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Gluteal Muscle Activation During Common Therapeutic Exercises

Gluteal muscle weakness has been associated with several lower extremity injuries, including patellofemoral pain syndrome,^{7,26,38,39} iliotibial band friction syndrome,¹⁵ anterior cruciate ligament (ACL) sprains,²³⁻²⁵ and chronic ankle instability.¹⁶ Weakness of the gluteus medius and maximus may contribute to lower extremity injury by influencing joint-loading

patterns and lower extremity control.^{17,26,36} An example of poor lower

extremity control is dynamic knee valgus, which results from



coupled hip internal rotation and adduction.^{15,19,24,26,38} As the gluteal muscles resist these possibly injurious motions, improving gluteal muscle strength and activation may be a critical aspect of rehabilitation and injury prevention programs.

Lower extremity injury prevention and rehabilitation programs frequently employ exercises with varying levels of difficulty to

target the gluteal muscles. These programs have demonstrated early success in improving strength, correcting faulty movement patterns, and reducing injury rates.^{22,29,31,32,34,41} However, a wide range of exercises are available for these purposes, with limited objective data regarding which exercises most effectively recruit the gluteal muscles. Specifically, it is unclear which of these exercises clinicians and researchers should implement to elicit the greatest benefits from rehabilitation and injury prevention programs. Investigators commonly accept the assumption that a high level of muscle activity, as evidenced by electromyography (EMG) signal amplitude, will lead to muscle strengthening effects.^{1-3,12,14,42} Therefore, EMG has frequently been used to compare muscle activity level between exercises.^{2,3,5,11,12,20,44}

There is a limited amount of literature regarding gluteal muscle activity during therapeutic exercises. Furthermore, the minimal evidence that exists is limited to

- **STUDY DESIGN:** Experimental laboratory study.
- **OBJECTIVES:** To quantify and compare electromyographic signal amplitude of the gluteus maximus and gluteus medius muscles during exercises of varying difficulty to determine which exercise most effectively recruits these muscles.
- **BACKGROUND:** Gluteal muscle weakness has been proposed to be associated with lower extremity injury. Exercises to strengthen the gluteal muscles are frequently used in rehabilitation and injury prevention programs without scientific evidence regarding their ability to activate the targeted muscles.
- **METHODS:** Surface electromyography was used to quantify the activity level of the gluteal muscles in 21 healthy, physically active subjects while performing 12 exercises. Repeated-measures analyses of variance were used to compare normalized mean signal amplitude levels, expressed as a percent of a maximum voluntary isometric contraction (MVIC), across exercises.
- **RESULTS:** Significant differences in signal amplitude among exercises were noted for the gluteus medius ($F_{5,90} = 7.9, P < .0001$) and gluteus maximus ($F_{5,95} = 8.1, P < .0001$). Gluteus medius activity was significantly greater during side-lying hip abduction

(mean \pm SD, 81% \pm 42% MVIC) compared to the 2 types of hip clam (40% \pm 38% MVIC, 38% \pm 29% MVIC), lunges (48% \pm 21% MVIC), and hop (48% \pm 25% MVIC) exercises. The single-limb squat and single-limb deadlift activated the gluteus medius (single-limb squat, 64% \pm 25% MVIC; single-limb deadlift, 59% \pm 25% MVIC) and maximus (single-limb squat, 59% \pm 27% MVIC; single-limb deadlift, 59% \pm 28% MVIC) similarly. The gluteus maximus activation during the single-limb squat and single-limb deadlift was significantly greater than during the lateral band walk (27% \pm 16% MVIC), hip clam (34% \pm 27% MVIC), and hop (forward, 35% \pm 22% MVIC; transverse, 35% \pm 16% MVIC) exercises.

• **CONCLUSION:** The best exercise for the gluteus medius was side-lying hip abduction, while the single-limb squat and single-limb deadlift exercises led to the greatest activation of the gluteus maximus. These results provide information to the clinician about relative activation of the gluteal muscles during specific therapeutic exercises that can influence exercise progression and prescription. *J Orthop Sports Phys Ther* 2009;39(7):532-540. doi:10.2519/jospt.2009.2796

