ABSTRACT

**Background:** Increased hip adduction and internal rotation during the early stance phase of running have been linked to an increased risk of lower extremity injury. Both the gluteus maximus (GMAX) and gluteus medius (GMED) eccentrically control these motions. GMAX and GMED activation levels during commonly used rehabilitation exercises requires further exploration.

**Hypothesis/Purpose:** The purpose of this study was to compare peak surface electromyography (sEMG) amplitudes of GMAX and GMED between three closed-chain rehabilitation exercises: bilateral hip external rotation with resistance band (BER), forward lunge with resistance band (FL), and single-leg rotational squat (SLS). It was hypothesized that the FL would elicit greater peak amplitude in the GMAX and GMED than SLS and BER.

**Study Design:** Descriptive, observational cohort study.

**Methods:** Twenty-two healthy runners (14 male, 8 female) had sEMG electrodes placed bilaterally on GMAX and GMED. Participants completed three repetitions each of BER, FL, and SLS exercises with sEMG data normalized to the maximal amplitude recorded at each muscle during the running trial (% MRC). Seven inertial measurement units affixed to the lower extremity measured joint kinematics to enable the exercises to be split into eccentric and concentric phases respectively.

**Results:** There were no significant differences between exercises during the eccentric phases with all peak amplitudes for GMAX and GMED being less than < 30% MRC. Both the SLS (GMAX: 48.2 ± 45.2% MRC, p = 0.019; GMED: 39.3 ± 24.8% MRC, p < .001) and FL (GMAX: 65.8 ± 58.9% MRC, p < .001; GMED: 52.2 ± 34.9% MRC, p < .001) elicited significantly greater peak amplitudes than BER (GMAX: 21.7 ± 22.3% MRC; GMED: 22.8 ± 21.2% MRC) during the concentric phase.

**Conclusion:** Running related injuries have been linked to deficits in GMAX and GMED activation and strength. When averaged bilaterally across 22 healthy runners, peak GMAX and GMED amplitudes during three weight bearing exercises were less than 70% MRC. All three exercises had comparable eccentric peak amplitudes; however, the BER exercise produced a significantly reduced GMAX and GMED amplitude during the concentric phase versus the FL and SLS. The FL and SLS appear equally effective at eliciting peak GMAX and GMED activation.

**Level of Evidence:** 3

**Key Words:** running, gluteus maximus, gluteus medius, muscle activation
INTRODUCTION

Hip muscle recruitment and activation is an important topic and is widely researched in many different contexts. Proper hip muscle recruitment can potentially reduce injury risk in a variety of movements. Both the gluteus maximus (GMAX) and gluteus medius (GMED) are heavily recruited during running and may assist with limiting biomechanical flaws linked with running-related injuries. The GMAX and GMED also stabilize the pelvis during dynamic activity while eccentrically controlling femoral adduction and internal rotation. Previous authors also have suggested that the main biomechanical factors that may put a runner at increased risk for iliotibial band syndrome (ITBS) are excessive hip adduction and internal rotation, and knee internal rotation and abduction during the stance phase. Clinically, GMED dysfunction has been implicated in numerous musculoskeletal disorders including low back pain, patellofemoral pain syndrome (PFPS) and other lower limb injuries. Maximizing hip muscle recruitment during rehabilitation exercises may increase treatment efficacy, improve lower limb kinematics, assist in injury prevention, improve athletic performance and result in decreased pain.

Two of the most common running-related injuries are PFPS and ITBS. Deficiencies in GMAX and GMED activation are potential etiological factors in injured runners who demonstrate biomechanical flaws linked to possible muscle weakness and/or inactivation. Souza & Powers reported that runners with PFPS had greater peak hip internal rotation angles, reduced hip torques, lower GMAX and GMED isotonic strength and greater GMED activation compared to pain-free runners. It has also been reported that female runners with PFPS had significantly less GMAX activation and hip extensor endurance which they speculated led to the observed increase in internal rotation.

