2021

The Effects of Hip Rotation on Hip Abductor Muscle Activation during Lateral Band Walk Exercise

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THE EFFECTS OF HIP ROTATION ON HIP ABDUCTOR MUSCLE ACTIVATION DURING LATERAL BAND WALK EXERCISE

BY

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A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Nutrition & Exercise Science

Specialization in Exercise Science

South Dakota State University

2021

THESIS ACCEPTANCE PAGE

Gina Fritz

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ACKNOWLEDGEMENTS

- To Dr. Bowser: I would like to thank my advisor, Dr. Bradley Bowser, for helping me work through the many stages of my thesis project. Your spiritual guidance and continuous patience throughout this journey will never be forgotten. Thank you for taking me on as one of your graduate students and assisting me throughout this research project and Master of Science degree program.

- To Northland American College of Sports Medicine: I would like to thank the College of Sports Medicine, Innovative Student Research Grant for funding this research project. Your generosity helped make this research possible.

- To My Parents: I would like to thank my mom and dad for all the love, encouragement, and continued support during this time. Without you giving me the extra push, I would not be where I am at today, not only in my education but in life overall. I could not have done this without you.

- To My Family: I would like to extend my thanks out to the rest of my family, especially my Grandma Great. For the constant, “are you done yet?” questions and continuing to never give up on me. This process may have taken longer than expected, but your persistence kept me motivated to see this part of my life through.

- To My Niece and Nephews: You brightened my most troublesome and stressful days with your love, hugs, and laughter. You helped me through this more than you will ever know or understand.

- To Alex: Your love and support has and never will go unnoticed. Your recent experience of writing your master’s thesis inspired me in more ways than one. You played a major role in me going for a master’s degree and you continue to push me to be a better version of myself every day. You have held my hand though it all and there are no words to show you how thankful I am.

TABLE OF CONTENTS

ABSTRACT

THE EFFECTS OF HIP ROTATION ON HIP ABDUCTOR MUSCLE ACTIVATION DURING LATERAL BAND WALK EXERCISE

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2021

BACKGROUND: Lateral band walks (LBW) have been used to strengthen hip abductors and decrease risk of lower extremity injuries. Several methods have been used to complete this exercise to determine which has the best outcome. PURPOSE: The purpose of this study is to compare muscle activation of the gluteus medius (Gmed), gluteus maximus (Gmax), and tensor fasciae latae (TFL) during straight leg LBW exercises performed using three different hip positions: 30-degree internal rotation, 30-degree external rotation, and a neutral hip position. METHODS: Thirty-seven recreationally active participants (10 male, 27 female; age=21.4±2.2 yr; mass=71.4±13kg; height=1.7±0.1 m) completed this study. Surface EMG sensors were placed bilaterally the on Gmax, Gmed, and TFL. Kinematic data and EMG data were analyzed during each step of the LBW tests. The meanRMS was calculated for the lead and trail legs. The mean of each participant was compared across the three different hip rotation. Each subject completed two trials of each hip rotation for a total of six lateral band walk trials. A one way ANOVA was used to compare EMG muscle activity for the Gmax, Gmed, TFL, and Gmed/TFL ratio followed by Post-hoc comparisons. Partial Eta squared and Cohen's *d* were used to determine effective sizes. RESULTS: Leg x hip rotation interaction was detected for the Gmax, Gmed, TFL, and Gmed/TFL ratio ($p<0.043$). Post-hoc testing revealed that the lead and trail legs in external hip rotation was greater than neutral and internal hip rotation in the Gmax and Gmed ($p \leq 0.001$; $d \geq 0.36$). Internal hip rotation of the lead leg was greater than neutral hip rotation ($p=0.008$; $d=0.46$) of the TFL. The trail leg in external hip rotation was greater than internal hip rotation in the Gmed/TFL ratio ($p=0.048$; $d=0.34$). When comparing lead and trail legs for each position, the trail leg displayed greater EMG activity with external hip rotation of the Gmed/TFL ratio. CONCLUSION: Hip abductors showed that external hip rotation tended to be greater in muscle activation when compared to the other hip rotations. Based on this data, clinicians may need to re-evaluate instructions they give when having someone complete the lateral band walk exercise.

INTRODUCTION

Muscle weakness and decreased muscle activation of the hip abductors have been linked to altered gait mechanics and an increased risk for developing musculoskeletal injuries in the lower extremity.[1-7] Weak hip abductors have been shown to result in excessive hip adduction, hip internal rotation, and knee abduction during the support phase of ambulation.[8] Injuries associated with hip abductor weakness include the development of patellofemoral pain syndrome, iliotibial band friction syndrome (ITBS), low back pain, and sprained ligaments.[4, 8-17] Strengthening the hip abductors is necessary to improve gait mechanics and reduce the risk of injury. Fredericson et al.[1] reported that strengthening hip abductors reduced the symptoms of ITBS after a six-week rehabilitation program.[1] Additionally, Nakagawa et al.[3] found that utilizing hip abductor exercises significantly increased hip abductor strength and reduced knee pain for individuals diagnosed with patellofemoral pain syndrome.

There are several different exercises that have been used to strengthen the hip abductors including clam shells, single leg squat, hip bridge, side lying hip abduction, and lateral band walks.[10, 11, 13, 14, 18-23] Lateral band walks (LBWs) are one of the most common rehabilitative exercises utilized by clinicians to strengthen the hip abductors.[10, 24] LBWs were developed to specifically target the hip abductors to reduce injury risk and facilitate rehabilitation following an injury.[14] This exercise is often used because it is an inexpensive exercise that can easily be implemented in a clinical setting or in a home rehabilitation program. Rehabilitation programs where LBWs were implemented have resulted in improved pelvic stability, increased hip abductor strength, and improved functional movements in both healthy and injured participants.[8, 10, 11, 18, 24]

The LBW exercise is also commonly used because it can be easily modified to vary the level of difficulty or to target different hip muscles.[10, 25] In addition to several levels of resistance bands, modifications to the LBW exercise made by clinicians include varied posture[8], hip rotation[18], and band placement[24]. However, there is limited evidence indicating which modifications will target the specific muscles and/or result in the greatest strength gains. When comparing band placement for the LBW exercise, Cambridge et al.[24] and Lewis et al.[25] both reported greater muscle activation of the gluteus maximus (Gmax), gluteus medias (Gmed), and tensor-fasciae latae (TFL) as the band moved from the knees to the ankles. However, only the Gmax and Gmed displayed greater muscle activation when moving the band placement from the ankle to the toes.[24, 25] When comparing squat posture, Berry et al.[8] found greater muscle activation of the Gmax and Gmed and lower muscle activation of the TFL when performing LBW exercises in a semi-squat compared to an upright posture.

One modification of the LBW that likely influences muscle activation of the hip abductors is the degree of internal/external hip rotation during the exercise. Clinicians have recommended an internally rotated hip position during LBW to specifically target the Gmed muscles.[22] Lee et al.[22] reported that when performing the side-lying hip abduction exercise, internal rotation of the hip resulted in greater Gmed muscle activation compared to a neutral hip rotation. They go on to suggest that internally rotating the hip during LBWs is better at isolating the Gmed due to limiting the amount of muscle activation of the TFL that also contribute to hip abduction. In contrast to Lee and colleuges[22], Youdas et al.[18] found no significant differences in muscle activation of the hip abductors when completing LBWs in three different hip rotation positions (internally rotated, toes forward, and externally rotated). [18] One possible explanation for the differences between these two studies may be due to differences in the amount of internal/external rotation used in each study. The degree of medial rotation of the hip was set at 50% of the total ROM in the Lee[22] study, whereas Youdas[18] did not control for the amount of hip rotation. It is possible that participants in the Youdas study did not have sufficient rotation at the hip to significantly alter the muscle activity. Another possible explanation for the differences could be due to the variable of interest used. Lee et al.[22] also looked at the average amplitude of muscle activity over the entire movement while Youdas[18] only looked at the peak amplitude over the entire LBW exercise. While the peak amplitudes may not be different, it is possible the overall amount of muscle activity will be greater when looking at the average amplitude over the entire movement, even with similar peak amplitudes. Finally, considering the TFL acts as a hip abductor, it is important to determine the contributions of the TFL across the three different hip positions. Without Youdas et al.[18] examining muscle activity of the TFL and not controlling the degree of hip rotation, it is unclear how much of an impact the TFL may have on hip abduction during the lateral band walk exercise. By controlling the amount of internal/external hip rotation, and examining the mean amplitude of the Gmed, Gmax, TFL, and the Gmed/TFL ratio during LBWs, researchers may better be able to determine at the relative contributions of those muscles and the impact of hip rotation on LBWs.

The purpose of this study is to compare muscle activation of the Gmed, Gmax, and TFL during straight leg LBW exercises performed using three different hip rotations: 30-degree internal rotation, 30-degree external rotation, and a neutral hip position. We hypothesize that muscle activity of the gluteus medius will be greatest in the internally rotated condition. Furthermore, we hypothesize that muscle activation of the tensor fasciae latae and gluteus maximus will be greatest in the externally rotated condition. Finally, we hypothesized that when comparing the lead and trail legs, the muscle activation of the trail leg would be greater. Being able to understand benefits of altering foot position will help clinicians to prescribe the most effective hip position for LBWs used in rehabilitation programs. Furthermore, clinicians will be able to target specific muscles of the hip musculature more accurately, potentially decreasing the risk of developing a lower extremity injury.

METHODS

Design

Our current study is a repeated-measures, laboratory-based study design that was completed during a single data collection session lasting 60-90 minutes in duration. All participants performed a side-stepping lateral band walk in three different hip positions (neutral, internally rotated 30 degrees, externally rotated 30 degrees) with an elastic band placed around their ankles. Muscle activity was collected for both the lead and trail legs during each trial.