• **KEY WORDS:** EMG, hip, gluteus medius, gluteus maximus

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exercises that are typically used in the beginning stages of rehabilitation.^{5,40} While information regarding muscle activation during these exercises is very important for clinical rehabilitation, knowledge about muscle activity during functional and more advanced exercises is critical for later stages of rehabilitation and injury prevention programs. Ayotte et al² evaluated and reported differences in gluteal muscle activity among various unilateral weight-bearing exercises, such as squats and step-ups, providing evidence regarding gluteal function during moderately demanding tasks. However, Ekstrom et al¹² published the only study that reported on gluteal muscle activity among basic and more progressive/demanding exercises. While this investigation identified differences in the abilities of each exercise to elicit gluteal activity, only 2 of the exercises were performed unilaterally and only 1 of the exercises did not require exercise equipment such as stairs. Therefore, a limited amount of information is available for clinicians to compare gluteal muscle activity among exercises that can be used at various stages of the rehabilitation process and injury prevention programs.

The purpose of this study was to quantify and compare gluteal muscle activation across 12 common strengthening exercises of varying difficulty. We chose exercises that incorporate a variety of therapeutic exercise components, including non-weight-bearing and weight-bearing positions, multiplanar motions, and single-limb balance. The findings of this study will provide valuable information about gluteal muscle activation during exercises used at various stages of rehabilitation and injury prevention programs, which will enhance clinical decision making with exercise progression and prescription.

METHODS

Subjects

TWENTY-ONE HEALTHY SUBJECTS (9 males, 12 females; mean \pm SD age, 22 ± 3 years; height, 171 ± 11 cm; mass, 70.4 ± 15.3 kg) volunteered to participate in this study and reported to

the research laboratory for a single testing session. All subjects completed an informed consent form that described the testing protocol, which was approved by the University of North Carolina at Chapel Hill Institutional Review Board for protection of human subjects. Subjects were recreationally active individuals who participated in physical activity for at least 60 minutes, 3 days per week. Subjects reported no symptoms of injury at the time of testing, were able to perform the exercises without pain, had no history of ACL injury, and had no recent (within the past 2 years) history of lower extremity surgery.

Testing Procedure

Subjects wore a T-shirt, shorts, and their own personal athletic shoes during the testing procedures. Prior to testing, subjects jogged around a gym for 5 minutes at a submaximal speed to prepare for the exercises. Subjects were instructed on the technique of 12 different exercises and practiced until they felt comfortable with performing the exercises correctly. All data were sampled from the dominant limb, defined as the limb used to kick a ball for maximal distance.

Preamplified/active surface EMG electrodes (Bagnoli-8; Delsys Inc, Boston, MA), with an interelectrode distance of 10 mm, an amplification factor of 10 000 (20–450 Hz), and a common-mode rejection ratio of 60 Hz (>80 dB) were used to measure activation of the gluteus maximus and gluteus medius. Electrodes were placed over the midsection of the muscle bellies, as in previous research evaluating the gluteal muscles^{2,5} and detailed by Rainoldi et al.³⁷ The placement for the electrodes for the gluteus maximus was 33% of the distance between the second sacral vertebra and the greater trochanter, while the electrodes for the gluteus medius were placed 33% of the distance between the greater trochanter and the iliac crest, starting from the greater trochanter. A single reference electrode was placed over the tibial tuberosity of the dominant limb. Electrode sites were

prepared by shaving any hair from the immediate vicinity of the muscle belly and cleansing the skin with isopropyl alcohol applied with a sterile gauze pad to reduce impedance to the EMG signal and to allow for proper electrode fixation. Electrodes were secured using prewrap and athletic tape. Proper location of the electrodes was confirmed by viewing the EMG signals on an oscilloscope, while the subject activated the muscles against manual resistance. EMG data were sampled at 1000 Hz.

A dual-axis electrogoniometer (Biometrics, Inc, Ladysmith, VA) was secured to the dominant limb to monitor sagittal-plane knee kinematics. A footswitch was placed directly on the plantar aspect of the first metatarsal to identify foot contact. These data were sampled at 1000 Hz and time-synchronized with the EMG data.

Subjects completed 8 repetitions of 12 therapeutic exercises, performed in a randomized order, while EMG data were collected. Subjects had 2 minutes of rest between each exercise. The 12 therapeutic exercises consisted of 3 non-weight-bearing and 9 weight-bearing exercises (**ONLINE VIDEOS**). These exercises were chosen based on suggestions we received from clinicians with regard to what exercises they would use to activate and strengthen the gluteal muscles, using primarily body weight as resistance. We incorporated exercises that required the gluteus medius and maximus primary actions of hip abduction, external rotation, and/or hip extension (non-weight-bearing exercises, band walk, deadlift), as well as exercises that demanded frontal-plane stability and concurrent activation of other lower extremity muscles (squat, deadlift, lunges, hops).

