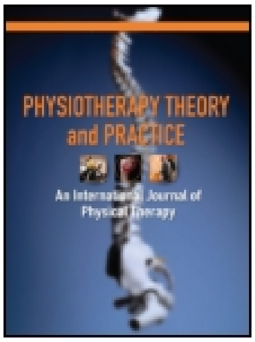


**Physiotherapy Theory and Practice**
An International Journal of Physiotherapy

ISSN: 0959-3985 (Print) 1532-5040 (Online) Journal homepage: http://www.tandfonline.com/loi/iptp20

# Relative electromyographic activity in trunk, hip, and knee muscles during unilateral weight bearing exercises: Implications for rehabilitation

**Lori A. Bolgla PT, PhD, MAcc, ATC, Mario F. Cruz PT, DPT, SCS, ATC, Lauren Hayes Roberts PT, DPT, Angela Minning Buice PT, DPT & Tori Smith Pou PT, DPT**

**To cite this article:** Lori A. Bolgla PT, PhD, MAcc, ATC, Mario F. Cruz PT, DPT, SCS, ATC, Lauren Hayes Roberts PT, DPT, Angela Minning Buice PT, DPT & Tori Smith Pou PT, DPT (2016) Relative electromyographic activity in trunk, hip, and knee muscles during unilateral weight bearing exercises: Implications for rehabilitation, Physiotherapy Theory and Practice, 32:2, 130-138, DOI: 10.3109/09593985.2015.1092059

**To link to this article:** http://dx.doi.org/10.3109/09593985.2015.1092059

PHYSIOTHERAPY THEORY AND PRACTICE
2016, VOL. 32, NO. 2, 130–138
http://dx.doi.org/10.3109/09593985.2015.1092059

Taylor & Francis
Taylor & Francis Group

RESEARCH REPORT

# Relative electromyographic activity in trunk, hip, and knee muscles during unilateral weight bearing exercises: Implications for rehabilitation

Lori A. Bolgla, PT, PhD, MAcc, ATC[a], Mario F. Cruz, PT, DPT, SCS, ATC[b], Lauren Hayes Roberts, PT, DPT[a], Angela Minning Buice, PT, DPT[a], and Tori Smith Pou, PT, DPT[a]

[a]Department of Physical Therapy, Georgia Regents University, Augusta, GA, USA; [b]CRMC Sports Medicine at Tennessee Technological University, Cookeville, TN, USA

**ABSTRACT**

***Background:*** Clinicians routinely prescribe unilateral weight bearing exercises to strengthen the lower extremity. Researchers have primarily examined thigh muscle activation with minimal attention to the hip and trunk muscles. The purpose of this study was to quantify trunk, hip, and thigh muscle activation during these types of exercises. ***Methods:*** Electromyographic (EMG) activity was collected for the abdominal obliques (AO), lumbar extensors (LE), gluteus maximus (GMX), gluteus medius (GM), and vastus medialis (VM) as subjects performed four unilateral weight bearing exercises. Data were expressed as 100% of a maximum voluntary isometric contraction (% MVIC). Separate analyses of variance with repeated measures were used to identify muscle activity differences across exercise. The sequentially-rejective Bonferroni test was used for all post-hoc analyses. ***Results:*** EMG activity for the AO, LE, and GMX was low (5.7–18.9% MVIC) during all the exercises. The GM activity was moderate (21.4–26.5% MVIC) while VM activity was high (40.0–45.2% MVIC). ***Conclusion:*** Lower AO and LE activation most likely resulted from subjects maintaining a vertical trunk position over the stance limb during each exercise. The fact that the exercises required greater frontal plane control (from balancing on a single limb) most likely accounted for lower GMX activity. The exercises would provide little, if any, benefit for individuals with AO, LE, or GMX weakness. The unilateral weight bearing exercises would be beneficial for GM neuromuscular re-education and endurance and VM strengthening.