Participants

An *a priori* power analysis using pilot data was used to determine the sample size needed to achieve statistical significance (G Power vs. 3.1.9.3). Based on the power analysis, 36 participants were needed to adequately power this study (η^2=0.25, α=0.05, β=0.20). Thirty-seven recreationally active participants (10 male, 27 female; age=21.4±2.2 yr; mass=71.4±13kg; height=1.7±0.1 m) completed this study. Participants were recruited by word of mouth through the local community and university. Prior to being enrolled in the study, informed consent was given, as approved by the institutional review board. A health history questionnaire and physical activity readiness questionnaire (PAR-Q) were then completed. Participants were included in the study if their age was between 18 and 29 years and were currently participating in moderate-vigorous physical activity at least three times per week for a minimum duration of 30 minutes per session. Participants diagnosed with a lower body musculoskeletal injury at the time of testing, an injury within the previous 30 days, cardiovascular, vestibular, visual, or balance disorders were excluded from the study. Participants with a history of back injury, pain or back deformity requiring medical treatment were also excluded.

Instrumentation

Muscle activation of the hip abductors was captured (2000Hz) using wireless surface electromyography (EMG) (Trigno; Delsys Inc, Natick, MA).

Motion capture (100 Hz) was used to track foot placement and to determine foot strike and toe off for each step (8-Qualisys Oqus 3 cameras, Gothenburg, Sweden). Motion capture data was time synchronized with the EMG signals using the Qualisys Track Manager software (Gothenburg, Sweden). A metronome was used to ensure step duration was consistent across participants (1 beat/second). A standardized 12-inch Thera-Band Professional Latex Band Loop (Green) was used around the ankles during each lateral band walk trial.

Procedure

Gender, age, height, weight leg length, leg dominance, and stance width were measured and recorded. Leg dominance was determined by asking participants which leg they would normally use to kick a ball. The distance between the right and left acromion process was measured and used to determine stance width. All participants were then fitted with standardized footwear (Nike Pegasus running shoes) provided by the researchers. Participants then completed a five-minute dynamic warm up that included the following exercises; light jogging, side shuffles, carioca, high knees, butt kickers, forward reverse and side lunges, straight leg kicks, quad stretches, and glute bridge hold.

Following the warm-up, EMG sensors were placed bilaterally over the muscle bellies and in line with the muscle fibers of the gluteus maximus (Gmax), gluteus medius

(Gmed), and tensor fasciae latae (TFL) according to guidelines for surface electrode placement.[26] Prior to surface electrode placement, the skin over the muscles were prepared by shaving and cleaning the area with a piece of gauze and rubbing alcohol. After electrode placement, Kinesiology Tape (K tape) was placed over each EMG sensor to secure sensors to the skin and reduce movement artifact. To ensure proper sensor placement EMG signals were visually inspected as the participants flexed and extended at the hip and internally rotated and abducted the hip joint. Visual inspection of the muscle activity also occurred during the maximal voluntary isometric contraction (MVIC) trials to ensure proper electrode placement.

After testing the placement of the EMG sensors by visual inspection of the EMG signal, EMG data was collected as participants completed maximum voluntary isometric contractions (MVIC). A resting EMG measurement was taken followed by three randomized MVIC trials. MVIC was assessed using three different manual muscle tests (figure 1). Manual muscle testing for the Gmed (figure 1A) was completed with the participant lying prone on the rehabilitation table with their legs positioned according to the stance width measurement. With a joint mobility belt wrapped around their ankles, participants completed the MVIC by abducting against the joint mobility belt for three seconds. Manual muscle testing for the Gmax (figure 1B) was performed with the participant lying prone on a rehabilitation table with the participant's legs strapped down to the table by a joint mobility belt. Participants were instructed to bend

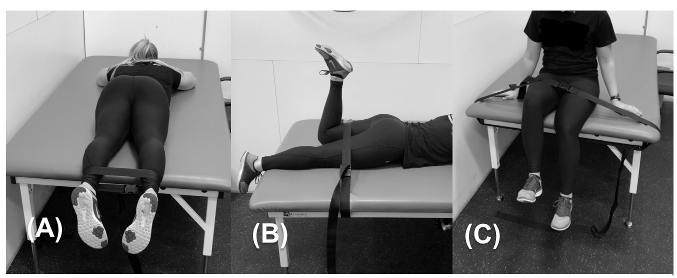

Figure 1. *(A) MVIC position for the Gmed. (B) MVIC for the Gmax. (C) MVIC for the TFL.*

their knee to 90 degrees to isolate the Gmax. In this position participants were instructed to complete the MVIC by extending at the hip[27] pushing up against the joint mobility belt. Manual muscle testing for the TFL (figure 1C) was performed with participants seated on the edge of rehabilitation table with their legs strapped down to the table. In this position, participants completed the MVIC by flexing at the hip, pushing up against the joint mobility belt.

Prior to completing the experimental trials, eighteen retro-reflective markers were taped bilaterally onto the head of the first, second, and fifth metatarsals, distal aspect of the foot, medial and lateral malleolus, and the proximal, distal and lateral aspects of the heel. A static standing trial with the participants in a neutral position was recorded. Anatomical markers were then removed from the participant leaving only the tracking markers (heel markers and head of the second meta-tarsal) for the experimental trials.

Experimental Task

In a randomized order, each participant completed two lateral band walk trials for each hip rotation[18] position for a total of six lateral band walk trials. Each trial consisted of three steps to the right followed by three steps to the left. A visual guide, using tape indicating each step and hip rotation position, was placed on the floor to create a path for participants to follow (figure 2). Step width was standardized to 150% of the participants shoulder width. Step frequency was standardized to one step per second using a metronome.[28] Resistance band loops were positioned around the participant's legs, just proximal to the lateral malleoli.[24, 25] Participants were given

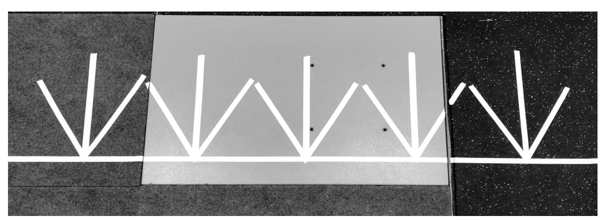

Figure 2. *Visual guide placed on the floor to map out the foot positions for each of the six trials.*

instructions before each data collection. Instructions included: keep a slight bend in the knee throughout each trial, focus on using the muscles around the hip through the lateral band walk and not incorporating the upper body to aid in hitting the marks, hit the marks in step to the metronome, keep feet planted on the floor once the step has been taken. Participants performed lateral band walks with a resistive band around the ankles in 1 of 3 hip rotations: externally rotated 30 degrees, internally rotated 30 degrees, or a neutral hip rotation (figure 3). Each participant was given a practice trial to ensure the rhythm of the metronome and practice which marks to hit during each trial. A trial was excluded if the participant did not step in time to the metronome, or if the foot position was off the specified mark. Once a trial was completed, 30-45 second rest[18] was given between each trial.

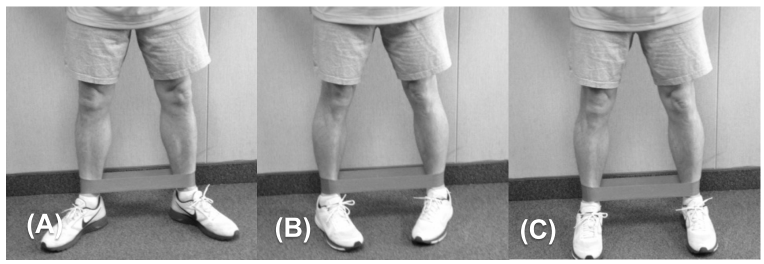

Figure 3. (A) *Straight leg lateral band walk with resistance band placed around ankles and feet position in 30° of ER.* ***(B)*** *Straight leg lateral band walk with resistance band placed around ankles and feet position in 30° of IR.* ***(C)*** *Straight leg lateral band walk with resistance band*

Data Processing

EMG data was filtered to get rid of the DC Bias by first using a high pass filter of 50 Hz, followed by a low pass filter of 500 Hz, and ending with a high pass filter of 20 Hz. The filtered EMG signals were further processed using root-mean-squared (RMS) with a 193-ms moving window.

Reflective markers were labeled using Qualisys Track Manager Software (Qualisys, Gothenburg, Sweden) then exported into Visual 3D (C-Motion, Inc, Germantown, MD). Marker data were then filtered using a 4th order recursive low pass filter with a cutoff frequency of 6Hz. The first derivative of the marker trajectories were calculated to determine velocity of the markers. Vertical velocity of the markers were then used to calculate the instant of toe off of the lead leg and foot strike of the trail leg. Six total steps were taken during each trial. An average was recorded for each muscle acting as a lead and trail leg across the entire trial.

Data Reduction

Muscle Activity.

For each muscle, the meanRMS was calculated for the lead and trail legs. Lead and trail legs were determined based on the direction in which that participant was stepping. For example, when taking steps to the right, the right leg is the lead leg and the left leg is the trail leg. Steps for each of the trials were divided out into heel off and heel strike. Heel off and heel strike were determined when the vertical velocity of the moving limb's proximal heel reflective marker exceeded a threshold of 0 m/s. A total of six steps were taken during each trial. Three steps were taken to the right, followed by three steps taken to the left. We evaluated the lead and trail leg separately.

Kinematics

The distance traveled during hip abduction and the degree of hip rotation maintained throughout the lateral band walk were our main interests. Average muscle activity was calculated through the concentric (lead leg movement) and eccentric (trail leg movement) muscle contractions during each step of the specified hip rotation.

Statistical Analysis

A two (leg factor) x three (hip rotation) repeated measures (muscle) ANOVA was used to compare EMG muscle activity for the Gmax, Gmed, TFL, and Gmed/TFL ratio.

Post-hoc comparisons were made for all significant interactions. Partial Eta squared and Cohen's *d* were used to determine effective sizes for the ANOVAs and Post-hoc tests respectively. P-values less than or equal to 0.05 were considered significant. Data are presented as means and standard deviations. All data were analyzed using SPSS software (Version 25.0, IBM. SPSS. Statistics, Chicago, IL, USA).