Hip Clams Two variations of this exercise were performed, using different positions of hip flexion. Clams were performed with subjects positioned side-lying on the floor, with their knees flexed 90° and hips flexed either 60° or 30°. Subjects abducted the top (dominant) knee off of the bottom knee while keeping their heels

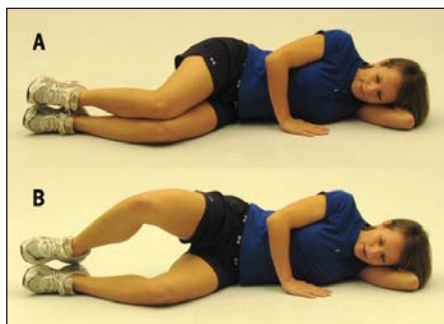


FIGURE 1. Start and end position for hip clam exercise with 60° hip flexion (**FIGURE 1A**); middle position for hip clam exercise with 60° hip flexion (**FIGURE 1B**).



FIGURE 2. Middle position for side-lying hip abduction exercise.

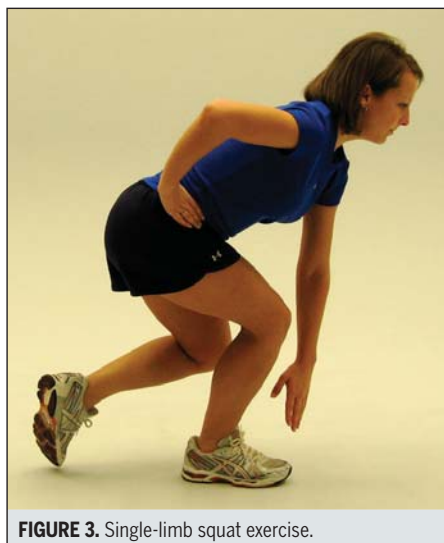


FIGURE 3. Single-limb squat exercise.



FIGURE 4. Single-limb deadlift exercise.

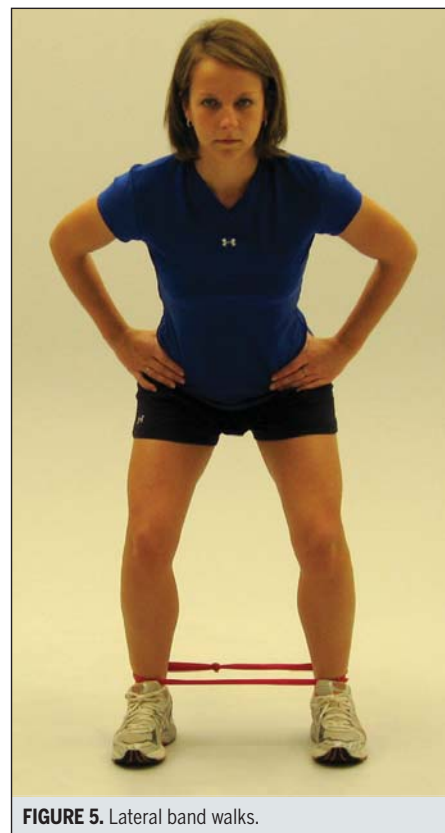


FIGURE 5. Lateral band walks.

together and their anterior superior iliac spines facing forward, and then returned to the starting position (**FIGURE 1**).

Side-Lying Hip Abduction Subjects were positioned side-lying on the floor, in a starting position of full knee extension and neutral hip position. Subjects slowly abducted the hip of the top (dominant) limb, while keeping the knee in extension, the tibia and femur in a neutral transverse plane position, and the bottom limb stationary. Subjects stopped at 30° of hip abduction and slowly returned to the starting position (**FIGURE 2**).

Single-Limb Squat Subjects started the squat by balancing on their dominant lower extremity, with their knee and hip flexed approximately 30° and their hands on their hips. Subjects slowly lowered themselves toward the ground, using their ankle, knee, and hip joints, until they could touch their contralateral middle finger to the outside of their dominant foot without reaching with their shoulder. Subjects then returned to the starting position and were instructed to keep their knees over their toes to prevent a knee valgus position (**FIGURE 3**).