Several authors have investigated the influence of hip muscle strengthening and its effects on participants’ lower limb kinematics; however, the results have been equivocal. Snyder et al. investigated the effects of a six-week strengthening program which included closed-chain hip rotation exercises on lower extremity biomechanics. They reported a trend towards reduced peak hip internal rotation angles and a significant decrease in knee abduction moment. This could possibly lead to altered joint loading which may reduce injury risk. Earl & Hoch investigated the effects of an eight-week hip and core strengthening program on lower extremity dynamic malalignment. They reported significant improvements in lateral core, hip abductor and hip extensor strength along with a significant reduction of knee abduction moment during running. Willy & Davis investigated the effect of a six-week hip strengthening and movement re-education program for the single-leg squat on running mechanics. They concluded that a hip strengthening and movement re-training program that is running specific does not alter abnormal running mechanics.

There has been minimal research that has investigated GMAX and GMED activation during functional hip external rotation exercises in a weight-bearing position. During loading response, the initial portion of the stance phase of running gait, eccentric control from the GMAX and GMED is likely important to prevent excessive hip internal rotation. Runners with excessive internal rotation may be at greater risk of injury which could be caused by insufficiencies of the GMAX and GMED. Although Willy & Davis advocated for hip strengthening that more closely resembles the demands of running, there has been no research comparing GMAX and GMED activity during such exercises. Hip muscle activation during weight-bearing exercises that challenge frontal and transverse plane control of the hip are lacking in the literature.

The purpose of the study was to investigate differences in GMAX and GMED peak surface electromyography (sEMG) amplitudes during both the concentric and eccentric phases of three functional closed-chain exercises: standing bilateral hip external rotation with resistance band (BER), rotational single-leg squat (SLS), and forward lunge with resistance band (FL). It was hypothesized that there would be a significant difference in GMAX and GMED activation between exercises, specifically greater GMAX and GMED activation during FL compared to BER and SLS as that exercise best replicated the first half of the stance phase during running.
METHODS
To compare the influence of three closed-chain rehabilitation exercises on hip muscle activation, twenty-two healthy runners were recruited and tested in a cross-sectional study design. This study was approved by Sacred Heart University's human subjects committee and all participants granted informed consent prior to enrollment. Purposive sampling was used to recruit participants from the local area using e-mail solicitation. Participants were recreational runners between the ages of 18 and 50 years, completing ≥ 24 km per week, with no reported lower extremity injuries in the prior 12 months. A lower extremity injury was defined as an injury to either lower extremity that resulted in the participant missing at least one day of running. Twenty-two participants (14 males, 8 females; 21.6 ± 2.3 years, 60.7 ± 7.1 kg, running volume: 66.6 ± 17.7 km·wk⁻¹) volunteered for this study. Cohort size was established a priori at ≥ 20 participants based on previous investigations utilizing similar methods reporting a range of 15-23 participants.22–27

Following informed consent, all participants were assessed for maximal isometric hip abductor strength via a handheld dynamometer (HHD) (Lafayette Instrument 01165; Lafayette Instruments, Lafayette, IN, USA) based on a previously reported method.28 The HHD was placed 5-cm proximal to the lateral malleolus with the participant in a side lying position. The top leg was positioned with the hip and knee neutral while the bottom leg was positioned with the hip at 45° of flexion and the knee at 90° of flexion. Participants performed a maximal isometric contraction against the resistance of one of the primary investigators. The HHD force was then normalized by body weight (BW) and hip abductor torque was computed as the product of normalized force (kg) times the HHD distance to the greater trochanter (cm). Normalized hip abductor torques were used to prescribe resistance band stiffness (TheraBand® CLX™ Resistance Band; Akron, OH, USA). Participants with hip abductor torque <9% BW were assigned a resistance band with minimal resistance from one set of three different bands (yellow - 9.8N per 100% elongation, green – 20.5N, blue – 25.8N), between 9-11.9% BW were assigned a resistance band with moderate resistance (20.5N per 100% elongation), and ≥12% BW were assigned a resistance band with maximum resistance (25.8N per 100% elongation) (Table 1). Resistance bands were placed approximately 5-cm above the superior border of the patella for both BER and FL exercises.