RESULTS

The meanRMS for each muscle, of each leg, and for each condition is presented in Table 1. The meanRMS is shown as a percent of the maxRMS of the MVIC for each of the muscle groups. The Gmed:TFL ratio for each leg and foot position are also reported in Table 1.

TABLE 1 Statistics for the mean peak values of muscle activation from the gluteus maximus, gluteus medius, and tensor fasciae latae of the lead and trail leg during three conditions of hip rotation while completing the lateral band walk.

		Hip Angle Condition		
Muscle	Limb Condition	External Rotation	Internal Rotation	Neutral
Gluteus Maximus	Lead	31.9±16.1	20.6±9.9	22.7±11.1
	Trail	38.4±20.2	19.3±9.2	23.8±11.6
Gluteus Medius	Lead	59.6±30.7	52.8±21.4	51.6±23.7
	Trail	64.8±32.4	49.7±18.6	52.2±23.4
Tensor Fasciae Latae	Lead	51.1±27.8	52.6±32.9	46.9±26.8
	Trail	52±27.6	49±25.8	46.9±24.7
Gmed/TFL Ratio	Lead	1.3±0.6	1.2±0.7	1.2±0.6
	Trail	1.3±0.6	1.2±0.7	1.2±0.7

Gluteus Maximus

A significant leg x hip rotation interaction was detected for the gluteus maximus ($F_{2,35}$ = 26.4, p<0.001; η^2=0.61). Post-hoc testing revealed that for both the lead and trail legs, an externally rotated hip position resulted in greater muscle activation of the Gmax compared to both the neutral and internally rotated hip positions (p≤0.001; d≥1.05) (Figure 4). Additionally, a neutral hip rotation resulted in greater Gmax muscle activity than the internally rotated hip position for both lead and trail legs (p≤0.001; d≥0.53) (Figure 4).

Gluteus Medius

A significant leg x hip rotation interaction was detected for the gluteus medius ($F_{2,35}$ = 22.4, *p<0.oo1;* η^2 =0.56). Post-hoc testing revealed that for both the lead and trail legs, an externally rotated hip position resulted in greater muscle activation of the Gmed compared to both the neutral and internally rotated hip positions ($p \leq 0.001$; $d \geq 0.36$) (Figure 4).

Tensor Fasciae Latae

A significant leg x hip rotation interaction was detected for the TFL ($F_{2,35}$ = 4.9, p=0.013*;* η^2=0.22). Post-hoc testing revealed that for the lead leg, an internally rotated hip position resulted in greater muscle activation of the TFL compared to the neutral hip position (p=0.008; d=0.46). However, the trail leg revealed an externally rotated hip position resulted in greater muscle activation of the TFL compared to the neutral hip position (p=0.013; d=0.43) (Figure 4).

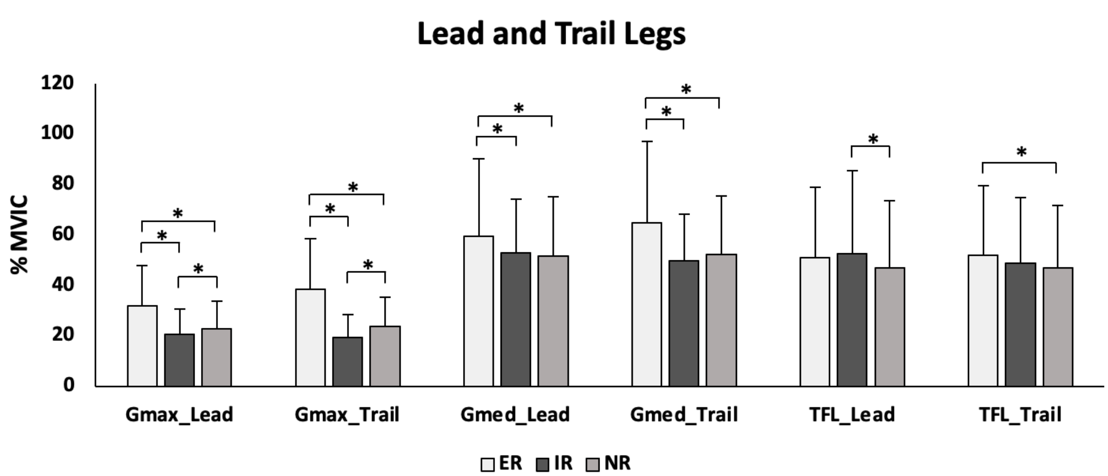

FIGURE 4 Significant differences in mean peak values of muscle activation from the gluteus maximus, gluteus medius, and tensor fasciae latae of the lead and trail leg during three conditions of hip rotation while completing the lateral band walk. *Significant differences between conditions (p<0.05).

Gluteus Medius/Tensor Fasciae Latae Ratio

A significant leg x hip rotation interaction was detected for the Gmed/TFL ratio ($F_{2,35}$ = 3.45, p=0.043; η^2=0.17). Post-hoc testing revealed that for the trail leg, an externally rotated hip position resulted in greater muscle activation of the Gmed/TFL ratio compared to the internally rotated hip position (p=0.048; d=0.34) (Figure 5). When comparing the lead and trail legs for each position, the lead leg displayed greater Gmed/TFL ratio EMG activity with the hips in an externally rotated hip position (Table 2).

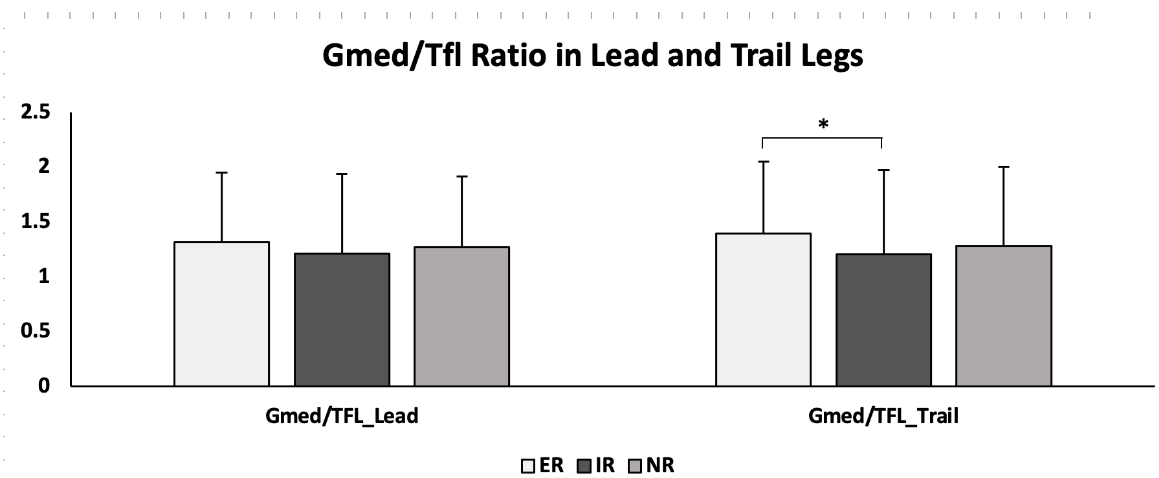

FIGURE 5 Significant differences in mean peak values of muscle activation from the Gmed/TFL ratio of the lead and trail leg during three conditions of hip rotation while completing the lateral band walk. *Significant differences between conditions (p<0.05).

Table two depicts muscle activation of the lead leg compared to trail leg (Table 2).

TABLE 2 Statistics for muscle activation from the gluteus maximus, gluteus medius, and tensor fasciae latae of the lead versus trail leg during three conditions of hip rotation while completing the lateral band walk. *Significant differences between conditions (*p*<0.05).

Lead Leg vs. Trail Leg				
Muscle	Hip Angle Conditions		p-value	Cohen's d
Gmax	ER	Lead < Trail	p<0.001*	0.99
	IR	Lead > Trail	p=0.005*	0.5
	NR	Lead < Trail	p=0.047*	0.34
Gmed	ER	Lead < Trail	p<0.001*	0.85
	IR	Lead > Trail	p=0.001*	0.59
	NR	Lead = Trail	p=0.455	
TFL	ER	Lead = Trail	p=0.211	
	IR	Lead > Trail	p=0.019*	0.4
	NR	Lead = Trail	p=0.966	
Gmed/TFL	ER	Lead < Trail	p=0.014*	0.43
	IR	Lead = Trail	p=0.726	
	NR	Lead = Trail	p=0.620	

DISCUSSION

The purpose of this study was to compare muscle activation of the Gmed, Gmax, and TFL during straight leg lateral band walks performed using three different hip rotation positions. We hypothesized that muscle activity in the Gmed would be greatest during the internally rotated hip position. Contrary to what we hypothesized, the results of this study revealed that the Gmed produced the most muscle activity during an externally rotated hip position. We also hypothesized that the Gmax and TFL would produce the greatest muscle activity during an externally rotated hip position. Partially confirming this hypothesis, muscle activation of the Gmax, and the TFL of the lead leg was greatest during the externally rotated hip position. However, the TFL of the trail leg displayed greater muscle activation during for the internal hip rotation trials. Finally, we hypothesized that when comparing lead and trail legs, the muscle activation of the trail leg muscles would be greater. With few exceptions, our findings generally support this hypothesis.

GLUTEUS MEDIUS

The Gmed displayed the greatest muscle activity during external hip rotation. Also, this condition showed greater EMG activity of the trail leg when compared to the lead leg. In contrast, Youdas et al.[18] found no differences in muscle activation of the Gmed when comparing the different hip rotation positions. A reason why the Gmed results may differ between our study and theirs could be based upon placement of the surface EMG sensors and which motor units are being analyzed by these sensors. The anterior fibers of the Gmed aide in internal rotation of the hip whereas the posterior fibers of the Gmed aide in external rotation of the hip.[29] When the hip is internally rotated, the anterior fibers of the Gmed are shortened, and when the hip is externally rotated, the posterior fibers of the Gmed are shortened. Based on the length tension relationship, the optimum way to create the largest muscle force is to have the hip be in a neutral position. Although, for example, when the Gmed is externally rotated, the muscle fibers are shortened. Being placed in an externally rotated hip position, the force created by the Gmed is less than the optimum neutral position. To make up for a decrease in force, more motor units are recruited to create the same amount of force as there would be in a neutral hip position. This increase in motor units creates a higher EMG signal.[18] With the placement of the EMG, the area in which it was placed may impact why we got the signals that we did in regards to which shortened muscle fibers were recorded.