Single-Limb Deadlift Subjects balanced on their dominant limb, with their knee and hip flexed approximately 30° and their hands on their hips. Subjects slowly flexed their hip and trunk and touched their contralateral middle finger to the ground beside their support foot, and returned to the starting position. Subjects were instructed to keep their knee flexed 30° when reaching for the desired level, to enable primarily trunk and hip flexion, and to keep their knees over their toes (**FIGURE 4**).

Lateral Band Walks An elastic band (resistance, 2.04 kg/30.5 cm of expansion) was tied around the subjects' ankles while they stood upright with their feet to-

gether. During the exercise, the subjects maintained their knees and hips in 30° of flexion. Subjects kept their hands on their hips and began with their feet together. Next, subjects sidestepped, leading with their dominant limb, a distance of 130% of their shoulder width (indicated by floor markings), assumed a single-limb stance on the dominant limb, and adducted their nondominant limb to replicate the starting position. All subjects were instructed to keep their toes pointed straight ahead and their knees over their toes (**FIGURE 5**).

Multiplanar Lunges Lunges were performed in the sagittal, frontal, and transverse planes. All 3 lunges started with the subjects standing with their feet near each other and hands on their hips. All lunges were performed with the dominant limb, keeping the trunk in an upright position, so that the knee and hip of the dominant limb flexed to 90°. This prevented the knee from moving anterior to the foot, and the knee of the nondominant limb was maintained above the



FIGURE 6. Forward lunge.



FIGURE 8. Transverse lunge.



FIGURE 7. Sideways lunge.



FIGURE 9. Landing position for multiplanar hop exercises.

ground. Subjects were instructed to keep their knees over the toes for all lunges. Subjects lunged forward, sideways (towards their dominant side), and rotated towards their dominant side. During the transverse-plane lunge, subjects rotated 135° on their nondominant limb towards their dominant side. Subjects twisted and lunged forward in this direction with consecutive motion (FIGURES 6-8).

Multiplanar Hops Similar to the lunges, hops were performed in the sagittal,

frontal, and transverse planes. Subjects started in the same position of the lunges and hopped in the desired direction off the nondominant limb and landed on the dominant limb. The same directions used for the multiplanar lunges were used for the multiplanar hops as the subjects jumped forward, sideways, and rotated 135° toward the ipsilateral side. All jumps were performed off of the subjects' nondominant limb, landing on the dominant limb, and subjects jumped a distance of half of their body height in the appropriate direction. Subjects were instructed to land "as softly as possible," with their knees flexed, and to keep their knees over their toes. They were also told to stabilize their body and balance upon landing for 3 seconds (FIGURE 9).

With the exception of the multiplanar hops, subjects used a metronome to perform each exercise at a rate of 60 beats per minute to standardize repetition speed. Both the concentric and eccentric phases of these exercises lasted 2 seconds. For example, subjects took 2 seconds to lower their body towards the ground during the single-limb squat and an additional 2 seconds to return to the standing posi-

tion. Similarly, subjects raised their knee during 2 beats (2 seconds) and lowered it during 2 beats for the hip clam exercises. During the multiplanar hops, subjects were required to stabilize in the landing position for 3 beats (the equivalent of 3 seconds). During the practice and recorded repetitions, subjects were observed to ensure that they performed the exercise correctly based on the instructions.

Five minutes after completing the 12 exercises, 3 separate 5-second maximal voluntary isometric contractions (MVICs) were performed for the gluteus maximus and medius to normalize muscle activation data recorded during the exercises. Positions for the MVIC testing were chosen based on commonly used positions for manual muscle testing and MVIC measurements.⁶ The MVIC for the gluteus maximus muscle was tested by resisting maximum-effort hip extension, performed with the subject lying prone on a treatment table, with the knee flexed 90°. Maximum-effort hip abduction, performed in a side-lying position with 25°

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of hip abduction, was used to test the MVIC for the gluteus medius.⁶ Subjects performed 1 practice trial, to ensure that they understood the task, and received standardized verbal encouragement during all MVIC trials to help them produce maximal effort.

Data Reduction

Data were collected and exported using Motion Monitor software (Innovative Sports Training, Inc, Chicago, IL). Raw EMG data were band-pass filtered (20-350 Hz), and smoothed using a root-mean-square sliding window function with a time constant of 20 milliseconds (MatLab; The Mathworks, Inc, Natick, MA). The customized software program was used to select the beginning and end of the middle 4 repetitions for each exercise, and the mean gluteus medius and maximus EMG signal amplitudes for each repetition were calculated and averaged. The electrogoniometer data were used to determine the start and stop points for the single-limb squat and single-limb deadlift exercises. Both the electrogoniometer and the footswitch were used to select the middle 4 trials for the multiplanar hops and lunges.

