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Examining the effects of altering hip orientation on gluteus medius and tensor fascae latae interplay during common non-weight-bearing hip rehabilitation exercises

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ABSTRACT

Background: Improving activity and strength of the gluteus medius muscle is a common goal among clinicians aiming to rehabilitate lower extremity and low back injuries. The functional anatomy of the hip is complex, particularly how position-dependent the activity and strength of many muscles surrounding the hip are, and the optimal exercise technique to isolate gluteus medius remains controversial. The objective of this study was to quantify the effect of altering hip orientation during side-lying clamshell and hip abduction exercises on the relative muscle activation profiles of gluteus medius and tensor fascae latae.

Methods: The ratio of gluteus-medius-to-tensor-fascae-latae peak electromyography signal amplitude of 13 healthy, male participants was compared across variations of the clamshell and abduction exercises. The hip flexion angle was varied from 30°, 45°, and 60° for the clamshell, while hip rotation orientation was varied from internal, neutral, and external rotation for the abduction exercise.

Findings: Varying hip angle – flexion in the clamshell exercise and internal/external rotation in the abduction exercise – did not significantly affect the interplay between gluteus medius and tensor fascae latae activation levels. Both exercises remained gluteus medius-dominant across all variations, but the gluteus-medius-to-tensor-fascae-latae ratio was far greater for the clamshell than for the abduction exercise; the clamshell may be the preferred rehabilitative exercise to prescribe when minimal tensor fascae latae muscle activation is desired by the clinician.

Interpretation: These findings provide information for clinical decision-making pertaining to effective gluteus medius activation in lower extremity and low back exercise rehabilitation programs.

1. Introduction

Increasing activity and strength of the gluteus medius (GMed) muscle is a common goal among clinicians aiming to rehabilitate lower extremity and low back injuries with therapeutic exercise. The rationale for targeting this muscle within lower extremity and low back injury exercise rehabilitation programs are the many known associations between hip dysfunction and both lower extremity and low back pain/dysfunction. There is evidence to suggest that perturbed gluteal mechanics may be both the cause and consequence of pain/dysfunction. Pain appears to inhibit the gluteal muscles. For example, chronic low back pain is linked to inhibition of the gluteal muscles (Janda, 1989; Janda et al., 2007) and, recently, acute hip pain was shown to inhibit gluteal activity (Freeman et al., 2013). Furthermore, perturbed gluteal function, specifically, a lack of hip abductor muscle strength is associated with lower extremity injuries, such as ankle sprains (Beckman and Buchanan, 1995; Friel et al., 2006), iliotibial band syndrome (Fredericson et al., 2000), and patellofemoral syndrome (Bolgla et al., 2011), as well as hip osteoarthritis (Rasch et al., 2007) and low back pain (Arab and Nourbakhsh, 2010). Exercise programs that incorporate hip abductor strengthening, specifically GMed strengthening, have demonstrated improvement in lower extremity pathologies (Fredericson et al., 2000; Khayambashi et al., 2012), low back pain in prolonged standing (Nelson-Wong and Callaghan, 2010), and explosive power output in athletes (Crow et al., 2012). It appears justifiable that gluteus medius is indeed a critical component of many lower extremity and low back injury rehabilitation and prevention programs as well as some performance training exercise programs. Questions remain as to how to best train this muscle.

Clinicians prescribe a wide variety of exercises that are assumed to primarily strengthen GMed (Presswood et al., 2008; Reiman et al., 2012) and/or integrate it into the motor control scheme, but this assumption is more often based on knowledge of the anatomy, mechanics, and functions of the muscles about the hip and shared experiences among clinicians rather than on empirical evidence confirming the

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level of GMed activation. Despite the complex nature of the functional anatomy of the hip (Gottschalk et al., 1989), particularly how position-dependent the activity (Delp et al., 1999; Dostal et al., 1986) and strength (Johnson and Hoffman, 2010) of many muscles surrounding the hip are, and evidence of the ability to selectively activate muscles of the posterolateral hip during functional rehabilitation (Cambridge et al., 2012), very little consideration has been given to the optimal variation (with respect to primary GMed activity) of commonly used GMed strengthening exercises and the contribution of synergistic muscles about the hip, such as tensor fascae latae (TFL) (Cobb et al., 2012; Lee et al., 2013). The clinical question regarding prescription of the most effective GMed strengthening exercise must address the relative muscle activation of GMed and TFL in variations of specific exercises.

