater lateral pelvic drop and less gluteal strength than males (Leetun et al., 2004). Future research should continue to focus on females and evaluate quadratus lumborum muscle activity and its association with hip kinematics since females are more likely to experience low back pain compared to males (Nadler et al., 1998).

Athletes often experience low back pain and it contributes to lost time participating in sport (Bono, 2004). Clinicians often observe excessive quadratus lumborum muscle activation in patients with low back pain (Cynn et al., 2006; McGregor & Hukins, 2009). The contralateral quadratus lumborum muscle may increase activation to compensate for weak hip abductors (Hardcastle & Nade, 1985). Runners with weak hip abductors may demonstrate more lateral pelvic drop and may increase their ipsilateral trunk lean (Noehren et al., 2012). Individuals with weak hip abductors also demonstrate more ipsilateral trunk lean during single-leg exercises (Dos Reis et al., 2015). Future research could compare individuals with low back pain to those without low back pain to evaluate whether training to constrain hip motion can decrease the symptoms of pain. In addition, future research should evaluate the use of visual feedback, verbal feedback, neuromuscular training, or strength training on decreasing lateral pelvic drop in female track and field athletes.

6 Conclusion

Correct lower extremity alignment in the frontal plane is important for athletes, during resistance exercises or while running, to reduce the risk of injury (Myer et al., 2005). Single-leg squats performed on the left side with mechanical restrictions significantly decreased ipsilateral quadratus lumborum muscle activation. Female track and field athletes have asymmetrical muscle activation patterns between the right and left sides, although it is unclear whether the asymmetries are advantageous or detrimental to performance. Future research should incorporate the use of verbal feedback, visual feedback, or neuromuscular training to improve athletes' lower extremity alignment in the frontal plane and decrease quadratus lumborum muscle activation.

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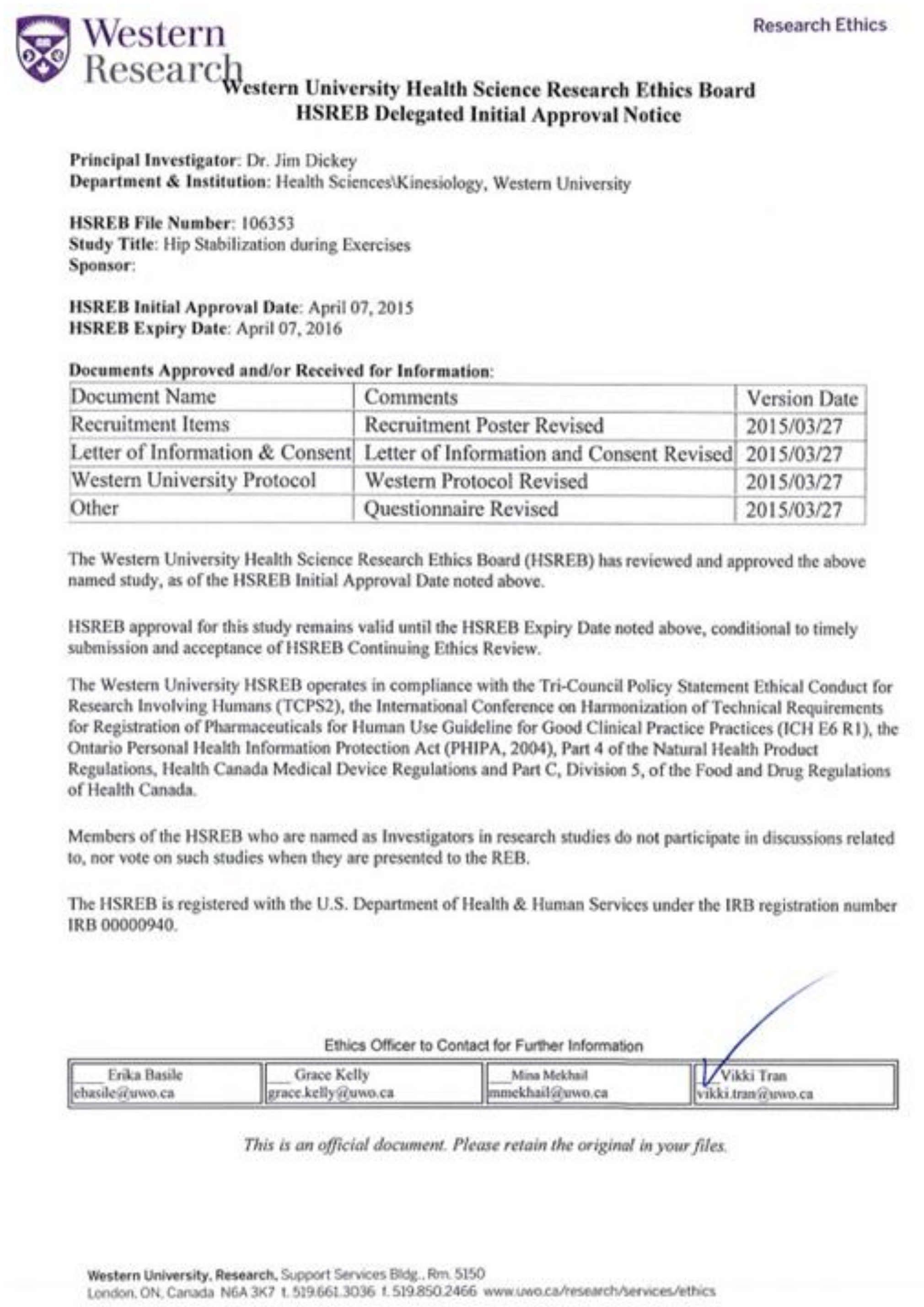
Appendix

Appendix A: The University of Western Ontario Human Research Ethics Board Form



Western Research

Research Ethics

Western University Health Science Research Ethics Board
HSREB Delegated Initial Approval Notice

Principal Investigator: Dr. Jim Dickey
Department & Institution: Health Sciences\Kinesiology, Western University

HSREB File Number: 106353
Study Title: Hip Stabilization during Exercises
Sponsor:

HSREB Initial Approval Date: April 07, 2015
HSREB Expiry Date: April 07, 2016

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Recruitment Items	Recruitment Poster Revised	2015/03/27
Letter of Information & Consent	Letter of Information and Consent Revised	2015/03/27
Western University Protocol	Western Protocol Revised	2015/03/27
Other	Questionnaire Revised	2015/03/27

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the above named study, as of the HSREB Initial Approval Date noted above.

HSREB approval for this study remains valid until the HSREB Expiry Date noted above, conditional to timely submission and acceptance of HSREB Continuing Ethics Review.

The Western University HSREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use Guideline for Good Clinical Practice Practices (ICH E6 R1), the Ontario Personal Health Information Protection Act (PHIPA, 2004), Part 4 of the Natural Health Product Regulations, Health Canada Medical Device Regulations and Part C, Division 5, of the Food and Drug Regulations of Health Canada.

Members of the HSREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Ethics Officer to Contact for Further Information

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