Another potential reason for the differences in results may be that Youdas et al.[18] quantified muscle activation using the maxRMS, whereas we looked at the meanRMS. The maxRMS looks at the maximum value achieved representing only one point during the entire phase. However, the meanRMS looks at the average muscle activation across the entire phase potentially providing a better indicator of the overall muscle activation during the entire phase. It is possible that there are no differences in maxRMS across the three different hip positions, but there are for the meanRMS. Finally, the inconsistencies between our results and those reported by Youdas et al.[18] may be due to the smaller sample size that was tested by Youdas and colleagues.

Based on the information provided from our study, one can imply that to optimally activate the Gmed during the lateral band walk, one should externally rotate the hip while standing in an upright position with a resistance band placed just above the lateral malleolus. More so, a clinician should place the targeted hip on the side where it will act as the trail leg during the external hip rotation. This will also help provide significant muscle activation of the Gmed.

GLUTEUS MAXIMUS

It has been reported that muscle activation should exceed a threshold of 50-60% of the MVIC in order to elicit muscle strengthening.[10, 18] Out of 12 gluteal activation strengthening exercises, Distefano[10] concluded that the LBW with a neutral hip rotation is not the ideal exercise to activate and strengthen the Gmax (27±16). In that aspect, our study agrees with Distefano et al[10]. Although Distefano et al[10] did not express their results based upon a lead or trail leg MVIC measurement, our study showed similar results in Gmax muscle activation while completing the LBW in a neutral foot position (lead leg=22.7±11.1; trail leg=23.8±11.6). While our results do not show a significant strengthening factor for the Gmax, there is a significant difference between the three hip conditions within our study. Like the Gmed, our results indicate that muscle activation of the Gmax in the lead and trail leg is significantly greater during external rotation of the hip when compared to internal rotation of the hip or neutral rotation of the hip. Once again, Youdas et al[18] examined the Gmax and did not find a significant difference between the three different hip rotation positions. Significant differences for the Gmax were found however, when Youdas et al[18] compared the lead leg to the trail leg. Consistent with our results, they reported that the trail leg produced greater muscle activation when compared to the lead leg. One may conclude that the LBW is not the ideal exercise to strengthen the Gmax muscle, but externally rotated or neutral hip rotation will result in the greatest muscle activation of the Gmax.

TENSOR FASCIAE LATAE

The TFL not only acts as a hip abductor, it also works in sync with the anterior fibers of the Gmed to act as an internal rotator. Thus, the TFL should be considered when examining muscle activity of the hip which is why the TFL was included in our study.

Berry et al[8] examined the LBW in a neutral hip rotation and the effects of standing or squatting while completing the exercise. When comparing the lead to the trail leg, they concluded that muscle activity was greatest in the trail leg for Gmed, Gmax, and TFL. In contrast, our study did not find a significant difference when comparing the lead leg to the trail leg in a neutral hip rotation during the LBW(p=0.966). This difference could be for several reasons. Berry[8] did not require a standardized cadence to complete the LBW. By setting a cadence, it elicits time under tension of the resistance band while completing the LBW. Time under tension produces more muscle activation by making the exercise more difficult during each step taken. In addition, Berry[8] standardized the step length to 12 inches, whereas step length was scaled to shoulder width for the participants in our study. Standardizing step width for each participant may not challenge those of a larger stature enough where it produces significant muscle activation. What our study did find was that there was a significant difference between the lead and trail leg during an internally rotated foot position and that the lead leg produced greater muscle activation. The reason for this could be that the TFL acts primarily as an internal rotator of the hip as well as a hip flexor. During internal rotation of the hip, the TFL will be more active. When the trail leg is fixed to the ground, the friction from the ground keeps the foot in an internally rotated hip position. With the moving lead leg, the TFL must produce more of muscle activation to keep the hip internally rotated while taking a step in the lateral direction. Contrary to greater muscle activation of the lead leg, between the lead and trail leg is important to know when choosing how to complete the LBW. Hip abductors in the trail leg work to produce enough torque to maintain a neutral pelvis and work against gravity.[8] The hip abductors also work to stabilize the pelvis and provide a fixation point for the contralateral hip abductors to move the lead leg in the direction in which the step is being taken.[8] All things considered, our research provides rationale to place the targeted hip abductor as the trail leg to optimize muscle activation while completing the LBW.

GMED/TFL RATIO

Few studies have considered the Gmed/TFL ratio during the LBW exercise. In our study, the Gmed/TFL ratio was used as a way to t Similar to our results, Selkowitz[11] found a significant difference in muscle activation of the Gmed/TFL ratio during a squatted lateral step with a resistance band placed around the thigh. They reported that the LBW exercise increases the gluteal muscle activation while reducing the muscle activation of the TFL.[11] The results of our study indicate that during the lateral band walk, among the three hip rotation positions, participants exhibited greater Gmed/TFL ratios during an externally rotated hip position compared to an internally rotated hip position. These findings indicate that the Gmed is more active than the TFL for the external hip rotation position. As stated above, the length tension relationship may play an important role when trying to explain why there is proportionately greater Gmed than TFL activation in the external hip rotation position. Because the Gmed is shortened during external rotation of the hip, the Gmed must work harder and recruit more muscles to perform the task. In comparing the Gmed/TFL ratio between the lead and trail leg our results indicate that the trail leg displays greater muscle activation of the hip abductors than that of the lead leg. For these reasons, one can conclude the lateral band walk as an ideal exercise to increase the activation of the Gmed and minimize the use of the TFL within the trail leg.

LIMITATIONS

One of the limitations of this study is that all participants were all college age, healthy individuals without any recent or current musculoskeletal injuries. While it limits the external validity of our results to this specific sample, pain and previous injuries can affect muscle activation patterns potentially confounding our results.[25] Furthermore, by first examining a healthy college age population, we are providing the foundation for future studies that may want to consider different age groups and injured populations.

A second limitation of our study is the specificity of our protocol. Although there have been several studies that looked at different posture, band positions, and hip rotation, further research is needed to expand upon the different ways to complete the lateral band walk. Our results provide data on hip rotation; however, future studies are needed to determine the interactions of hip rotation position with band placement, knee flexion, and different resistance during LBWs.

CLINICAL IMPLICATIONS

Previously, studies have been recommending the LBW to be performed in an internally rotated hip position; however, results of our study suggest that to optimize muscle activation of the Gmed, external hip rotation may be better. If the goal is to strengthen the overall musculature of the hips, according to this study, the best way to produce the most muscle activation of the Gmed, Gmax and TFL is to perform the LBW exercise in an externally rotated hip position. This study also recommends that the targeted hip abductor be placed as the trail leg to optimize muscle activation. For this reason, it is important to understand that the LBW is to be performed in both directions of lateral stepping. With the LBW being a common exercise used within the rehabilitative setting, there is a lack of information on this exercise. This study provides new evidence for how this exercise should be conducted to focus on these three muscles.

CONCLUSION

To our knowledge, this is the first study to indicate that hip position in the transverse plane during a LBW can influence muscle activation of the hip abductor muscles. Lateral band walks have shown to improve pelvic stability, increase hip abductor strength, improve functional movements in both healthy and injured populations. With these improvements, the lateral band walk will then help reduce the risk of injury or facilitate rehabilitation following injury. In our study, hip abductors showed that external hip rotation was greater in muscle activation when compared to the other hip rotations. Based on this data, clinicians may need to re-evaluate instructions they given when having someone complete the lateral band walk exercise.

LITERATURE REVIEW

This literature review aims to evaluate the following: journal articles evaluating rehabilitative exercises for the hip abductors that include the Lateral Band Walk exercise, journal articles evaluating rehabilitative exercises for the hip abductors that do not include the Lateral Band Walk exercise, maximal voluntary isometric contraction methods, injuries that are associated with hip abductor weakness. For this literature review, we have chosen to utilize review tables. The literature review is divided into five sections to help better understand the topic of lateral band walks. These sections will critically review published journal articles written about common hip abduction rehabilitative exercises, use of surface electromyography on the lower extremity, isometric contraction methods of the Gmed, Gmax, and TFL, and injuries associated with hip abductor weakness.

Lateral Band Walk

Lateral band walks are a common hip strengthening rehabilitative exercise that utilizes a resistance band around the lower extremity through a series of steps. A lateral band walk may be performed in a number of different variations. Band placement, posture, hip rotation, and which muscles to include in the EMG signals are all different aspects of the lateral band walk to consider when utilizing this exercise in a rehabilitation setting. Information gathered from this section of the literature review gave insight on how we decided to perform the lateral band walk exercise during our study. Recurrent findings in this section included muscle activation of the hip abductors increases as a resistance band was placed more distally on the body, more specifically the ankle placement. We found the band being placed around the ankles and a straight leg position produces optimal muscle activation of the hip abductors. No significant information was found on which hip rotation produces optimal muscle activity of the hip abductor musculature. See table 1 for these results.

Table 1: Review on Studies Involving Muscle Activation during Hip Abduction Exercises, Including the Lateral Band Walk Exercise.