Perhaps two of the most common GMed strengthening exercises used in clinical practice are the side-lying clamshell (CLAM) and the side-lying hip abduction (ABD) exercise (McGill, 2007). These are typically used in the early stages of lower extremity and low back injury rehabilitation programs because they are non-weight-bearing exercises that put the patient in a highly stable position, isolate movement about the hip, and do not require additional equipment. The level of GMed activation has been reported on for both the CLAM and ABD, but is typically only compared across different GMed strengthening exercises (Bolgla and Uhl, 2005; Distefano et al., 2009; Selkowitz et al., 2013) rather than within variations of the same CLAM or ABD exercise. Only one study (Distefano et al., 2009) has compared two variations of the CLAM – 30° and 60° of hip flexion – and found similar levels of GMed activity between the two variations, but did not report on the contribution of TFL. GMed and TFL activity have been measured during the standard CLAM (Cobb et al., 2012), but variations were not compared. In addition, anecdotal evidence, consistent with the informal evidence acquired by others (Cobb et al., 2012), suggests that many clinicians prescribe variations of ABD, such as ABD while maintaining hip external or internal rotation. One study (Cobb et al., 2012) has compared GMed and TFL activation across two variations of ABD (i.e., ABD and ABD while maintaining hip external rotation) and found that GMed was significantly more active and TFL was significantly less active in ABD, but ABD while maintaining hip internal rotation was not included in this comparison and a weight equivalent to five percent body mass was applied to the ankle in both conditions. The relative muscle activity of GMed and TFL was compared during ABD and ABD while maintaining hip external and internal rotation in another study (Lee et al., 2013); however, all variations of ABD were performed isometrically, so only one point during the movement was measured and findings may not represent muscle activity when the exercise is performed dynamically. Clearly, a comparison of GMed and TFL activity across all three variations of ABD is needed to gain a clear understanding of the interplay between GMed and TFL for each variation.

The objective of this study was to assess the effect of altering hip angle – flexion during the side-lying clamshell and internal/external rotation during the side-lying hip abduction exercises – on the relative muscle activation profiles of GMed and TFL. Based on previous *in vivo* study findings (Boren et al., 2011; Cobb et al., 2012; Distefano et al., 2009) and assumptions formulated from muscle modeling studies (Delp et al., 1999; Dostal et al., 1986; Gottschalk et al., 1989), it was hypothesized that GMed and TFL activation ratios would not be influenced by altering the hip orientation in variations of the CLAM or ABD, respectively.

2. Methods

2.1. Participants

Thirteen healthy males were recruited to participate in this study. Their average age, height, and weight were 24.8 (SD 4.2) years, 179.7 (SD 5.4) centimeters, and 75.9 (SD 9.8) kilograms, respectively. Participants did not have a history of spinal, abdominal, or hip surgery, a pre-existing disabling back or hip condition, or current and relevant musculoskeletal concerns.

All subject recruitment and data collection procedures received the approval of the university's Office of Research Ethics.

2.2. Experimental design

To determine the effect of altering hip orientation on the relative muscle activation profiles of GMed and TFL during two common non-weight-bearing hip rehabilitation exercises (CLAM and ABD), a repeated measures design was employed. The independent variable, hip orientation, was varied three times for each exercise while electromyography (EMG) signals of selected hip muscles were continuously collected for the duration of each trial. For CLAM, the hip flexion angle was varied from 30°, 45°, and 60° while the hip rotation orientation was varied from internal, external, and neutral for ABD. The dependent variables in this study were the EMG signal amplitudes of the right GMed and TFL. Specifically, the ratio of GMed-to-TFL peak EMG signal amplitude was compared across variations of each exercise.