**ARTICLE HISTORY**
Received 18 February 2015
Revised 16 April 2015
Accepted 3 May 2015

**KEYWORDS**
EMG; lower extremity; rehabilitation



## Introduction

Recently, much attention has been focused on the influence of trunk and hip function on the prevention of and rehabilitation following knee injuries such as: iliotibial band syndrome (Ferber, Noehren, Hamill, and Davis, 2010; Fredericson and Weir, 2006; Noehren, Davis, and Hamill, 2007); patellofemoral pain (Earl and Hoch, 2011; Fukuda et al, 2012; Khayambashi et al, 2014); and anterior cruciate ligament tear (Pfile et al, 2013; Zazulak et al, 2007). Researchers (Fredericson et al, 2000; Hewett, Lindenfeld, Riccobene, and Noyes, 1999; Powers, 2010) believe that the combination of excessive hip internal rotation, hip adduction, and knee abduction (i.e., valgus stress) represents faulty movement patterns contributing to these injuries. Powers (2010) has theorized that altered movement patterns may reflect gluteus maximus (GMX) and gluteus medius (GM) weakness, and data support hip weakness in individuals with knee injuries (Niemuth, Johnson, Myers, and Thieman, 2005; Noehren et al, 2014; Prins and van der Wurff, 2009).

Poor trunk control also may cause altered lower extremity kinematics (Ireland, 1999; Powers, 2010). Zazulak, Cholewicki, and Reeves (2008) have described the effect that poor trunk control may have on lower extremity function. They believe that altered trunk control will result in the transmission of greater forces and translations to distal joints. Therefore, aberrant trunk movement can potentially lead to excessive knee joint loading that may contribute to injury. Zazulak et al (2007) measured trunk neuromuscular control in 277 athletes and prospectively followed them throughout their competitive season. They found that athletes who sustained a knee injury demonstrated less trunk neuromuscular control than those who remained injury free. These findings highlighted the importance of trunk control on lower extremity function.

Unilateral weight bearing exercises (e.g., front step-down, lateral step-down, mini-squat) are commonly prescribed for rehabilitation purposes because they require activation of several trunk and lower extremity muscles needed to perform many activities of daily living (Ekstrom, Donatelli, and Carp, 2007; Krause

**CONTACT** Lori A. Bolgla, PT, PhD, MAcc, ATC lbolgla@gru.edu Department of Physical Therapy, Georgia Regents University, Augusta, GA 30912, USA.

et al, 2009). Unilateral contraction of the lumbar extensors (LE) and abdominal obliques (AOs) causes lateral trunk flexion and is important for maintaining frontal plane truck stability (Neumann, 2010). The GM can prevent excessive contralateral pelvic drop (e.g., ipsilateral hip adduction) and the GMX can control hip internal rotation. Together, optimal trunk and hip activation likely minimize knee valgus loading during dynamic activities (Powers, 2010; Zazulak, Cholewicki, and Reeves, 2008). Finally, quadriceps muscle strength is a key component for the return to work and sports activities (Natri, Kannus, and Jarvinen, 1998; Wilk et al, 2012).

For the past 10 years, researchers have focused their efforts toward quantifying GMX and GM (Boren et al, 2011; Distefano, Blackburn, Marshall, and Padua, 2009) as well as GMX, GM, and quadriceps (Ayotte, Stetts, Keenan, and Greenway, 2007; Boudreau et al, 2009) activity during various unilateral weight bearing exercises. Only Ekstrom, Donatelli, and Carp (2007) and Bouillon et al (2012) have simultaneously examined trunk, hip, and knee EMG activity during these types of exercises. Understanding the interrelationship between trunk, hip, and knee muscle activation during unilateral weight bearing exercises may enhance clinical decision-making for exercise prescription.