Authors	Sample Size (n)	Sample characteristics Mean(SD)	Intervention / Movement	EMG Electrode Muscles	Main Findings	PEDro Score
Cambridge et al. (2012)[24]	n= 9 9 male 0 female	Age: 22.6±2.2 yrs Height: 181.9±9.2 cm Mass: 85.8±15.4 kg	Thera-Band: Tibial tuberosity (KP), Lateral Malleoli (AP), around the forefoot (FP); LBW in the sagittal and frontal plane	Bilat. over the following: RA, EO, IO, UES, LES, LD, Gmed, Gmax, TFL, BF	TFL, Gmed, and Gmax increased when modifying band placement during LBW and SW; TFL and Gmed increased as band moved distally; Gmax increased during FP	5
Berry et al. (2015)[8]	n= 24 12 male	Age: 22.9±2.9 years	Thera-Band: AP; LBW	Bilat. over the	TFL, Gmed, and Gmax: Stance limb>moving	5

	12 female	Height: 171.1±10.5 cm Mass: 68.6±12.9 kg		following: Gmax, post Gmed, TFL	limb; Gmed and Gmax decreased during the SQ compared to standing; ABD excursion: Stance>moving	
Youdas et al. (2013)[18]	n= 21 10 male 11 female	Age: 25.0±3.1 yrs Height: 1.8 ±0.1 m Mass: 82.2 ±7.9 kg	Thera-Band: AP; NT, IR, ER foot positions	Bilat. over Gmed, Gmax, EO, and LES;	Gmed and Gmax: Stance>moving; LES muscle activation: IR>NT; LES muscle activation: moving>stance	5
Distefano et al. (2009)[10]	n= 21 9 male 12 female	Age: 22±3 yrs Height: 171±11 cm Mass: 70.4±15.3 kg	Thera-Band: AP; Clams (2 variations), side-lying ABD, SLSQ, SLDL, LBW, LUN (3 variations), hops (3 variations)	Gmed and Gmax	Gmed and Gmax differed between all 12 exercises; Gmed: side-lying ABD > clam exercises, LUN exercises, forward hop, and transverse hop; Gmed and Gmax: similar in the SLSQ and SLDL; Gmax: greatest during SLSQ and SLDL than in LBW, clam, and hop exercises	5
Lewis et al. (2018)[25]	n=22 11 male 11 female	Female: Age: 23.0±1.7 yrs Height: 163.9±7.6 cm Mass: 60.9±7.9 kg Male: Age: 22.6±4.1 yrs Height: 179.4±8.1 cm Mass: 76.1±10.8 kg	LBW with KP, AP, and FP	Gmax, post Gmed, TFL	Hip ABD: women>men; women: > trunk flexion and > hip excursion; Gmax and Gmed increased as band was placed lower on the body; TFL only increased when band went from KP to AP	5

Selkowitz et al. (2013)[11]	n= 20 10 male 10 female	Age: 27.9± 6.2 yrs	Side-lying ABD, clam, BRG, SL BRG, QKE, QKF, forward LUN, SQ, LBW, HIKE, and forward SU	Sup Gmax, Gmed, and TFL	Gmed, and Sup Gmax>TFL in the BRG and SL BRG, QKE, QKF, clam, LBW, and SQ; Gluteal:TFL ratio: clam>LBW>SL BRG>QKE>QKF	6
Jacobs et al. (2009)[12]	n= 15 9 male 6 female	Age: 57.4±10.2 yrs BMI: 31.8 ± 6.7 kg/m^2	NWB standing ABD with weighted cuff, WB standing ABD with weighted cuff; LBW	Gmed and Gmax	No significant differences found in the Gmed between four different exercises	5

Key: Knee band placement = KP; Ankle band placement = AP; Foot band placement = FP; Bilaterally = bilat; Rectus Abdominus = RA; External Oblique = EO; Internal Oblique = IO; Upper Erector Spinae = UES; Lower/Lumbar Erector Spinae = LES; Latissimus Dorsi = LD; Gluteus Medius = Gmed; Gluteus Maximus = Gmax; Tensor Fascia Latae = TFL; Biceps Femoris = BF; Lateral Band Walk = LBW; Sumo Walk = SW; Posterior = post; Squat = SQ; Hip Abduction/Abductor of the hip = ABD; Neutral/neutral rotation of the hip = NT; Internal Rotation/Internal rotation of the hip = IR; External Rotation/ external rotation of the hip = ER; Medial Malleolus/Malleoli = MM; Single-leg squat = SLSQ; Single-leg deadlift = SLDL; Lunge = LUN; Bridge = BRG; Single-leg Bridge = SL BRG; Hip extension in quadruped on elbows with knee extending = QKE; Hip extension in quadruped on elbows with knee flexed = QKF; Hip Hike = HIKE; Step-Up = SU; Superior = Sup Non-weight-bearing = NWB; Weight-bearing = WB

Hip Abduction Exercises

In addition to the lateral band walks, there are several other exercises that are utilized in a rehabilitation program to help strengthen and decrease pain within the hip abductors. This section of the review addresses the variations of hip abductor exercises that do not include the lateral band walk exercise. Based on the articles in this table, one would be able to use other variations of hip abductor exercises to see what muscles are activating during each exercise. This table also provides information on how different variations of the same exercise can differ in activation of the hip musculature. A component of our study is looking at hip rotation and how hip musculature activates during different conditions. Recurrent information within this section suggests an internally rotated hip joint produces more gluteus medius muscle activity during a side-lying hip abduction exercise than a neutral or externally rotated hip position. The Gmed:TFL ratio also suggests that the Gmed activated more over the TFL during internal rotation of the hip compared to a neutral or externally rotated hip. See Table 2 for these results.

Table 2: Overview of Studies Involving Muscle Activation during Hip Abduction Exercises, not including the Lateral Band Walk Exercise.

Authors	Sample Size (n)	Sample characteristics Mean(SD)	Intervention/ Movement	EMG Electrode Muscles	Main Findings	PEDro Score
Ekstrom et al. (2007)[13]	n= 30 19 male 11 female	Age: 27±8 yrs Height: 176±8 cm Mass: 74±11 kg	Side-lying ABD, BRG, SL BRG, side plank, plank, opposite arm and leg lift, Lat SU, standing LUN, dynamic edge	Unilat. over RA, EO, longissimus thoracis, lumbar multifidus, Gmax, Gmed, VMO, HAM	Gmed: >during side plank; Gmax: > during quadruped arm/lower extremity lift	5

Bolgla et al. (2005)[14]	n= 16 8 male 8 female	Age: 27±5 yrs Height: 1.7±0.2 m Mass: 76±15 kg	NWB side-lying ABD, NWB standing ABD, NWB standing flexed ABD, PD, WB left ABD, WB with flex in left ABD	Right Gmed	WB exercises and NWB side-lying ABD > NWB standing ABD exercises	5
Sidorkewicz et al. (2014)[9]	n= 13 13 male 0 female	Age: 24.8±4.2 yrs Height: 179.7±5.4 cm Mass: 75.9±9.8 kg	Clams at 30°, 45°, or 60°, and side-lying ABD with IR, ER, and NT hip rotations	Gmed, TFL	Gmed greatest comparing all variations of the clam and side-lying ABD	5
Ayotte et al. (2007)[15]	n= 23 16 male 7 female	Age: 31.2±5.8 yrs Height: 173.1±10.1 cm Weight: 77.0±13.9 kg	Unilat. WS, unilat. mini-SQ, For SU, Lat SU, retro SU	Gmax, Gmed, VMO, BF	four muscles differed across all five exercises; Gmax, Gmed, and VMO exceeded strengthening threshold	5
Boudreau et al. (2009)[16]	n= 44 22 male 22 female	Age: 23.3±5.1 yrs Height: 174.5±9.1 cm Mass: 74.6±16.5 kg	LUN, SLSQ, SUO	Gmax, ADD longus, RF, Gmed_D, Gmed_ND	RF, Gmax, Gmed_D: SLSQ > LUN > SUO; Gmed_ND: LUN > SUO > SLSQ	5

O'Sullivan et al. (2010)[17]	n= 15 7 male 8 female	Age: 22±4 yrs Height: 170±12 cm Mass: 68±12 kg	WS, PD, WP	ANT, MID, POST Gmed	Gmed: exercise, between subdivisions, and between each exercise; WS > PD > WP; MID and POST Gmed increased more than ANT Gmed; WP increased in the POST Gmed	5
Kang et al. (2013)[30]	n=30 18 male 12 female	Age: 22.8±2.9 yrs Height: 170.3±4.1 cm Mass: 66.9±10.8 kg	30°, 15°, and 0° ABD, each during PHEKF exercise	Gmax	Gmax greatest during PHEKF and > ABD positions; Gmax greatest during 30° of ABD > 15° > 0°	6
Boren et al. (2001)[19]	n=26	Age: >21 yrs	Clam, PD, side-lying ABD, side plank ABD_DLT, side plank ABD_DLB, front plank with hip ext, SL BRG_SS,	Gmed and Gmax	Gmed values > 70% MVIC: side plank ABD_DLB > side plank ABD_DLT > SLSQ	6

			SL BRG_US, hip circumduction _SS, hip circumduction _US, SLSQ, SLDL, dynamic leg swing, For SU, skater SQ, gluteal squeeze, Lat SU, quadruped hip ext		> clam > front plank with hip ext; Gmax values > 70% MVIC: front plank with hip ext > gluteal squeeze > side plank ABD_DLT > side plank ABD_DLB > SLSQ	
Willcox et al. (2013)[20]	n= 17 10 male 7 female	Male: Age: 25±5 yrs Height: 182±8 cm Mass: 77±13 kg Female: Age: 23±4 yrs Height: 165±4 cm Mass: 60±11kg	Six clam variations: NT pelvis position at 0°, 30°, and 60° of hip rotation; 35° Reclined pelvis position at 0°, 30°, and 60° of hip rotation	Gmax, Gmed, TFL	Gmax and Gmed: NT pelvis > reclined pelvis; Gmed greatest during hip flex of 60°	5
Lee et al. (2014)[22]	n= 19 8 male 11 female	Age: 21.00±1.73 yrs Height: 166.00±0.07 cm Weight: 59.79±9.61 kg	NT side-lying ABD, IR side-lying ABD, ER side-lying ABD	Gmax, Gmed, and TFL	Gmed: IR > NT side-lying ABD; TFL: ER > NT side-lying ABD; Gmed:TFL and Gmed:Gm	6

					ax ratio IR > NT or ER side-lying ABD	
Lee et al. (2013)[21]	n= 20	Age: 22.3±1.9 yrs Height: 168.7±7.2 cm Weight: 65.5±12.4 kg	NT side-lying ABD, IR side-lying ABD, ER side-lying ABD	Gmed and TFL	Gmed: IR > NT or ER side-lying ABD; TFL: ER > NT side-lying ABD; Gmed:TFL: side-lying ABD IR > NT or ER; side-lying ABD: NT > ER	6
McBeth et al. (2012)[23]	n= 20	Age: 18-40 yrs	Side-lying ABD, Clam, ER side-lying ABD	Gmax, Gmed, TFL, ANT hip flexors	Gmed: greatest during side-lying ABD; ANT hip flexors: greatest during clam	5
Sung-Kwang et al. (2016)[31]	n=15 15 male	Age: 29.13±2.85 yrs Height: 173.4 ± 7.08 cm Mass: 71.3 ± 8.52 kg	Hip fire hydrant, FBABD, WP, and PD	ANT, MID, POST Gmed	Gmed greatest during PD, WP and FBABD, compared to fire hydrant; ANT Gmed: PD	5