2.3. Tasks

Participants were provided with a demonstration of each exercise and variation and were required to practice these until the researcher deemed their technique and execution to be satisfactory. Achieving this satisfactory level of technique and execution typically only took a few attempts or approximately five minutes per task. Once the practice trials were completed, three consecutive trials of each variation of each exercise were performed with proper execution (visually evaluated by the researcher). The order that each of the following exercises and their variations were performed by each participant was randomized.

2.3.1. Side-lying clamshell

Participants were instructed to lie on their left side with their legs together, hips and knees flexed, and left arm supporting the weight of their head (Fig. 1a). Before each trial, the researcher adjusted the hip flexion angle of the participant to 30°, 45°, or 60° using a standard goniometer and then adjusted their knee angle so that the heels of the participant's feet were in line with their buttocks (from an overhead perspective) (Fig. 1b). Participants were then instructed to keep the medial borders of their feet together as they externally rotate their right hip as much as they can to separate the right knee from the left, stop the movement before having to rotate their pelvis backwards, keep the left leg in contact with the floor throughout the entire movement (Fig. 1c), and, finally, return their right leg to the starting position. Participants were cued to limit any spine 'twisting' during the exercise by stiffening (i.e., co-contracting) their trunk musculature throughout the exercise and coached to initiate external rotation of their hip from their hip muscles (i.e., GMed) — not by rotating their pelvis backwards.

2.3.2. Side-lying hip abduction

Participants were instructed to lie on their left side in a straight line (from an overhead perspective) with their legs together, knees extended, and left arm supporting the weight of their head (Fig. 2a). Before initiating the exercise, participants were asked to change the orientation of their right hip from internal, neutral, or external rotation (Fig. 2b) — to do this, the researcher cued them to point their toes either toward the floor (i.e., internal rotation), forwards (i.e., neutral), or toward the ceiling (i.e., external rotation) by rotating from the hip (not the knee or ankle) as much as they could, without rotating their pelvis forwards or backwards and within a comfortable range. Participants were then instructed to lift their right leg toward the ceiling (i.e., hip abduction) as high as they could, initiate this movement with their hip muscles instead of 'hiking' their hip to abduct, maintain the hip rotation orientation they began with throughout the entire movement, stop the movement before having to 'hike' their pelvis up or

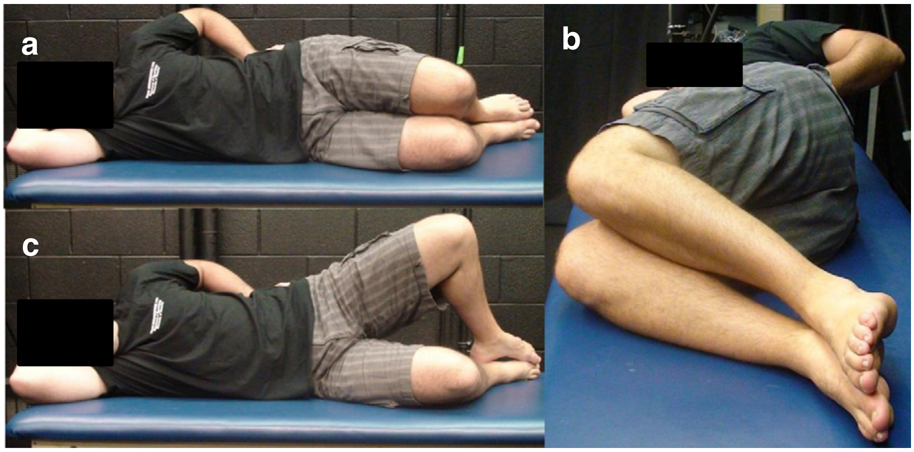

Fig. 1. Side-lying clamshell at (a, b) zero percent and (c) approximately fifty percent of the movement.

flex their right hip (Fig. 2c), and then return their right leg to the starting position. Participants were cued to limit any spine 'twisting' during the exercise by stiffening (i.e., co-contracting) their trunk musculature throughout the exercise.