The reported EMG activity during unilateral weight bearing exercises has differed between studies (Reiman, Bolgla, and Loudon, 2012). EMG values generally have been higher in investigations that reported peak EMG amplitudes (Boren et al, 2011; Ekstrom, Donatelli, and Carp, 2007) or only concentric phase EMG activity (Ayotte, Stetts, Keenan, and Greenway, 2007; Boudreau et al, 2009). It is noteworthy that individuals typically perform a given set of repetitions, with each repetition requiring concentric and eccentric muscle activation, for rehabilitation purposes. Therefore, analyzing the average EMG activity during a given repetition may better represent the muscle activity generated during the exercise.

The purpose of this investigation was to quantify the average trunk, hip, and knee EMG activity during four unilateral weight bearing exercises commonly prescribed for rehabilitation purposes. We hypothesized that subjects would exhibit similar activation amplitudes among muscles during each of the unilateral weight bearing exercises.

## Methods

This study used a single-occasion, repeated measures design. The independent variable was the unilateral lower extremity weight bearing exercise. The dependent measure was each muscle's EMG amplitude, expressed as a percent of the maximum voluntary isometric contraction (% MVIC), during each exercise.

### *Subjects*

A sample of convenience was recruited from a local university setting. Subjects were recreationally-active (i.e., exercised at least 30 minutes three times a week) and participated if they met the following inclusion criteria: (1) no history of surgery for the spine or lower extremities; (2) ability to stand on each lower extremity (e.g., perform a single leg stance on each lower extremity) at least 30 seconds while keeping their eyes open; and (3) demonstrate normal lower extremity range of motion and strength with manual muscle testing. Exclusion criteria included the following: (1) inability to stand on a single lower extremity less than 30 seconds while keeping their eyes open; (2) history of disease affecting the spine and lower extremities such as diabetes, peripheral neuropathy, arthritis, or fibromyalgia; (3) history of significant spine or lower extremity injury in the previous year; or (4) history of allergic reaction to adhesive tape. The investigators explained the benefits and risks of this study to all participants who then signed an informed consent document approved by the Georgia Regents University Human Assurance Committee.

### *Procedures*

After obtaining informed consent, subjects participated in a warm-up session. They rode a stationary bike for 3 minutes at a sub-maximal speed and performed gentle stretching to the trunk extensor, trunk rotator, hamstrings, quadriceps, and calf muscles. Stretching consisted of three repetitions of each stretch with a 15-second hold. Then, an investigator instructed subjects in four standardized unilateral lower extremity weight bearing exercises (Table 1). The exercises were standardized in the following manner. First, each incorporated a 15-cm excursion because this height is a standard step height for stair ambulation (Ayotte, Stetts, Keenan, and Greenway, 2007). For this purpose, we used a handmade pole to measure a 15-cm excursion during the unilateral wall squat (Figure 1) and mini-squat (Figure 2) exercises. Subjects stood on a 15-cm high step to perform the lateral step down (Figure 3) and the front step down (Figure 4) exercises. Second, subjects maintained a neutral, vertical trunk position via verbal feedback from an investigator and visual feedback from a mirror (Table 1). A neutral, vertical trunk position was important as excessive lateral trunk lean over the

**Table 1.** Description of the unilateral weight bearing exercises.

| Exercise | Description |
|---|---|
| Unilateral wall squat | Subjects stood with their backs against a wall, the knee of the stance (dominant) limb extended, and the heel of the dominant limb a 30-cm distance away from the wall. They positioned the other leg (non-dominant leg) in front of them with the knee fully extended and the hip flexed so that the heel of this leg did not touch the floor. During this exercise, subjects lowered themselves 15 cm (by sliding their back down the wall while bending the knee of the stance leg) and returned to the start position. |
| Unilateral mini-squat | Subjects stood solely on the stance (dominant) limb while bending the knee of the non-stance limb enough to keep the non-stance foot off the floor. While keeping the trunk vertical, they bent the knee of the stance limb to lower the trunk 15 cm and returned to the start position. |
| Lateral step-down | Subjects stood solely on the stance (dominant) limb on the edge of a 6-inch step. They positioned the non-stance limb with the knee extended, foot dorsiflexed, and the hip in a neutral position. The foot of the non-stance limb did not contact the step. While keeping the trunk vertical, subjects bent the knee of the stance limb until the heel of the non-stance limb touched the ground and returned to the start position (a 15-cm excursion). |
| Front step-down | Subjects stood solely on the stance (dominant) limb on the edge of a 6-inch step facing away from the step. They positioned the non-stance limb with the knee extended, foot dorsiflexed, and the hip in a slightly flexed position. The foot of the non-stance limb did not contact the step. While keeping the trunk vertical, subjects bent the knee of the stance limb until the heel of the non-stance limb touched the ground and returned to the start position (a 15-cm excursion). |