Participants then had bipolar wireless sEMG electrodes (Noraxon U.S.A. Inc.; Scottsdale, Arizona USA) placed bilaterally on the GMAX and GMED in previously reported locations.29 This was preceded by shaving the area if necessary and then abrading and cleaning the skin with alcohol. The GMAX sEMG electrode was placed exactly one-third the distance between the second sacral vertebrae and greater trochanter starting at the second sacral vertebrae.29 The GMED sEMG electrode was placed exactly one-third the distance between the lateral midline of the iliac crest and greater trochanter, starting from the greater trochanter.29

Seven inertial measurement units (IMUs; Noraxon U.S.A. Inc.; Scottsdale, Arizona USA), synced with sEMG data, were firmly attached to the sacrum between the posterior superior iliac spines, lateral mid-thigh between the greater trochanter and lateral epicondyle, lateral mid-shank between the head of the fibula and the lateral malleolus, and on the dorsal surface of the feet bilaterally (Figure 1). A standing calibration trial was utilized to define anatomical neutral position and allow the subsequent determination of lower extremity kinematics during both running and exercise trials. Hip kinematics were computed via Noraxon myoMotion™ software (Noraxon U.S.A. Inc.; Scottsdale, Arizona USA) and used to partition exercise trials into respective eccentric and concentric phases. Transition between phases was determined via maximal knee flexion during the FL and SLS exercises and maximal hip external rotation for the BER exercise. Subsequent

| % BW abduction | Band Color | Band Resistance (reported by Theraband® CLX™) |
|----------------|------------|---------------------------------------------|
| ≤ 9%           | Yellow     | 9.8N per 100% elongation                    |
| 9% - 11.9%     | Green      | 20.5N per 100% elongation                  |
| ≥ 12%          | Blue       | 25.8N per 100% elongation                  |
peak amplitudes were then assigned to eccentric and concentric phases, respectively.

Participants then ran on a treadmill (Desmo; Woodway USA, Inc.; Waukesha, WI USA) at a self-selected comfortable pace (5-6/10 effort) for five minutes.

![Figure 1. Participant in the starting (A) and ending (B) positions for the bilateral external rotation (BER) with resistance band. A resistance band was approximately placed 5-cm proximal to the superior patellar border and band stiffness was prescribed based on hip abductor strength. Seven inertial measurement units (IMUs) (Noraxon U.S.A. Inc.; Scottsdale, Arizona USA) were placed on the sacrum and bilaterally on the feet, shank, and thighs.](image-url)

Both sEMG and IMU data were collected for 30 seconds at the four-minute mark. Following the five-minute running trial, participants performed the BER, SLS, and FL bilaterally in one of the following two counter-balanced orders: (1) BER, SLS, FL; (2) FL, SLS, BER. The starting leg for the FL and SLS was self-selected by each participant and was held consistent for each exercise. Each exercise was performed for three repetitions bilaterally with a two-minute rest period between exercises to minimize fatigue. A digital metronome (Pro Metronome; EUM Lab, Hangzhou, China) set at 60 beats per minute was utilized to standardize movement speed for all exercises.

For BER, participants were instructed to start in a slightly internally rotated position with knees and hips slightly flexed, and perform a concentric external rotation at the hips (Figure 1). Participants were then instructed to return their hips to a slightly internally rotated position in a controlled manner. The exercise was performed going out (concentric phase) for one beat and coming back (eccentric phase) for three beats with the metronome (Table 2).

For SLS, participants were instructed to start with one leg off the ground. They were then instructed to squat down until the femur was as close to parallel

| Exercise | Instructions | Metronome Info |
|----------|--------------|----------------|
| BER      | Start with your knees turned in, with a slight bend in your knees and hips. Actively turn your knees out using your hips, then return to the starting position. | One beat out and three beats back in at 60 BPM. |
| SLS      | Start with one leg off the ground, squat down as close to parallel to the floor as possible with the leg you are standing on. Keep the leg off the ground behind you and reach your arm across your body towards the leg you are standing on. Then return to the starting position in a controlled manner. | Two beats down and two beats back up at 60 BPM. |
| FL       | Start standing normally and then perform a forward lunge where your leg comes forward and your knee does not move in front of the toes. Prevent your knee from moving inward, then return to the starting position in controlled manner. | Two beats down and two beats back up at 60 BPM. |