2.4. Electrode placement and data collection protocol

EMG signals of each participant were measured unilaterally (right side) from the following two hip muscles: GMed and TFL. Electrode placements and orientations on the skin over GMed and TFL were consistent with recommendations from the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) project (updated 1999). Specific surface EMG electrode placement locations and orientations for this research project are illustrated in Fig. 3; the GMed electrodes were placed approximately over the middle fibers. A reference electrode was placed on the right iliac crest of each participant.

To measure GMed and TFL EMG signal amplitude with the least electrode-skin interface impedance, the skin over the muscles where surface electrodes would be placed was shaved with a new disposable razor, rubbed with an abrasive skin gel (Nuprep®, Weaver and Company, Cambridge, ON, CAN), and cleaned using rubbing alcohol. Pre-gelled, disposable, monopolar Ag-AgCl disk-shaped surface electrodes (30 mm diameter, Medi-trace™ 100 Series Foam Electrodes, Covidien, MA, USA) were then placed on the skin over each muscle of interest. Two electrodes (30 mm interelectrode distance) were placed at each muscle site, so that the difference in potential between the electrodes could be recorded (i.e., a bipolar configuration). Non-woven, adhesive fabric (Hypafix™, Smith & Nephew, Mississauga, ON, CAN) and adhesive tape (3M, St. Paul, MN, USA) were used for the fixation of the electrodes

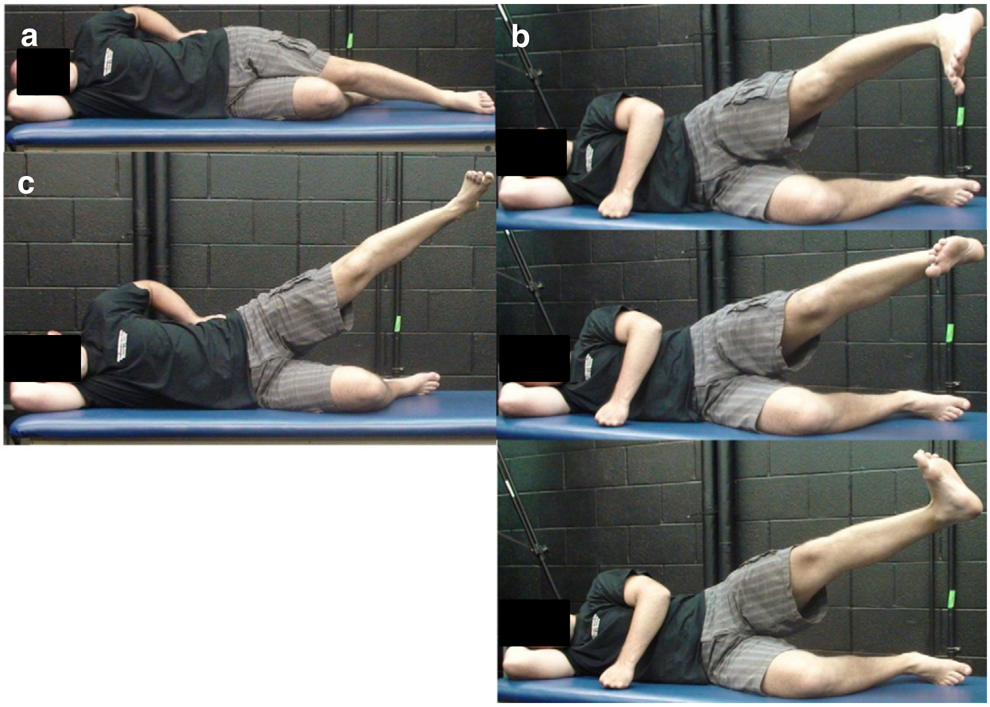

Fig. 2. Side-lying hip abduction at (a) zero percent and (c) approximately fifty percent of the movement. Hip rotation orientations varied in the starting position of the side-lying hip abduction exercise are also depicted here. From top to bottom in (b): internal, neutral, and external hip rotation.