Note: A piece of cloth tape was placed on a full length mirror to bisect it into equal left and right sides. Before beginning each exercise, subjects assumed the start position in front of the mirror. The mirror was positioned so that the midline of the subject's body was aligned with the cloth tape. Subjects were instructed to complete each exercise keeping the midline of the body in line with the cloth tape to maintain a vertical trunk position.

stance limb can lower the demands of the hip and trunk muscles (Bolgla and Uhl, 2005). Finally, subjects performed each exercise using the dominant limb, defined as the leg with which the subject naturally kicks a ball (Bolgla and Keskula, 1997).

The subject's skin was prepared for the surface EMG electrodes by shaving (if needed) and cleaning the skin with isopropyl alcohol over the following muscles: (1) abdominal oblique (AO); (2) lumbar extensors (LE); (3) gluteus maximus (GMX); (4) gluteus medius (GM); and (5) vastus medialis (VM). Bi-polar Ag-AgCl surface electrodes (Medicotest, Rolling Meadows, IL), measuring 5 mm in diameter with an interelectrode distance of approximately 20 mm, were placed in parallel alignment over the muscle belly of each muscle (Table 2). A ground electrode was placed on the ulnar styloid process on the same side of the instrumented leg. Electrodes were then secured with tape to minimize slippage during testing. Placement was confirmed by observing the electrical signal on an oscilloscope during


**Figure 1.** Unilateral wall squat.


**Figure 2.** Unilateral mini-squat.

Figure 3. Lateral step-down.



common manual muscle testing techniques (Kendall et al, 2005). A 3-second standing "rest" file was taken to exclude ambient noise.

The subjects performed 2 MVICs (Table 3) for each muscle to enable normalization of the raw EMG data. Subjects generated the MVIC for each muscle in accordance with the "make" test (Bohannon, 1997) to the beat of a Matrix MR500 quartz metronome. They generated force over a 2-second period and held the maximum force for an additional 5-second period. Subjects were allowed 1 practice trail (Mohr et al, 2003) and performed 2 test trials. They received strong verbal encouragement (Campenella, Mattacola, and Kimura, 2000) during each test trial and rested 30 seconds between each MVIC. A computer algorithm determined the maximum root-mean-square (RMS) amplitude recorded across a moving 500-millisecond average window across the MVICs (Bamman, Ingram, Caruso, and Greenisen, 1997). The window having the greatest amplitude was used to express all data as a % MVIC for statistical analysis.

Figure 4. Front step-down.

Table 2. Summary of electromyographic surface electrode placement.

| Muscle | Position |
|---|---|
| Abdominal oblique | ½ the distance between iliac crest and the inferior border of the rib cage in line with the anterior superior iliac spine |
| Lumbar extensors | 3 cm lateral to the spinous process of the third lumbar spinous process |
| Gluteus maximus | 1/3rd the distance from the 2nd sacral vertebra to the greater trochanter |
| Gluteus medius | 1/3rd the distance from the iliac crest to the greater trochanter |
| Vastus medialis | 5.2 cm from the superior medial side of the patella along a line medially oriented at a 50° angle with respect to the anterior superior iliac spine |

Source: Cowan, Bennell, and Hodges (2000); Criswell (2011); Rainoldi, Melchiorri, and Caruso (2004).