Only muscle activity during the landing phase, defined as the 3-second period immediately following foot contact, was calculated during the multiplanar hops. Data from the footswitch and the processed EMG signal established the middle 4 trials for the lateral band walks. The beginning of a lateral band walk trial was when the subject lifted the dominant foot from the ground to begin the abduction motion, and the end of the trial was the instant immediately before the start of the subsequent trial. The processed gluteus medius EMG signal amplitude clearly discriminated between repetitions for both hip clam exercises and the side-lying hip abduction exercise. Therefore, we used visual onset and offset of this EMG signal amplitude to select the middle 4 trials of these 3 exercises.

The middle of each MVIC trial was visually selected, and the computer al-

TABLE 1	WITHIN-SUBJECT RELIABILITY VALUES FOR EACH EXERCISE			
	Gluteus Medius		Gluteus Maximus	
	ICC _{3,1}	SEM (% MVIC)	ICC _{3,1}	SEM (% MVIC)
Side-lying hip abduction	0.98	7	0.94	5
Clam with 30° hip flexion	0.98	6	0.95	7
Clam with 60° hip flexion	0.97	6	0.98	5
Single-limb squat	0.95	8	0.93	7
Single-limb deadlift	0.95	8	0.95	7
Lateral band walk	0.96	8	0.93	5
Forward lunge	0.91	6	0.91	8
Sideways lunge	0.91	6	0.85	9
Transverse lunge	0.93	7	0.95	5
Forward hop	0.37	41	0.42	30
Sideways hop	0.55	30	0.21	35
Transverse hop	0.56	35	0.27	22

Abbreviations: ICC, intraclass correlation coefficient; MVIC, maximum voluntary isometric contraction; SEM, standard error of measurement.

gorithm selected 100 milliseconds before and after this point, resulting in a 200-millisecond window. The mean amplitude during this 200-millisecond window was calculated for the 3 MVIC trials per muscle. For each muscle, these 3 means were averaged to obtain 1 MVIC value. The mean EMG amplitudes for each exercise were normalized to these reference values and expressed as percentage MVIC.

Statistical Analysis

Normalized mean EMG signal amplitudes were compared among exercises using a repeated-measures 1-way analysis of variance (ANOVA), with an a priori level of significance of 0.05 for both muscles. Confidence intervals were used to evaluate pairwise comparisons among the 12 exercises. Pairwise comparisons were deemed to be significant when there was a complete separation of the 2 confidence intervals (ie, a lack of interval overlap). In addition, we also conducted a reliability analysis, using intraclass correlation coefficients (ICCs) across the 4 repetitions of each exercise to confirm that the EMG measures were stable within subjects. SPSS, Version 15.0 (SPSS Inc, Chicago, IL) was used for all statistical analyses.

RESULTS

THE RELIABILITY ANALYSIS ACROSS the 4 repetitions of each exercise resulted in ICC_{3,1} values ranging from 0.93 to 0.98, with standard error of measurement (SEM) values between 6% and 8% MVIC for the gluteus medius, with the exception of the hopping tasks, which were less reliable. Similarly, the gluteus maximus data resulted in ICC_{3,1} values ranging from 0.85 to 0.98, with SEM values between 5% and 9% MVIC. These data suggest moderate to high reliability across trials for both muscles during each exercise except the hopping tasks. **TABLE 1** provides the reliability values for each muscle and each exercise.

Normalized mean amplitudes, as well as standard deviations and confidence intervals, for gluteus medius muscle activity during the 12 exercises are rank ordered in **TABLE 2**. There was a significant difference observed among the 12 exercises for gluteus medius mean muscle activity ($F_{5,90} = 7.9, P < .0001$). The side-lying hip abduction exercise was found to produce significantly greater activation of the gluteus medius than both of the clams exercises, all 3 lunge exercises, the forward hop, and the transverse hop. The gluteus

TABLE 2

NORMALIZED GLUTEUS MEDIUS
MEAN SIGNAL AMPLITUDE (% MVIC)

Exercise	Mean ± SD (95% CI)
Side-lying hip abduction	81 ± 42 (62, 101)
Single-limb squat	64 ± 24 (53, 75)
Lateral band walk	61 ± 34 (46, 76)
Single-limb deadlift	58 ± 25 (47, 70)
Sideways hop	57 ± 35 (41, 73)
Transverse hop*	48 ± 25 (37, 59)
Transverse lunge*	48 ± 21 (38, 57)
Forward hop*	45 ± 21 (38, 57)
Forward lunge*†	42 ± 21 (33, 52)
Clam with 30° hip flexion*	40 ± 38 (23, 57)
Sideways lunge*†	39 ± 19 (30, 47)
Clam with 60° hip flexion*†	38 ± 29 (25, 51)

Abbreviations: CI, confidence interval; MVIC, maximum voluntary isometric contraction.