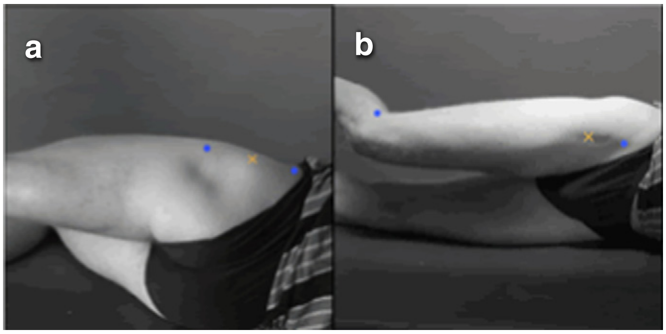

Fig. 3. (a) GMed and (b) TFL electrode placement, indicated by the "x" (SENIAM [updated 1999]).

and the bioamplifiers to the skin, respectively. This fixation ensured that the electrodes were properly secured to the skin, movement was not hindered, and the cables were not pulling the electrodes off of participant's skin.

2.5. Maximum voluntary contraction (MVC) task

Prior to performing the non-weight-bearing hip rehabilitation exercises described above, one maximum voluntary contraction (MVC) task, consistent with SENIAM recommendations (updated 1999), was performed. This MVC trial was performed with the intention of producing the largest amplitudes of myoelectric activity from the selected hip muscles (i.e., GMed and TFL) of each participant to provide a basis for normalization of these EMG signals. Participants were instructed to lie on their left side on a table and abduct their right hip against isometric resistance applied manually in the direction of hip adduction at the right ankle by the researcher. The researcher ensured that the participant's pelvis did not deviate anteriorly or posteriorly. This MVC task was repeated three times with a minimum rest period of two minutes between contractions. Finally, one quiet-lying trial (with the participant lying prone) was performed prior to the data collection.

2.6. Data processing

The raw EMG signal was sampled at a rate of 2160 Hz, amplified with an eight-channel differential amplifier (common-mode rejection ratio of 115 dB at 60 Hz; input impedance 10 GΩ; Model AMT-8, Bortec Biomedical, Calgary, AB, CAN), and set to the same amplification setting (gain = 1000). The EMG signals were analog-to-digital converted (Vicon MX 64-channel analog-to-digital interface unit, Vicon Motion Systems, Oxford, UK) using a 16-bit converter (Vicon MX 20 MX control box, Vicon Motion Systems, Oxford, UK) with a +/− 2.5 V range. Gains were individually set for each channel to fill this input range without clipping the signal. The digitized signal was collected on a personal computer (Vicon Antec® Intel® Core™ 2 Duo PC, Vicon Motion Systems, Oxford, UK) using Vicon Nexus 1.7 software (Vicon Motion Systems, Oxford, UK).

2.7. Higher data processing

Higher processing of the EMG signal data was performed using a custom computer program in LabVIEW software (Version 8.5, National Instruments Corp., Vaudreuil-Dorion, QU, CAN). To preserve as much of the biological signal and filter out as much noise as possible, raw EMG was filtered using a second-order, band-pass, digital filter (10–500 Hz), which was dual-passed to create a fourth-order filter with zero phase shift. The direct current bias was removed from each EMG signal channel for all trials by subtracting the zero bias calculated from the raw EMG signal amplitudes in the prone quiet-lying trial. The filtered EMG signals were then full-wave rectified to generate the absolute value of the EMG and low-pass filtered using a second-order Butterworth filter (single-pass to introduce a phase lag, which represents electromechanical delay between the onset of the motor unit action potential and the resultant muscle tension) with a cut-off frequency of 3 Hz to produce a linear envelope. By selecting a 3 Hz cut-off frequency that matches the 3 Hz twitch response of the hip musculature (Winter and Yack, 1987), the linear envelope closely resembled the muscle twitch tension curves of the hip musculature (Winter and Yack, 1987). The EMG signals were then normalized to the maximum EMG signal amplitudes achieved at each muscle site during the MVC task and expressed as a percentage of these maximums (% MVC). Finally, the normalized EMG signals for GMed and TFL (see Fig. 4) were used to calculate the peak EMG signal amplitudes and the ratio of GMed-to-TFL peak EMG signal amplitude for each variation of each exercise.