					> FBABD and WP; POST Gmed: FBABD > WP and PD; POST Gmed WP > PD	
Homan et al. (2013)[32]	n= 75 39 male 36 female	High Strength (n=25): Hip ABD: Age: 21±3 yrs Height: 1.8±0.1 m Mass: 74.9±9.3 Hip ER: Age: 20±2 yrs Height: 1.8±0.1 m Weight: 73.1±10.2 kg Low Strength (n=25): Hip ABD: Age: 21±3 yrs Height: 1.7±0.1 m Weight: 64.8±11.9 kg Hip ER: Age: 21±3 yrs Height: 1.7±0.1 m Weight:	DL jump landing from 30cm high box	Gmax, Gmed	Gmed and Gmax: increased strength in low strength ABD and ER groups comparted to high strength group	5

		64.0±9.2 kg				
Monteiro et al. (2015)[28]	n= 17 6 male 11 female	Age: 25.6±1.4 yrs Height: 168.29±8.64 cm Weight: 70.00±9.98 kg	NT PD; IR PD; ER PD	Gmed, TFL, quadratus lumborum	Gmed: NT and IR > ER; Gmed:TFL ratio remained the same in all positions	5
Nakagawa et al. (2008)[3]	n= 14 4 male 10 female	Age: 23.6±5.9 yrs	Control: Patellar mobilization, stretching of the QUADS, GASTROC, IT band and HAM, and open and closed kinetic chain exercises for QUAD strengthening Intervention: Above stretching, strengthening and functional training focused on the TRAN AB, hip ABD, and lat rotator muscles	Two placements on the Gmed	Intervention group decreased symptoms during functional activities; Gmed increased during MVIC in the intervention group; ECC knee extensors torque increased within both the control and intervention groups	7
Allison et al. (2017)[4]	Intervention Group: n= 8 3 male 5 female Control Group:	Intervention Group: Age: 54±10 yrs Height: 166±1 cm Weight: 67±15 kg	Six walking trials	Bipolar fine wire electrodes: ANT Gmed, MID Gmed, POST	Intervention: increased initial muscle activity in POST Gmin and MID	5

	n=8 3 male 5 female	Control Group: Age: 51±10 yrs Height: 168±1 cm Weight: 72±15 kg		Gmed, ANT Gmin, POST Gmin Surface electrodes: TFL, Upper Gmax, VL	Gmed compared to controls; POST Gmin, POST Gmed, and TFL increased during period of SL support; reduced within-participant variability of POST Gmed and reduced between-participant variability of ANT Gmin and Gmed, and upper Gmax	
Lin et al. (2016)[33]	n= 12 6 male 6 female	Age: 26.1±4.7 yrs Height: 168.8±2.7 cm Weight: 63.6±9.6 kg	Clam, SLSQ, ForLUN, elliptical exercise under three conditions: regular elliptical, resisting IR torque, resisting ADD force	VL, VM, BF, Med GASTROC, Lat GASTROC, Gmed, Gmax	Gmed: highest during ADD-resistance > ForLUN and regular elliptical and similar during clam and SLSQ; Gmax:	3

					ADD-resistance and IR-resistance > regular elliptical and similar during clam, SLSQ, and ForLUN; QUAD and GASTROC: SLSQ > elliptical	
Krause et al. (2009)[34]	n= 20 6 male 14 female	Male: Age:26.3±2.5 yrs Height: 172.2±12.9 cm Weight: 85.0±10.1 kg Female: Age: 23.6±1.7 yrs Height: 169.3±9.5 cm Weight:65.0±9.2 kg	DL stance on floor, SL stance on floor, SLSQ on floor, SL stance on Airex cushion, SLSQ on Airex cushion	Gmed	Gmed: SL stance > DL stance, as well as SLSQ > SL stance; dynamic SL exercises on unstable surface is the best way to increase Gmed	5
Choi et al. (2015)[35]	n= 21 6 male 15 female	Age: 22.5±1.0 yrs Height: 165.3±7.1 cm Weight: 57.5±8.7 kg	BRG without isometric ABD, BRG with isometric ABD	Sup Gmax, HAM, and ES	Gmax: increase during BRG with isometric ABD; ANT pelvic tilt decreased	5

			during the BRG with isometric ABD with band

Key: Hip Abduction/Abductor of the hip = ABD; Bridge = BRG; Single-Leg = SL; Lateral = lat; Step-Up = SU; Lunge = LUN; Unilateral = unilat.; Rectus Abdominus = RA; External Oblique = EO; Gluteus Maximus = Gmax; Gluteus Medius = Gmed; Vastus Medialis Oblique = VMO; Hamstring = HAM; Non-weight-bearing = NWB; Pelvic Drop = PD; Weight-bearing = WB; Flexion = flex; Internal Rotation/Internal rotation of the hip = IR; External Rotation/ external rotation of the hip = ER; Neutral/neutral rotation of the hip = NT; Tensor Fascia Lata = TFL; Wall Squat = WS; Squat = SQ; Forward Step Up = ForSU; Lateral Step Up = LatSU; Step Up = SU; Biceps Femoris = BF; Single-leg squat = SLSQ; Step up and over = SUO; Hip Adduction/Adductor of the hip = ADD; Rectus femoris – RF; Gluteus Medius Dominant = Gmed_D; Gluteus Medius Nondominant = Gmed_ND; Wall Press = WP; Anterior = ANT; Middle = MID; Posterior = POST; Prone hip extension with knee flexion = PHEKF; Anterior superior iliac spine = ASIS; Electromyography = EMG; Abduction with Dominant Leg on Top = ABD_DLT; Abduction with Dominant Leg on Bottom = ABD_DLB; Extension = ext; Stable surface = SS; Unstable surface = US; Single-leg deadlift = SLDL; Maximal Voluntary Isometric Contraction = MVIC; Standing forward bent-horizontal hip abduction = FBABD; Double Leg = DL; Quadricep = QUAD; Gastrocnemius = GASTROC; Iliotibial band = IT band; Transverse Abdominus = TRAN AB; Eccentric = ECC; Gluteus Minimus = Gmin; Vastus Lateralis = VL; Gluteal Tendinopathy = GT; Forward Lunge = ForLUN; Vastus Medialis = VM; Superior = Sup; Erector Spinae = ES

Maximal Voluntary Isometric Contraction: Manual Muscle Test

To conduct this study, a maximal voluntary isometric contraction was collected for each of our hip abductor muscles. This section provides information on the different methods to measure maximal voluntary isometric contractions. Manual muscle tests were utilized in each of these journal articles and were conducted in a way that was congruent with how manual muscle tests are performed to test for strength in a rehabilitation setting. This section indicates manual muscle test methods were predominantly used in testing for maximal voluntary isometric contractions due to convenience and reliability of the MMT. Resistance was either applied by an examiner or a mobility strap. See Table 3 for these results.

Table 3: Overview of maximal voluntary isometric contraction during manual muscle tests of hip abduction musculature.

Authors	Sample Size (n)	Sample Characteristics Mean (SD)	Population Demographic	EMG Placement/ Tested Muscle Groups	Maximal Voluntary Isometric Contraction Method	PEDro Score
Cambridge et al. (2012)[24]	n= 9 9 male 0 female	Age: 22.6±2.2 yrs Height: 181.9±9.2 cm Mass: 85.8±15.4 kg	Convenience sample of college aged students	bilat. over RA, EO, IO, UES, LES, LD, Gmed, Gmax, TFL, BF	MMT of the abdominals, Biering-Sorensen, hip ABD, knee flex/hip ext, shoulder ADD	5
Berry et al. (2015)[8]	n= 24 12 male 12 female	Age: 22.9±2.9 yrs Height: 171.1±10.5 cm	Convenience sample of healthy college-aged adults	Bilat. over Gmax, post Gmed, TFL	MMT	5

		Mass: 68.6±12.9 kg				
Youdas et al. (2013)[18]	n= 21 10 male 11 female	Age: 25.0±3.1 yrs Height: 1.8±0.1 m Mass: 82.2±7.9 kg	Convenience sample of college aged students	Bilat. over Gmed, Gmax, and EO	MMT	5
Distefano et al. (2009)[10]	n= 21 9 male 12 female	Age: 22±3 yrs Height: 171±11 cm Mass: 70.4±15.3 kg	Recreationally active healthy subjects	Gmed and Gmax	MMT	5
Ekstrom et al. (2007)[13]	n= 30 19 male 11 female	Age: 27±8 yrs Height: 176±8 cm Mass: 74±11 kg	Healthy participants recruited from a university community	Unilat. over RA, EO, longissimus thoracis, lumbar multifidus, Gmax, Gmed, VMO, HAM	MMT	5
Bolgla et al. (2005)[14]	n= 16 8 male 8 female	Age: 27±5 yrs Height: 1.7±0.2 m Mass: 76±15kg	Sample convenience of healthy subjects recruited from the university community	Right Gmed	MMT: Side-lying with top leg supported by pillows in 25° of ABD; resistance applied by mobility strap located over the LFC to create MMT	5