* Exercises are significantly different than the hip abduction exercise ($P < .05$).

† Exercises are significantly different from the single-limb squat ($P < .05$).

TABLE 3

NORMALIZED GLUTEUS MAXIMUS
MEAN SIGNAL AMPLITUDE (% MVIC)

Exercise	Mean ± SD (95% CI)
Single-limb squat	59 ± 27 (47, 72)
Single-limb deadlift	59 ± 28 (46, 71)
Transverse lunge	49 ± 20 (39, 58)
Forward lunge	44 ± 23 (33, 54)
Sideways lunge	41 ± 20 (32, 50)
Side-lying hip abduction	39 ± 18 (31, 47)
Sideways hop	30 ± 19 (31, 48)
Clam with 60° hip flexion	39 ± 34 (24, 54)
Transverse hop*†	35 ± 16 (28, 43)
Forward hop*†	35 ± 22 (25, 45)
Clam with 30° hip flexion*†	34 ± 27 (21, 46)
Lateral band walk*†‡	27 ± 16 (20, 35)

Abbreviations: CI, confidence interval; MVIC, maximum voluntary isometric contraction.

* Exercises are significantly different than the single-limb squat ($P < .05$).

† Exercises are significantly different from the single-limb deadlift ($P < .05$).

‡ Exercises are significantly different from the transverse lunge ($P < .05$).

medius activation during the single-limb squat exercise was significantly greater than during the clam exercise performed with the hips at 60°, the forward lunge, and the sideways lunge. No significant differences were observed among any other comparisons based on the confidence intervals.

Normalized mean amplitudes, as well as standard deviations and confidence intervals, for gluteus maximus muscle

activity during the 12 exercises are rank ordered in TABLE 3. A significant difference was observed for gluteus maximus mean amplitudes among the 12 exercises ($F_{5,95} = 8.1, P < .0001$). The single-limb squat and single-limb deadlift exercises produced significantly greater activation of the gluteus maximus compared to the lateral band walk, hip clams with 30° of hip flexion, forward hop, and transverse hop. The gluteus maximus muscle

activity during the transverse lunge was greater than during the lateral band walk. No other significant differences were observed.

DISCUSSION

THE MAIN OBJECTIVE IN THIS STUDY was to evaluate gluteal muscle activity during several exercises that are commonly used in injury prevention and rehabilitation programs. We found significant differences among the exercises for both the gluteus medius and the gluteus maximus. Our findings will be discussed based on statistical findings, as well as qualitative interpretation based on the rank order results of the exercises.

The exercises in this study were all performed using only body weight, an elastic band, or segment weight as resistance. No additional equipment was required, so the exercises can be easily incorporated into any setting of rehabilitation or injury prevention. The reduced need for equipment is of particular importance for injury prevention programs that are often performed on a field or court. Previous literature suggests that muscle activation greater than 50% to 60% MVIC is conducive for muscle strength gains.^{1,2,35} Using this threshold value, the single-limb squat and the single-limb deadlift both strongly activated the gluteal muscles. Side-lying hip abduction, lateral band walk, and sideways hop exercises also activated the gluteus medius above this threshold. It is reasonable to expect that adding a weight to any of the exercises would further increase the level of muscle activation and potentially improve the strengthening effects.

When solely considering the exercise rankings based on mean EMG amplitude, 5 exercises appear to be especially effective to activate the gluteus medius. Based on the 10% observed difference among these top 5 exercises and the remaining 7 exercises with relatively lower gluteus medius activation, we divided the exercises into a “top tier” and “lower tier” for

discussion purposes. The gluteus medius concentrically abducts the hip, isometrically stabilizes the pelvis, and eccentrically controls hip adduction and internal rotation.³³ All 5 exercises in the top tier (hip abduction in side-lying, single-limb squat, band walk, single-limb deadlift, sideways hop) involve the primary functions of the gluteus medius directly. Both side-lying hip abduction and lateral band walk exercises require the pure concentric movement of hip abduction as part of the exercise. The single-limb squat, single-limb deadlift, and sideways hop demand frontal-plane pelvic stability and control of the distal lower extremity in the frontal and transverse planes, which probably contributed to the high neural drive to the gluteus medius during these exercises.