2.8. Data analysis

IBM® SPSS® Statistical software (Version 19, IBM Corporation, Somers, New York, USA) was used for statistical analysis of the data collected. To determine if the independent variable, hip orientation, had an effect on the dependent variable, relative muscle activation profile of GMed and TFL, separate one-way repeated measures analysis of variance (ANOVA) tests were performed for each exercise across conditions. If a main effect was found, a Bonferroni post hoc test for pair wise comparisons was used. Statistical significance was held at alpha = 0.05.

3. Results

Regardless of the hip flexion angle when performing CLAM, the mean GMed-to-TFL peak EMG signal amplitude ratio did not vary a significant amount ($F(2,36) = 1.170$, $P = 0.322$) and the GMed-to-TFL peak EMG signal amplitude ratio remained well above 1.0 (Table 1). For the interested reader, the following are the average peak EMG signal amplitudes of GMed and TFL for each condition of CLAM: 26.80 (SD 24.08) % MVC and 7.96 (SD 6.13) % MVC, respectively for 30° of hip flexion, 35.55 (SD 34.25) % MVC and 8.16 (SD 5.17) % MVC, respectively for 45° of hip flexion, and 36.49 (SD 33.06) % MVC and 7.04 (SD 4.65) % MVC, respectively for 60° of hip flexion.

Similar results were found across ABD variations — hip rotation orientation did not have a significant effect on the relative muscle activity of GMed and TFL ($F(2,36) = 0.739$, $P = 0.485$) and the average ratio of GMed-to-TFL peak EMG signal amplitude also remained above 1.0 (Table 1). The average peak EMG signal amplitudes of GMed and TFL during the side-lying hip abduction exercise were 48.67 (SD 20.21) % MVC and 49.69 (SD 25.11) % MVC, respectively, for ABD with internal rotation at the hip; 36.70 (SD 14.55) % MVC and 36.20 (SD 17.51) % MVC, respectively, for ABD; and 36.50 (SD 16.46) % MVC and 40.21 (SD 30.72) % MVC, respectively, for ABD with external rotation at the hip.

4. Discussion

The hypothesis that altering hip orientation during the CLAM and ABD on the relative muscle activation profiles of GMed and TFL would not change activation ratios was supported. In fact, GMed activity dominated TFL activity in all exercise variations. Clinicians may use this information when choosing gluteus medius training exercises. This is in spite of suggestions from muscle modeling (Dostal et al., 1986) and *in vitro*(Delp et al., 1999) studies on the influence of hip flexion on rotational moment arms of some hip muscles that suggested as hip flexion increases, the internal rotation moment arm of GMed increases. However, the results of this study together with previous *in vivo* work (Distefano et al., 2009) have not found a significant difference in GMed muscle activity in the CLAM across a hip flexion range of 30° to 60°. Since Delp et al. (1999) found that the rotational moment arm of