Sidorkewicz et al. (2014)[9]	n= 13 13 male 0 female	Age: 24.8±4.2 yrs Height: 179.7±5.4 cm Mass: 75.9±9.8 kg	Healthy males	Gmed, TFL	MMT	5
Boudreau et al. (2009)[16]	n= 44 22 male 22 female	Age: 23.3±5.1 yrs Height: 174.5±9.1 cm Mass: 74.6±16.5 kg	Convenience sample of healthy individuals	Gmax, ADD longus, RF, Gmed_D, Gmed_ND	Seated MMT of RF with mobility strap; Standing MMT of Gmed_D and Gmed_ND with mobility strap simultaneously; ADD tested while standing and pushing one foot against the other; Standing MMT of Gmax with mobility strap	5
Kang et al. (2013)[30]	n=30 18 male 12 female	Age: 22.8±2.9 yrs Height: 170.3±4.1 cm Mass: 66.9±10.8 kg	Healthy subjects	Gmax, HAM	MMT	6
Selkowitz et al. (2013)[11]	n= 20 10 male 10 female	Age: 27.9±6.2 years	Healthy subjects	Sup Gmax, Gmed, TFL	Sup Gmax: Two ways - (1) Prone with 45° hip flex and 90° knee flex with strap across POST thigh; (2) hip ext with 90° knee flex with applied resistance; Gmed MMT with mobility strap;	6

					TFL tested in same way as Gmed but with 45° of hip flex added	
Willcox et al. (2013)[20]	n= 17 10 male 7 female	Male: Age: 25±5 yrs Height: 182±8 cm Mass: 77±13 kg Female: Age: 23±4 yrs Height: 165±4 cm Mass: 60±11kg	Healthy subjects	Gmax, Gmed, TFL	Gmed and Gmax: MMT; TFL tested supine, resistance applied during flex, ABD, and IR of the hip with knee ext	5
Lee et al. (2014)[22]	n= 19 8 male 11 female	Age: 21.00±1.73 yrs Height: 166.00±0.07 cm Weight: 59.79±9.61 kg	Subjects with weak Gmed determined through MMT	Gmax, Gmed, TFL	MMT	6
Lee et al. (2013)[21]	n= 20	Age: 22.3±1.9 yrs Height: 168.7±7.2 cm Weight: 65.5±12.4 kg	Healthy subjects	Gmed, TFL	MMT	6
McBeth et al. (2012)[23]	n= 20	Age: 18-40 yrs	Distance runners from the communit	Gmax, Gmed, TFL, ANT hip flexors	MMT	4

			y, local running clubs, and collegiate track teams			
Sung-Kwang et al. (2016)[31]	n= 15 15 male	Age: 29.3±2.85 yrs Height: 173.4±7.08 cm Weight: 71.73±8.52 kg	Healthy subjects	ANT, MID, POST Gmed	MMT for Side-lying hip ABD: prone, ER, and IR	5
Willson et al. (2011)[2]	Injured Group n= 20 20 female Control Group: n=20 20 female	Injured Group: Age: 21.3±2.6 yrs Height: 1.68±0.06 m Weight: 62.9±7.7 kg Miles run/week: 15.6±8.1 Running experience: 4.1±3.1 yrs Control Group: Age: 21.6±4.5 yrs Height: 1.69±0.09 m Weight: 62.1±8.9 kg	PFP group and healthy control	Gmed, Gmax	Gmed: side-lying with involved knee straight and hip in 0° of flex, ABD, and ER with mobility strap; Gmax: prone position on examination table with 0° of hip flex and 90° of knee flex with mobility strap	3

		Miles run/week: 21.1±12.2 Running experience: 5.0±3.6 yrs				
Jacobs et al. (2009)[12]	n= 15 9 male 6 female	Age: 57.4±10.2 yrs BMI: 31.8±6.7 kg/m^2	Volunteers six weeks post-op unilat. primary total hip arthroplasty	Gmed, Gmax	Side-lying position on uninvolved side with involved extremity positioned in the slight ABD by placing pillows between the participant's legs; resistance applied with mobility strap	5
Monteiro et al. (2015)[28]	n= 17 6 male 11 female	Age: 25.6±1.4 yrs Height: 168.29±8.64 cm Weight: 70.00±9.98 kg	Healthy subjects participating in activity for three or more times per week for at least 60 minutes per day	Gmed, TFL, quadratus lumborum	Gmed: MMT with mobility strap; quadratus lumborum: MMT with mobility strap and resistance applied at the shoulder to resist lat flex of the trunk; TFL: MMT and limb being tested at 45°of hip flex, 30° of hip ABD, and knee extended with mobility strap	5
Lin et al. (2016)[33]	n= 12 6 male 6 female	Age: 26.1±4.7 yrs Height: 168.8±2.7 cm Weight: 63.6±9.6	Healthy volunteers	VL, VM, BF, Med GASTROC, Lat GASTROC, Gmed, Gmax	MMT	3

		kg				
Krause et al. (2009)[34]	n= 20 6 male 14 female	Male: Age:26.3±2.5 yrs Height: 172.2±12.9 cm Weight: 85.0±10.1 kg Female: Age: 23.6±1.7 years Height: 169.3±9.5 cm Weight:65.0±9.2 kg	Recreationally active healthy subjects	Gmed	MMT	5
Cooper et al. (2016)[6]	LBP Group: n= 150 53 male 97 female Age & sex-matched controls: n= 75 26 male 49 female	LBP Group: Age: 41.4±13.0 yrs Height: 169.4±11.4 cm Weight: 84.9±22.2 kg Control Group: Age: 40.7±13.9 yrs Height: 168.2±9.4 cm Weight: 73.2±21.2 kg	People seeking care for LBP; age and sex matched controls	Gmed, TFL, Gmax	MMT	5

Choi et al. (2015)[35]	n= 21 6 male 15 female	Age: 22.5±1.0 yrs Height: 165.3±7.1 cm Weight: 57.5±8.7 kg	Healthy subjects	Sup Gmax, HAM, ES	MMT	5

Key: Bilateral = bilat; Rectus Abdominus = RA; External Oblique = EO; Internal Oblique = IO; Upper Erector Spinae = UES; Lower Erector Spinae = LES; Latissimus Dorsi = LD; Gluteus Medius = Gmed; Gluteus Maximus = Gmax; Tensor Fascia Lata = TFL; Biceps Femoris = BF; Manual Muscle Testing = MMT; Hip Abduction/Abductor of the hip = ABD; Flexion = flex; Extension = ext; Hip Adduction/Adductor of the hip = ADD; Posterior = POST; Medial Malleolus/Malleoli = MM; Unilateral = Unilat.; Vastus Medialis Oblique = VMO; Hamstring = HAM; Lateral femoral condyle = LFC; Rectus femoris – RF; Gluteus Medius Dominant = Gmed_D; Gluteus Medius Nondominant = Gmed_ND; Anterior superior iliac spine = ASIS; Superior = SUP; Internal Rotation/Internal rotation of the hip = IR; Anterior = ANT; Middle = MID; External Rotation/ external rotation of the hip = ER; Patellofemoral Pain Syndrome = PFPS; Vastus Lateralis = VL; Vastus Medialis = VM; Medial: med; Gastrocnemius = GASTROC; Lateral = lat; Low Back Pain = LBP; Erector Spinae = ES

Maximal Voluntary Isometric Contraction: Dynamometer

This section provides information from research articles that utilize a dynamometer to measure maximal voluntary isometric contractions. Dynamometer readings are considered an accurate and reliable way to assess maximal effort of the hip abductors. This section demonstrates that although reliable, it is not the predominant way of testing for maximal voluntary isometric contractions based on the journal articles found for this study. The choice of a Biodex dynamometer or a hand-held dynamometer has been indicated in table 4 below.

Table 4: Overview of maximal voluntary isometric contraction during dynamometer tests of hip abduction musculature.

Authors	Sample Size (n)	Sample Characteristics Mean (SD)	Population Demographic	EMG Placement/ Tested Muscle Groups	Maximal Voluntary Isometric Contraction Method	PEDro Score
Ayotte et al. (2007)[15]	n= 23 16 male 7 female	Age: 31.2±5.8 yrs Height: 173.1±10.1 cm Weight: 77.0±13.9 kg	Physically active Department of Defense beneficiaries	Gmax, Gmed, VMO, BF	Biodex Dynamometer	5
O'Sullivan et al. (2010)[17]	n= 15 7 male 8 female	Age: 22±4 yrs Height: 170±12 cm Mass: 68±12 kg	Healthy subjects recruited from the university campus	Three placements along the Gmed	Biodex Dynamometer	5
Nadler et al. (2002)[36]	n= 236	N/A	NCAA Division I	Gmax, Gmed	Dynamometer	4

	162 male 74 female		college athletes			
Heinert et al. (2008)[37]	n= 110 110 female	Age: 23.4±2.8 yrs Height: 165.5±7.6 cm Weight: 69.0±11.8 kg	Recreationally active, healthy subjects	ABD, hip extensor	Hand-held dynamometer mounted on top of an anchoring station	5
O'Dwyer et al. (2011)[38]	n= 15 7 male 8 female	Age: 22±4 yrs Height: 170±12 cm Weight: 68±12 kg	Healthy subjects	ANT Gmed, MID Gmed, POST Gmed, POST ilium	Biodex Dynamometer	5
Nadler et al. (2000)[39]	n= 210 140 male 70 female	N/A	NCAA Division I athletes	Gmax, Gmed	Dynamometer mounted on specially designed anchoring system for Gmed and Gmax MMT	4
Homan et al. (2013)[32]	n= 75 39 male 36 female	High Strength Group (n=25): Hip ABD: Age: 21±3 yrs Height: 1.8±0.1 m Mass: 74.9±9.3 20 males, 5 females Hip ER: Age: 20±2	Convenience sample of healthy, physically active volunteers who participate in at least 30 minutes of physical activity three times per week	Gmax, Gmed	Handheld dynamometer	5

		yrs Height: 1.8±0.1 m Weight: 73.1±10.2 kg 21 males, 4 females Low Strength Group (n=25): Hip ABD: Age: 21±3 yrs Height: 1.7±0.1 m Weight: 64.8±11.9 kg 8 males, 17 females Hip ER: Age: 21±3 yrs Height: 1.7±0.1 m Weight: 64.0±9.2 kg 4 males, 21 females				
Diamond et al. (2016)[40]	Intervention Group: n= 15 11 male 4 female	Intervention Group: Age: 24.7±4.9 yrs Height: 176.0±8.7 cm Weight:	Intervention Group: Convenience sample enrolled in a separate invasive intramusc	ABD, ADD, Hip flex, Hip ext, IR, ER	Hand-held dynamometer	5