BER = bilateral hip external rotation with resistance band, SLS = rotational single-leg squat, FL = forward lunge with resistance band.
to the floor as possible on their stance leg, while keeping their non-stance leg back and reaching their opposite arm across their body, rotating their trunk toward the stance leg about 90° and thereby internally rotating the stance hip (Figure 2). Participants were instructed to return to the starting position in a controlled manner. The exercise was then repeated for the opposite leg. The exercise was performed going down (eccentric phase) for two beats and coming up for two beats (concentric phase) with the metronome.

For FL, participants were instructed to stand normally and then perform a forward lunge without allowing their knee to move anterior to the toes (Figure 3). They were also instructed to prevent their knee from “moving inward” throughout the lunge movement due to the resistance from the band. Participants were then told to return to the starting position in a controlled manner. The exercise was then repeated for the opposite leg. The exercise was performed going down (eccentric phase) for two beats and coming up (concentric phase) for two beats with the metronome.

Electromyography data were collected at 1500 Hz (Noraxon 87-8M 8 Channel DDTS; Noraxon; Scottsdale, Arizona USA), band-pass filtered at 20-450 Hz, full-wave rectified, smoothed via 50ms root mean square algorithm. The peak amplitudes recorded during each of five consecutive running strides that occurred after the 4 minute mark, were averaged and used to normalize amplitudes collected during the three exercises. This was used to determine the maximal contraction for the running trial (% MRC). This functional normalization method was chosen because it has been reported to decrease the variability between individuals compared to either using raw EMG data or normalizing to maximum voluntary contractions for dynamic tasks.

**STATISTICAL METHODS**

Data analysis was performed using four univariate analyses of variance (ANOVA) followed by a Bonferroni post-hoc analysis (PASW Statistics; SPSS, Hong-Kong, China) to assess for differences in peak sEMG magnitudes between both phases of the BER, SLS, and FL respectively. For all participants, data from both legs were included within the statistical analysis. Significance level was set a priori at $\alpha = 0.05$.

**RESULTS**

Analysis of GMAX peak amplitudes across all participants during the concentric phase revealed a significant main effect of exercise (BER, FL, SLS) on peak amplitude ($F_{2,131} = 10.850$, $p < .001$). For the concentric phase, post-hoc comparisons demonstrated that the FL ($65.8 \pm 58.9\%$ MRC; $p < .001$) and SLS ($48.2 \pm 45.2\%$ MRC; $p = 0.019$) resulted in significantly
greater peak amplitudes than the BER (21.7 ± 22.3% MRC), however there was no significant difference between the FL and SLS (p>0.05). For the eccentric phase no exercise resulted in peak amplitudes > 25% MRC and there was not a significant main effect of exercise on peak GMAX amplitude (Figure 4).

Analysis of GMED peak amplitudes across all participants during the concentric phase revealed a significant main effect of exercise (BER, FL, SLS) on peak amplitude (F_{2,131} = 12.505, p<.001). For the concentric phase, post-hoc comparisons demonstrated that the FL (52.2 ± 34.9% MRC; p<.001) and SLS (39.2 ± 24.8% MRC; p<.001) resulted in significantly greater peak amplitudes than the BER (22.8 ± 21.3% MRC), however there was no significant difference between the FL and SLS (p>0.05). For the eccentric phase no exercise resulted in peak amplitudes > 30% MRC and there was not a significant main effect of exercise on peak GMED amplitude (Figure 5).

**DISCUSSION**

The aim of the current study was to evaluate differences in GMAX and GMED activity between three functional closed-chains rehabilitation exercises designed to simulate demands during the stance phase of running. When averaged across 22 active runners and bilaterally, peak GMAX and GMED amplitudes during three weight bearing activities were less than 70% MRC. All three exercises had comparable eccentric peak amplitudes; however, the BER exercise produced a significantly reduced GMAX and GMED amplitude during the concentric phase versus the FL and SLS.