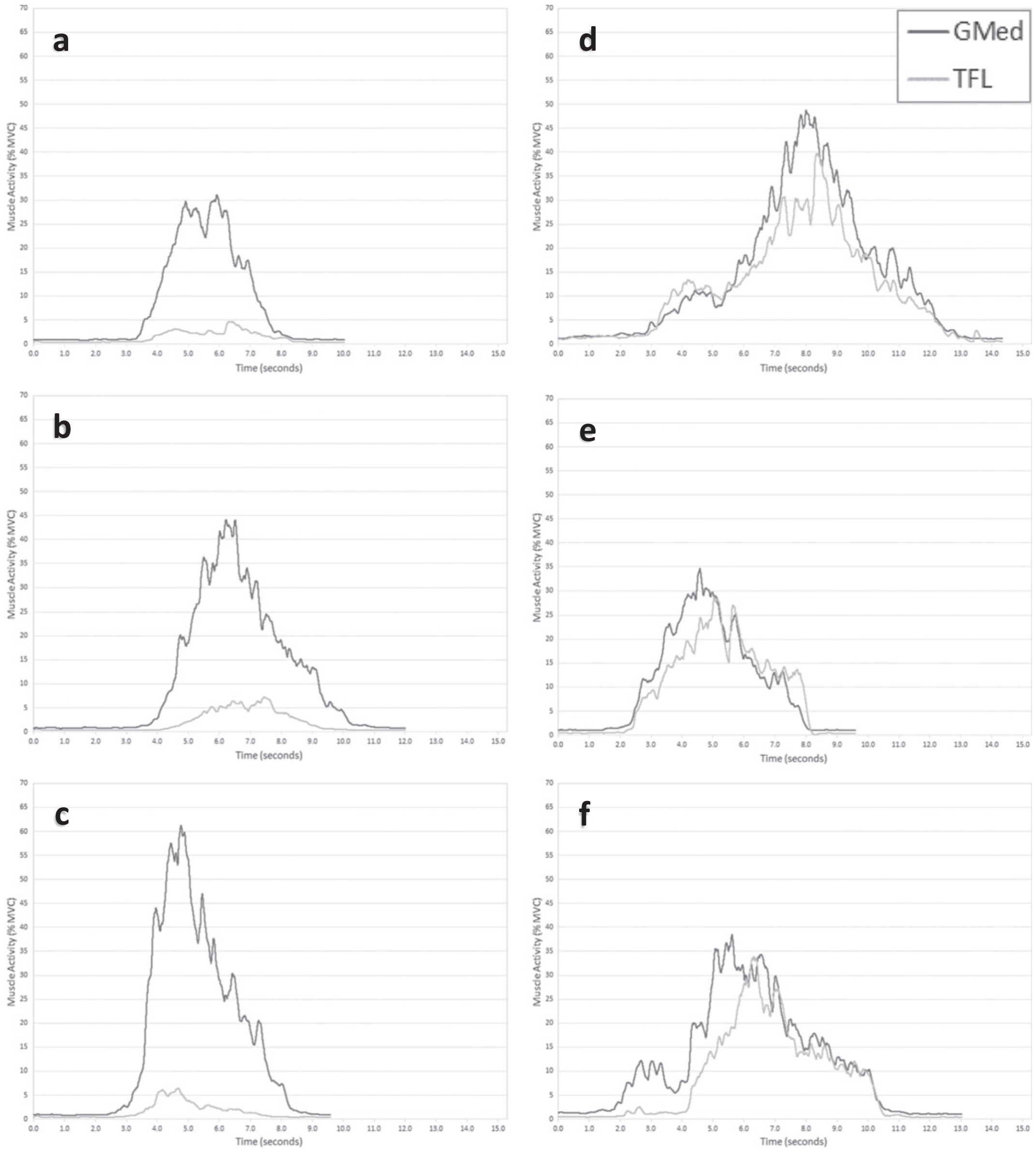

Fig. 4. Time-history of GMed (dark gray line) and TFL (light gray line) muscle activity for a single subject during the side-lying clamshell exercise with (a) 30°, (b) 45°, and (c) 60° of hip flexion and the side-lying hip abduction exercise with hip rotation orientation at (d) internal rotation, (e) neutral rotation, and (f) external rotation.

the middle compartment of GMed changed from external to internal after approximately 20° of hip flexion, it is possible that this would be the threshold of a significant difference in GMed activity in the CLAM, but the clinical value of investigating this further is minimal.