	Control Group: n=14 10 male 4 female	76.0±11.8 kg Control Group: Age: 27.1±4.5 yrs Height: 176.1±8.3 cm Weight: 72.6±11.6 kg	ular EMG study Control Group: Healthy participants, comparable to intervention group			
Plastaras et al. (2015)[41]	PFPS Group: n= 21 0 male 21 female Control Group: n= 36 0 male 36 female	PFPS Group Age: 30.5±6.1 yrs Height: 164.6±5.8 cm Weight: 62.1±9.9 kg Control Group: Age: 30.4±15.2 yrs Height: 166.4±6.6 cm Weight: 62.6±8.0 kg	Female with PFPS Control group of participants who did not meet the PFPS criteria	Hip abductors	Handheld dynamometer	6
Ireland et al. (2003)[5]	PFPS Group: n= 15 15 female	PFPS Group: Age: 15.7±2.7 yrs Weight: 63.1±16.5 kg	Recreationally active females	ABD and ER of the hip	Hand-held dynamometer	5

	Control Group: n= 15 15 female	Age-matched Control Group: Age: 15.7±2.7 yrs Weight: 56.6±12.5 kg				
Ferber et al. (2011)[7]	PFPS Group: n=15 5 male 10 female Control Group: n= 10 4 male 6 female	PFPS Group: Age: 35.2±12.2 yrs Height: 1.65±0.34 m Weight: 69.1±11.6 kg Control Group: Age: 29.9±8.3 yrs Height: 1.73±0.41 m Weight: 73.1±15.7 kg	Recreationally active subjects running at least 30 minutes per day, a minimum of 3 days per week	HA muscles	Dynamometer	5

Key: Gluteus Maximus = Gmax; Gluteus Medius = Gmed; Vastus Medialis Oblique = VMO; Biceps Femoris = BF; Hip Abduction/Abductor of the hip = ABD; Anterior = ANT; Middle = MID; Posterior = POST; Manual Muscle Testing = MMT; Electromyography = EMG; Hip Adduction/Adductor of the hip = ADD; Flexion = flex; Extension = ext; Internal Rotation/Internal rotation of the hip = IR; External Rotation/ external rotation of the hip = ER; Patellofemoral Pain Syndrome = PFPS; Hip abductor = HA

Injuries Associated with Hip Abductor Weakness

This section of the literature review evaluates journal articles that have examined the relationship between injury and weakness of the hip abductor musculature. After assessing these articles, one may conclude that lower extremity mechanics become altered with a decrease in ABD strength. This section also provides information on different interventions that will significantly increase ABD strength and improve the signs and symptoms of lower extremity injuries. One study indicates that after a six-week intervention program of the hip abductors, there was a significant increase in hip abductor strength and there was no reoccurrence in symptoms after six months post intervention. See table five for these results.

Table 5: Injuries associated with hip abductor weakness.

Authors	**Sample Size (n)**	**Sample characteristics Mean(SD)**	**Population Demographic**	**Injury Evaluated**	**Main Findings**	**PEDro Score**
Fredericson et al. (2000)[1]	Injured Group: n= 24 14 male 10 female Control Group: n= 30 16 male 14 female	Injured Group: Age: Males: 27.07 yrs Females: 27.60 yrs Height: Males: 178 cm Females: 167 cm Weight: Males: 71.85 kg Females: 58.73 kg	Injured Group: Collegiate and club long-distance runners Control Group: Randomly selected university cross-country and track runners	ITBS	Hip ABD torque in injured groups before intervention showed differences between injured leg, non-injured leg, and the control group; Increase in hip ABD torque after six-week intervention	5

		Control Group: Age: Males: 20.06 yrs Females: 19.71 yrs Height: Males:180 cm Females: 170 cm Weight: Males: 66.28 kg Females: 56.92 kg			(US, two ITB stretches, side-lying ABD, and PD) for both males and females; 22 of 24 injured participants pain free and back running after six-week intervention; six month follow up: no reports of reoccurrence	
Willson et al. (2011)[2]	Injured Group n= 20 20 female Control Group: n=20 20 female	Injured Group: Age: 21.3±2.6 yrs Height: 1.68±0.06 m Weight: 62.9±7.7 kg Miles run/week: 15.6±8.1 Running experience: 4.1±3.1 yrs Control Group: Age: 21.6±4.5 yrs Height: 1.69±0.09 m	PFPS group and a control group	PFPS	Females with PFPS showed delayed and shorter Gmed than controlled group; greater hip ADD and IR excursion associated with delayed Gmed and Gmax onset, respectively	3

		Weight: 62.1±8.9 kg Miles run/week: 21.1±12.2 Running experience: 5.0±3.6 yrs				
Nakagawa et al. (2008)[3]	n= 14 4 male 10 female	Age: 23.6±5.9 yrs	Patients with PFPS and referred for physical therapy treatment	PFPS	Intervention group: improved symptoms during functional activities Gmed increased during the MVIC; ECC knee ext torque increased in both control and intervention groups	7
Allison et al. (2017)[4]	Intervention Group: n= 8 3 male 5 female Control Group: n=8 3 male 5 female	Intervention Group: Age: 54±10 yrs Height: 166±1 cm Weight: 67±15 kg Control Group: Age: 51±10 yrs Height: 168±1 cm Weight: 72±15 kg	Participants with GT and healthy age-matched controls	GT	GT increased activity in the POST Gmin and MID Gmed compared to controls; GT Participants: POST Gmin, POST Gmed, and TFL increased during period of	5

					SL support, reduced within-participant variability of POST Gmed and reduced between-participant variability of ANT Gmin and Gmed, and upper Gmax	
Ireland et al. (2003)[5]	PFPS Group: n= 15 15 female Control Group: n= 15 15 female	PFPS Group: Age: 15.7±2.7 yrs Weight: 63.1±16.5 kg Age-matched Control: Age: 15.7±2.7 years Weight: 56.6±12.5 kg	Recreationally active females	PFPS	PFPS: decrease in strength of hip ABD and hip ER compared to age-matched controls	5
Cooper et al. (2016)[6]	LBP Group: n= 150 53 male 97 female Age & sex-matched controls: n= 75 26 male 49 female	LBP Group: Age: 41.4±13.0 yrs Height: 169.4±11.4 cm Weight: 84.9±22.2 kg Control Group: Age: 40.7±13.9	People seeking care for LBP; age and sex matched controls	LBP	Gmed: weakness in LBP group compared to controls or unaffected side; positive Trendelenburg in LBP group compared to controls; tenderness	5

		yrs Height: 168.2±9.4 cm Weight: 73.2±21.2 kg			over gluteal muscles, greater trochanter, and paraspinals in LBP group compared to controls	
Ferber et al. (2011)[7]	PFPS Group: n=15 5 male 10 female Control Group: n= 10 4 male 6 female	PFPS Group: Age: 35.2±12.2 yrs Height: 1.65±0.34 m Weight: 69.1±11.6 kg Control Group: Age: 29.9±8.3 yrs Height: 1.73±0.41 m Weight: 73.1±15.7 kg	Recreationally active subjects running at least 30 minutes per day, a minimum of 3 days per week	PFPS	PFPS: decrease in ABD strength compared to controls; stride-to-stride knee-joint variability increased in PFPS group compared to the control group; PFPS differed with an increase in strength, less pain, and reduced stride-to-stride knee joint variability compared to baseline measurements	5

Key: Iliotibial band syndrome = ITBS; Hip Abduction/Abductor of the hip = ABD; Ultrasound = US; Iliotibial band = ITB; Pelvic Drop = PD; Patellofemoral Pain Syndrome = PFPS; Gluteus Medius = Gmed; Gluteus Maximus = Gmax; Hip Adduction/Adductor of the hip = ADD; Internal Rotation/Internal rotation of the hip =

IR; Diagnosis = dx; Electromyography = EMG; Maximal Voluntary Isometric Contraction = MVIC; Eccentric = ECC; Gluteal tendinopathy = GT; Posterior = POST; Gluteus Minimus = Gmin; Middle = MID; Tensor Fascia Lata = TFL; Single-Leg = SL; Anterior = ANT; External Rotation/ external rotation of the hip = ER; Low Back Pain = LBP

Literature Review Summary

Few studies have included the lateral band walk exercise within their study, and of those few studies, only one has evaluated hip abductors during different hip rotation conditions while performing the lateral band walk. In section one of this literature review, each study uses different variations of the lateral band walk and evaluates their information in a different way depending on what their main focus is. These different focal points make it difficult to decipher which variation of the lateral band walk is most beneficial. This literature review provides reasoning for why the lateral band walk is beneficial as a hip abductor exercise, as well as guide us in the direction to which variation of the lateral band walk should be performed. Based on this literature review, we decided that a straight leg lateral band walk with the band placed just above the lateral malleoli will elicit the most muscle activation of the three muscles we have chosen for our study. Hip rotation was another aspect in which the lateral band walk may vary. We found only one journal article that focused on this variation and provided no significant information between internal, neutral, and external hip rotations.

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