Pilot testing was performed to determine measurement reliability for the MVIC procedures. For this purpose, MVIC data were collected prior to and immediately following exercise. This assessment was conducted to determine the consistency of the MVIC procedures and ensure that subjects did not experience fatigue during exercise. Intraclass correlation coefficients ($ICC_{3,1}$) for the muscles ranged from 0.80 to 0.97, which suggested good-to-excellent reliability (Portney and Watkins, 2009).

Next, subjects performed 15 repetitions of each exercise to the beat of a Matrix MR500 quartz

Table 3. Description of the positions used to collect electromyographic activity during a maximum voluntary isometric contraction.

| Muscle | Position |
|---|---|
| Abdominal oblique | Subjects were positioned in supine with the hips and knees flexed to 90° and the feet manually fixed to the table by an investigator. To assess the right abdominal obliques, the subject flexed and rotated the trunk to the left while keeping the left shoulder on the table. Resistance to this movement was applied to the anterior aspect of the right shoulder. The opposite movement was resisted when assessing the left abdominal obliques. |
| Lumbar extensors | Subjects were positioned in prone on the plinth with trunk fully extended and hands clasped behind the head. Stabilization straps were applied to posterior aspect of the hips and legs. Resistance to this movement was applied to the scapulae. Resistance at the shoulders in the direction of trunk flexion. |
| Gluteus maximus | Subjects were positioned in with the knee of the test extremity flexed to 90°. A stabilization strap was applied to the distal aspect of the thigh. Resistance to this movement was applied to the distal thigh. |
| Gluteus medius | Subjects were positioned in the sidelying with the test extremity on top of the other. A stabilization strap was applied just proximal to lateral femoral epicondyle. Resistance to this movement was applied to the distal thigh. |
| Vastus medialis | Subjects were positioned in short sitting with the hips flexed to 90° and the test knee flexed to 60°. A stabilization strap was applied to the distal tibia. Resistance to this movement was applied to the distal tibia. |

Source: Bolgla, Malone, Umberger, and Uhl (2010); Souza, Baker, and Powers (2001).



metronome set at 40 beats per minute (Ayotte, Stetts, Keenan, and Greenway, 2007) while the investigators collected the EMG data. Specifically, subjects performed each repetition by lowering themselves down during the first beat, returning to the start position on the second beat, and resting on the third beat. All subjects were provided practice prior to data collection to ensure that they performed each exercise in the proper sequence. The investigators used an external trigger switch to delineate between each repetition and between each exercise. The order of testing was randomly determined to reduce ordering effects. Subjects rested 3 minutes between each exercise to minimize fatigue. Upon completion of testing, subjects were instructed to refrain from any physical activity, other than normal walking, for a 24-hour period to minimize the potential for muscle and joint soreness.

## *EMG analysis*

An 8-channel EMG system (Run Technologies, Mission Viejo, CA) recorded all muscle activity. Subjects wore a Myopac-Jr transmitter belt unit (Run Technologies) that transmitted raw EMG data at 2000 Hz via a fiber optic cable to its receiver unit. Unit specifications included a common mode rejection ratio exceeding 90 dB, amplifier gain of 2000, and input impedance exceeding 1 MΩ. Raw EMG data were band pass filtered between 20 and 500 Hz using Datapac software (Run Technologies), stored on a personal computer, and analyzed using the Datapac software. For each exercise, we determined the RMS amplitude for each repetition. Data were then expressed as a % MVIC. The last 10 repetitions during each exercise were averaged and used for statistical analysis.

## *Statistical analysis*

Separate analyses of variance with repeated measures were used to determine differences in muscle amplitudes across exercise. Statistical analysis was performed using IBM SPSS Version 21.0 (IBM SPSS, Inc., Armonk, NY). The level of significance of established at the 0.05 level. The sequentially-rejective Bonferroni test was used to adjust the significance level for multiple comparisons to protect against a potential Type I error (Holm, 1979).