Gottschalk et al.'s (1989) muscle modeling work defined GMed primarily as a hip stabilizer – specifically, stabilizing the femoral head in the acetabulum in different positions of rotation of the femoral head – and regarded its secondary function as the initiation and assistance in abduction; therefore, the primary function of hip abduction was proposed to be TFL (Gottschalk et al., 1989). Trends in the data suggest that these defined roles may exist, but that the demand on GMed and TFL does not vary significantly across ABD variations. These differences may be more pronounced when weight is added to ABD and there is a higher demand on GMed to stabilize and TFL to abduct the hip (Cobb et al., 2012). One study did find significant differences between ABD variations when the exercise was performed isometrically (Lee et al., 2013), which also supports this hypothesis. Since the relative muscle activation of GMed and TFL for variations of the CLAM and ABD is now understood, clinicians can be sure that these exercises are appropriate choices for activating GMed in lower extremity and low back exercise rehabilitation programs and can use this data to appropriately progress the patient when non-weight-bearing exercises are required.

Although the focus of this study was not to test for differences between the CLAM and ABD and both exercises, across variations, were found to be GMed-dominant, it should be noted that the GMed-to-TFL peak EMG signal amplitude ratio was far greater for CLAM than ABD. This finding is consistent with other work (Selkowitz et al., 2013) and suggests that CLAM may be the preferred rehabilitative exercise to prescribe when minimal TFL muscle activation is desired by the clinician.

It appears that hip flexion angle and rotation orientation are not important considerations for increasing GMed muscle activation and the GMed to TFL activation ratio when prescribing and performing the CLAM and ABD, respectively. Proper technique (e.g., no spine 'twisting' or rotation at the pelvis to initiate the movement) is likely a more substantial consideration when prescribing and performing these exercises.

Table 1
GMed-to-TFL peak EMG signal amplitude ratios for all three conditions of the side-lying clamshell and hip abduction exercises.

Exercise	Condition	Mean GMed-to-TFL peak EMG signal amplitude ratio (1 SD)[a]
Side-lying clamshell	30° of Hip flexion	5.85 (5.66)
	45° of Hip flexion	5.13 (3.96)
	60° of Hip flexion	9.29 (10.83)
Side-lying hip abduction	Internal rotation	1.10 (0.45)
	Neutral rotation	1.13 (0.38)
	External rotation	1.40 (1.04)

[a] A ratio that is greater than 1.00 indicates a GMed-dominant condition.

For example, providing the patient with positional feedback using a pressure biofeedback unit has been shown to significantly minimize compensation of other muscles (i.e., quadratus lumborum) and increase GMed activity when performing ABD (Cynn et al., 2006), but simply providing patients with appropriate coaching of these exercises may have similar benefits.

Measuring hip muscle activation with surface EMG has inherent limitations, such as crosstalk; however, several measures were taken to enhance the integrity of the biological signal, such as all electrode placements being performed by the same researcher and confirming that these placements were appropriate with the MVC task. Furthermore, these rehabilitation exercises were performed by participants that did not have a pre-existing disabling back or hip condition, but in a clinical setting, will typically be performed by patients with a lower extremity or low back injury. Different muscle activation patterns may be observed among these populations when performing variations of the CLAM and ABD, since they are presumably being prescribed GMed rehabilitation exercises because GMed activity and/or strength are diminished.

5. Conclusions

Activation of GMed and TFL does not appear to be influenced by hip joint angle, and both the CLAM and ABD exercises appear to be GMed-dominant. These findings provide information for clinical decision-making pertaining to integrating GMed with therapeutic exercise.

Conflict of interest statement

The authors of this work do not have any financial or personal relationships with other people or organizations that could inappropriately influence the work. This includes no potential conflicts of interest in the preparation or submission of this manuscript.

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