Although all three rehabilitation exercises produced comparable GMAX and GMED contractions during the eccentric phase, the BER stimulated significantly lower peak GMAX and GMED activation during the concentric phase. Potential explanations for this finding may be due to a lower exercise difficulty of the BER or the bilateral nature of the exercise. Both of the other exercises included within this study were more unilateral in design. In general, exercises that are bilateral in nature will produce lower muscle activity than unilateral exercises that use the same muscle groups.33,34 However, both of these previous reports investigated concentric contractions, so the results of the current study are interesting in that deficits were not noted during the eccentric phase. Clinically, utilizing a stiffer resistance band or performing unilateral resisted hip external rotation may result in increased concentric phase GMAX and GMED activation and improve overall exercise efficacy.

Exercise progression is a common prescriptive design utilized by clinicians. As suggested by Boren et al., percentage of maximal voluntary isometric contraction may be used to rank order exercises to improve strength building effectiveness.35 Although
all three exercises had similar eccentric amplitudes, the FL and SLS may be more effective for building muscular strength for both the GMAX and GMED than the BER. Despite the fact that these exercises produced substantially lower peak amplitudes as compared to running, they should still be taken into consideration when developing a rehabilitation program for runners returning from injury or seeking to gain improved pelvic control. All of the exercises are functional in nature as they are performed in a weight bearing position similar to the stance phase of running gait. Additionally, SLS and FL are performed unilaterally, which improves the running-specificity of each exercise possibly improving the transfer to single limb support in running.

As stated previously, peak eccentric amplitudes for all three exercises fell substantially below (<30% MRC) the peak activations measured during running. A potential reason why this may have occurred was because the eccentric phases of each exercise was performed at a controlled speed as prescribed by the researchers and controlled by the metronome. While this did improve the methodological design, it did not approximate the speed of loading response during the stance phase. Muscle activity has been positively associated with running speed. Specifically, Kyrolainen et al. suggested that with higher running speeds, GMAX muscle activations are higher due to greater contribution from stretch reflexes and pre-activation of muscle fibers. The purposefully slow eccentric motion during the exercises may have limited peak muscle activity when compared to the faster speeds occurring during the loading response with running.

There are several limitations to the current study. In an attempt to standardize the exercise difficulty for the BER and FL, a resistance band was prescribed for each runner based on their normalized hip abductor muscle group strength. In an effort to improve the methodological design and increase the clinical applicability of study, the study was delimited to three resistance bands of varying stiffness, however, this could explain why inter-participant variations were large for the BER and FL. The current study only assessed differences in peak amplitudes and not the onset of activations. Female runners with PFPS have been shown to demonstrate a delayed gluteal muscle response during running, however, it is unknown if the timing of GMAX and GMED peak activations are different between the three tested exercises. Additionally, this study was delimited to healthy runners so it is challenging to draw conclusions on the efficacy of these exercises in a runner rehabilitating from injury.

CONCLUSIONS

Due to the high prevalence of running-related injuries and the potential role of the GMAX and GMED in reducing these injuries, identifying exercises that effectively activate the gluteal muscles in runners is of great importance. Although none of the exercises investigated in this study approached the peak activation levels obtained with running, the results indicate that the FL with resistance band and SLS were superior to the BER exercise for concentric activation of the GMAX and GMED. All three exercises produced similar results in terms of eccentric activation of the GMAX and GMED.

The ability to analyze the concentric and eccentric phases of these exercises is clinically meaningful as the muscle activity required to reduce the excessive hip adduction and internal rotation often observed in risky running posture is eccentric. In that regard, it is recommended that all three exercises may be used in a program focused on improving dynamic hip strength and control in runners rehabilitating from injury or hoping to potentially reduce lower extremity injury risk. Clinicians should also consider these exercises in a recommended progression, beginning with the BER exercise and then transitioning to the SLS and FL with resistance band. Future research is needed to investigate the efficacy of functional closed-chain hip exercises within a population of injured runners and if their adoption transfers to an alteration of running mechanics.

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