The side-lying hip abduction exercise was very effective in targeting the gluteus medius, as it produced almost 16% more activation than the other 4 exercises in the top tier exercises and at least 30% more activation than the lower tier exercises. A reason for these relative differences in activation is the large external moment created by the mass and position of the lower extremity being lifted. The external moment arm is larger due to the hip and knee being kept in an extended position equal to the length of the entire lower extremity, in contrast to the hip and knee being flexed during the hip clam exercises. Secondly, a portion of the weight of the lower extremity is supported during the hip clam exercises, as the foot of the test limb rests on that of the nontest limb. In contrast, the subject must contract the hip abductors to lift the weight of the entire lower extremity during the hip abduction exercise.

The gluteus medius was most active when performing an isolated non-weight-bearing exercise with a large external moment arm (side-lying hip abduction), followed by single-limb weight-bearing exercises that demand frontal-plane pelvic stability (single-limb squat and single-limb deadlift). Gravitational force

creates substantial hip adduction torque during single-limb stance that must be resisted by the gluteus medius and other muscles of the hip and pelvis to maintain upright stance. The contribution of other muscles besides the gluteus medius to overcome this hip adduction torque may provide one explanation for why the side-lying hip abduction exercise results in relatively more gluteus medius muscle activation than the single-limb squat and single-limb deadlift exercises.

The finding of high gluteus medius activity during side-lying hip abduction suggests that patients who are unable to perform weight-bearing exercises can effectively strengthen the gluteus medius with a non-weight-bearing exercise. The finding of substantial gluteus medius activity during the abduction exercise agrees with previous research that compared simple pelvic-control exercises with hip abduction.⁵

We incorporated 2 variations of the hip clam exercise to determine if sagittal-plane hip position influences gluteal muscle activation. Previous research has shown that the hip external rotation moment arm for the posterior portion of the gluteus medius decreases with hip flexion.¹⁰ Therefore, hip external rotation in hip flexion is primarily attributable to the gluteus maximus and deep lateral rotators. However, both versions of the hip clam exercise activated the gluteus medius similarly, suggesting that the amount of hip flexion within the range of 30° to 60°, as used in this study, is not an important clinical consideration when instructing patients to perform this exercise to promote gluteus medius activation.

All 3 lunge exercises were in the lower tier of gluteus medius muscle activation, and both the forward and sideways lunge had significantly less activation than the side-lying hip abduction and single-limb squat exercises. The forward lunge exercise occurred in the sagittal plane, resulting in minimal gluteus medius activation, which acts primarily for movements performed in the frontal plane. While the

sideways and transverse lunge did require frontal-plane pelvic stability, we believe the relatively stable position of these exercises, provided by bilateral weight bearing, reduced the need for gluteus medius activation to stabilize the pelvis and lower extremity, compared to exercises that required balancing on 1 limb, such as the single-limb squat, single-limb deadlift, and hop exercises. The sideways hop exercise was the only multiplanar hop exercise that was included in the top tier of gluteus medius muscle activity. The sideways hop was also the only hop to involve solely frontal-plane movement, and may be the reason for the relative, although not statistically significant, differences in muscle activity.

In contrast with the gluteus medius, specific tiers of exercises based on gluteus maximus were not clearly evident. The single-limb squat and single-limb deadlift exercises were prime activators of the gluteus maximus, as both exercises demonstrated activation levels greater than 50% MVIC and activated the gluteus maximus at least 10% more than the other exercises. These findings are logical as both of these exercises require stability of the lumbar-pelvic region, single-limb balance, eccentric control of hip flexion, and concentric hip extension, which are all major functions of the gluteus maximus.^{33,43} Similar to our results, Ayotte et al² found higher gluteus maximus activity during a unilateral wall squat compared with a mini-squat, and lateral and retro step-up exercises. Based on this previous study and our current results, exercises that require single-limb balance and hip flexion/extension throughout a large range of motion and cause changes in the body's center of mass relative to the base of support appear to result in the greatest level of gluteus maximus activation.