## Results

Eighteen males (mean age 24.3 ± 3.4 y, mass 81.2 ± 9.7 kg, and height 1.8 ± 0.1 m) and 16 females (mean age 24.0 ± 1.5 y, mass 59.9 ± 8.8 kg, and height 1.65 ± 0.1 m) volunteered for this study. EMG activity for the AO ranged from 5.7 to 7.4% MVIC. A main effect existed ($p$ = 0.01) with post-hoc analysis showing that subjects generated significantly greater AO EMG activity during the mini-squat and front step-down ($p < 0.01$). EMG activity for the LE ranged from 6.1 to 7.4% MVIC. No main effect existed ($p$ = 0.08), suggesting that subjects generated similar LE EMG activity during each exercise. EMG activity for the GMX ranged from 10.3 to 18.9% MVIC. A main effect existed ($p < 0.001$) with post-hoc analysis showing that subjects generated significantly greater GMX EMG activity during the wall squat ($p < 0.001$). EMG activity for the GM ranged from 21.4 to 26.5% MVIC. A main effect existed ($p$ = 0.001) with post-hoc analysis showing that subjects generated significantly greater GM EMG activity during the wall squat than the lateral step-down ($p$ = 0.001) and front step-down ($p$ = 0.005). EMG activity for the VM ranged from 40.0 to 45.0% MVIC. A main effect existed ($p$ = 0.04) with post-hoc analysis showing that subjects generated significantly greater VM EMG activity during the front step-down ($p < 0.001$) and mini-squat ($p$ = 0.008) than the lateral step-down. Table 4 summarizes all EMG data.

**Table 4.** Mean ± standard deviation, expressed as 100% maximum voluntary isometric contraction, for muscle electromyographic (EMG) activity during each of the unilateral weight bearing exercises.

| Muscle | Wall squat | Mini-squat | Lateral step-down | Front step-down |
|---|---|---|---|---|
| Abdominal obliques* | 5.7 ± 3.2 | 7.4 ± 5.0 | 5.7 ± 3.0 | 6.4 ± 3.5 |
| Lumbar extensors† | 7.5 ± 4.4 | 7.3 ± 3.4 | 6.2 ± 3.4 | 6.1 ± 3.5 |
| Gluteus maximus‡ | 18.9 ± 11.8 | 10.8 ± 7.9 | 10.3 ± 6.4 | 10.9 ± 7.0 |
| Gluteus medius§ | 26.5 ± 12.0 | 23.2 ± 12.2 | 21.4 ± 10.7 | 22.8 ± 12.2 |
| Vastus medialis‖ | 42.5 ± 17.2 | 45.2 ± 17.3 | 40.0 ± 17.4 | 45.0 ± 17.8 |

*Mini-squat and front step-down had significantly greater EMG than the wall squat and lateral step-down ($p < 0.01$).
†Similar EMG for all muscles ($p = 0.08$).
‡Wall squat had significantly greater EMG than the mini-squat, lateral step-down, and front step-down ($p < 0.001$).
§Wall squat had significantly greater EMG than the lateral step-down, and front step-down ($p < 0.01$).
‖Front step-down and mini-squat had significantly greater EMG than the lateral step-down ($p < 0.01$).