Even though balance was not an integral aspect of the multiplanar lunge exercises, moderate levels of gluteus maximus activation were created by these exercises. The transverse-plane lunge required the most balance and appears to activate the

gluteus maximus slightly more than the other 2 lunge directions, but this difference was not statistically significant. One reason the lunges may have activated the gluteus maximus slightly more than the hops is that the lunges required production of hip extension, in contrast to the hops, which required stability and eccentric control of concentric hip flexion. This seems logical given that concentric muscle actions result in more neural drive compared with eccentric and isometric actions.^{13,18,28,30}

We originally hypothesized that the hip clam exercises would target the gluteus maximus because of its role in hip external rotation.¹⁰ However, these exercises did not activate the gluteus maximus differently than the other non-weight-bearing exercises, the side-lying hip abduction exercise, or the other weight-bearing exercises, with the exception of the single-limb squat and single-limb deadlift. Changes in the moment arm of the gluteus maximus may explain these findings. Delp et al¹⁰ demonstrated that the hip external rotation moment arm for a portion of the gluteus maximus decreases with hip flexion. Therefore, it is possible that the gluteus maximus was not very active during the clams exercises because the hip was flexed. It is possible the gluteus maximus may be more active when the hip is in a neutral position, but future research would be needed to confirm this hypothesis.

Limitations

EMG provides information about motor unit activity within a muscle and has been used frequently to compare therapeutic exercises' abilities to recruit certain muscles,^{2,5,12,20,35} explain muscle activation patterns,^{8,11,21,27} and observe differences in muscle activity between populations and conditions.^{4,9,21} While EMG is a valuable instrument, there are also significant limitations to using EMG as a sole indicator of muscle function. Cross talk may occur, especially when using surface electrodes. For example, we assume the EMG signal captured

with electrodes over the gluteus medius originate solely from the gluteus medius; but it is possible that the muscle activity of the tensor fascia lata and gluteus minimus also contributed to the recorded EMG signal, as these muscles are in close proximity to the gluteus medius. We minimized the potential for error by using standardized methods of applying the surface electrodes, properly securing the electrodes to prevent movement and observing the output of the electrodes prior to collecting data to ensure that the electrodes were in the proper location.

Variability with EMG signal may be a result of natural variation in dynamic muscle function or poor data collection methodologies. All exercises, with the exception of the multiplanar hops, showed good reliability for the EMG signal. The EMG activation levels with the multiplanar hops were highly variable, which is probably due to the dynamic nature of these tasks. Therefore, caution should be used with the interpretation of the multiplanar hops results until further research can determine the precise cause of the variability.

Another assumption that is made based on previous studies is that high EMG signal amplitudes represent large levels of muscle or motor unit activity, which is assumed to be needed for muscle strengthening to occur. Further research needs to be performed to determine if the high levels of muscle activity observed during certain exercises in this study actually result in muscle strength gains over time. Finally, EMG signal data collection and interpretation is complicated when studying actions requiring changes in muscle length, so collecting more detailed kinematics and kinetics, along with EMG data, may enhance interpretation of the differences in activity levels among exercises. Despite these limitations, we believe EMG is still useful to gain knowledge about muscle activity as long as the limitations of this instrument are understood.

This study compared gluteal muscle activity across a large group of exercises;

however, no exercises included hip extension in a non-weight-bearing position. This limitation reduces the ability to compare gluteus maximus activation between weight-bearing and non-weight-bearing exercises. Future research should further evaluate non-weight-bearing exercises that use the primary function of the gluteus maximus. Finally, only healthy subjects were evaluated, so future research should investigate muscle activity in individuals with injuries or pathologies.

CONCLUSION

A BASIC EXERCISE, THE SIDE-LYING hip abduction exercise, demonstrated high levels of gluteus medius activation, suggesting its usefulness for patients who may not be able to perform weight-bearing exercises. The single-limb squat and single-limb deadlift exercises effectively activated both the gluteus medius and gluteus maximus. Performing these exercises may improve the efficiency of rehabilitation and prevention programs and result in strength gains. ●

KEY POINTS

FINDINGS: The best exercise for the gluteus medius was side-lying hip abduction, while the single-limb squat and single-limb deadlift exercises led to the greatest activation of the gluteus maximus.

IMPLICATION: The results of this study provide evidence for the amount of muscle activity actually generated by several commonly used functional therapeutic exercises, which can help guide clinical decision making for injury prevention and rehabilitation programs.

CAUTION: Only healthy, physically active subjects participated in this study, so the results may not be similar in patients with pathologies.

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