## Discussion

The purpose of this study was to determine the relative activation of trunk, hip, and knee muscles during unilateral weight bearing exercises commonly used for rehabilitation. Researchers have used EMG to determine the relative muscle activation, expressed as a % MVIC, generated during exercise (Ayotte, Stetts, Keenan, and Greenway 2007; Bolgla and Uhl, 2005; Boren et al, 2011; Boudreau et al, 2009; Distefano, Blackburn, Marshall, and Padua, 2009; Dwyer et al, 2010; Ekstrom, Donatelli, and Carp, 2007). Reiman, Bolgla, and Loudon (2012) have interpreted the relative amount of EMG activity generated as follows: low (0–20% MVIC); moderate (21–40% MVIC); high (41–60% MVIC); and very high (greater than 60% MVIC). Exercises that require moderate EMG activity have been recommended for neuromuscular reeducation and endurance purposes (Ekstrom, Donatelli, and Carp, 2007; Reiman, Bolgla, and Loudon, 2012). Higher levels of EMG activity are required for more meaningful strength gains (Anderson and Behm, 2004; Escamilla et al, 2010). Identification of these EMG differences between exercises will provide the clinician an evidence-based approach for exercise prescription.

### *Trunk muscle activation*

EMG activity for the AO and LE ranged from 5.7 to 7.4% MVIC and 6.1 to 7.5% MVIC, respectively. Although significant differences existed between the exercises for AO activity, this finding was not clinically important due to the low EMG amplitudes (Ekstrom, Donatelli, and Carp 2007; Reiman, Bolgla, and Loudon, 2012). Therefore, these exercises would not benefit individuals needing improvements in AO and LE neuromuscular control, endurance, or strength.

We assessed the AO and LE because unilateral contraction of theses muscles causes lateral trunk flexion and is important for maintaining frontal plane truck stability (Neumann, 2010). To date, Ekstrom, Donatelli, and Carp (2007) are the only researchers to examine activation of these muscles during a lateral step-down exercise. They reported 15% MVIC AO and 25% MVIC LE activity, which were relatively greater than the current investigation. Higher activation levels most likely resulted from the manner the exercise was performed and the EMG data were processed. Their subjects performed the task with the trunk in a more flexed position and held the lowered position for a 5-second period. Peak EMG activity over a 1-second period during the hold period was identified and analyzed.

Our study differed as trunk position was standardize by having subjects perform the exercise with the trunk in a vertical position over the stance limb. We also analyzed the average EMG data for each repetition to determine overall muscle activity during each exercise. Performing the exercise in this manner most likely optimized trunk position over the stance leg and required less trunk muscle activation (Bolgla and Uhl, 2005). Maintaining a vertical trunk position, in combination with analyzing mean EMG activity, would account for our lower EMG values.

In summary, our findings suggest that the unilateral weight bearing exercises will not benefit patients who need improvements in AO and LE neuromuscular control, endurance, and strength. Due to the paucity of data, additional investigations are needed to better understand the relative activation of the AO and LE during unilateral weight bearing exercises.

### *Hip muscle activation*

On average, subjects in the current study generated approximately 10% MVIC GMX activity and 21.4 to 23.2% MVIC GM activity during the mini-squat, lateral step-down, and front step-down exercises. However, GMX (18.9% MVIC) and GM (26.5% MVIC) activity was significantly higher during the wall squat compared to the other exercises. A possible reason for this finding was that subjects shifted their center of mass posterior to the stance limb during the wall squat exercise. This posterior shifting of the body's center of mass posterior to the base of support would require greater muscle activation to counterbalance the increased applied torque due to gravity (Blanpied, 1999).

The exercises used in the current study were similar to Ayotte, Stetts, Keenan, and Greenway (2007); however, their subjects generated relatively greater GMX (86% MVIC) and GM (52% MVIC) activity. These investigators only analyzed the average magnitude during the concentric phase of each exercise, the phase in which EMG activity is generally greatest (Anderson and Behm, 2004; Dwyer et al, 2010; Selseth et al, 2000). A combination of concentric and eccentric activity would account for our relatively lower values (Bolgla and Uhl, 2005).

Although different in absolute magnitude, subjects in the Ayotte, Stetts, Keenan, and Greenway (2007) study and the current investigation generated relatively greater GMX and GM activity during the wall squat than the other exercises. From a clinical standpoint, clinicians should consider prescribing the wall squat after an individual with GMX and GM weakness can safely perform the other unilateral weight bearing exercises used in the current study. With respect to overall EMG activity, subjects generated low GMX activity and moderate GM activity. This finding suggests that the exercises would only be beneficial for GM neuromuscular re-education and endurance (Ekstrom, Donatelli, and Carp, 2007). Additional exercises that specifically target the GMX and GM would be necessary for strength gains (Reiman, Bolgla, and Loudon, 2012).

### Knee muscle activation

Subjects in the current study generated between 40 to 45% MVIC VM activity among all the exercises. Researchers (Anderson and Behm, 2004; Escamilla et al, 2010) have reported that activation greater than 40% MVIC will promote strength gains. Therefore, any of the exercises used in the current study would be appropriate for VM strengthening.

Subjects in the current study generated less VM activity during the lateral step-down exercise, a pattern that agreed with Ayotte, Stetts, Keenan, and Greenway (2007). Increased VM activity exhibited during the wall squat, mini-squat and front step-down required subjects to place the stance foot in a more anterior position relative to the hip. Posterior displacement of the body's center of mass away from the knee joint axis of rotation would increase the external torque due to gravity and require greater VM activation (Bolgla, Shaffer, and Malone, 2008).

In summary, Ayotte, Stetts, Keenan, and Greenway (2007) reported greater VM amplitudes than the current study due to differences in data processing and analysis as explained regarding GMX and GM activity. Regardless of these differences, all of the exercises used would generate sufficient EMG activity for strength gains and benefit individuals with VM weakness.

### Clinical implications

We standardize each exercise to a 15-cm excursion since this height is a standard step height for stair ambulation (Ayotte, Stetts, Keenan, and Greenway, 2007). We acknowledge that this excursion may not necessarily represent the required intensity needed for strength gains in healthy individuals (Andersen et al, 2006). However, squatting to a maximum knee angle may not necessarily be appropriate for individuals with patellofemoral pain or following ACL injury.

Subjects performed 15 repetitions of each exercise which most likely did not represent an exercise load equal to a 15-repetition maximum. Therefore, healthy individuals may require more demanding exercises that require a larger excursion of movement (e.g., squatting as low as possible) and application of an external load (e.g., performing the exercises with hand weights or a weighted chest vest).

In summary, the relatively lower activation levels (less than 50% MVIC) during all of the exercises will more likely help individuals with evident weakness. The exercises also may be more beneficial for improving endurance and neuromuscular control. As individuals reach endurance and neuromuscular control milestones, they will require more demanding exercises to achieve additional strength gains.

### Limitations

The current study has certain limitations. The possibility of crosstalk from adjacent muscles due to the use of surface EMG electrodes existed. However, this factor was minimized by placing the electrodes in a standardized manner (Cram and Kasman, 1998; Rainoldi, Melchiorri, and Caruso, 2004). Subjects could have experienced fatigue during some of the exercises. Pilot testing of the MVIC procedures before and after data collection showed good-to-excellent reliability and suggested that subjects did not experience muscle fatigue. Kinematic variables were not assessed which prohibited the ability to determine sagittal and frontal plane variability during the exercises. To be consistent with prior investigations (Bolgla and Uhl, 2005; Distefano, Blackburn, Marshall, and Padua, 2009; Ekstrom, Donatelli, and

Carp, 2007), we normalized EMG data during exercise to a MVIC. Ekstrom et al (2012) found that submaximal quadriceps concentric contractions during weight bearing exercises generated relatively greater activity compared to a MVIC. This finding suggested that values obtained during dynamic exercise may be overestimated when expressed as a percentage of a MVIC. Future investigations are needed that normalized EMG data to activity during a maximum dynamic contraction (Ekstrom et al, 2012). Finally, subjects were healthy, young adults and our results cannot be generalized to individuals with pathology.

## Conclusion

The purpose of this study was to compare the relative activation of select trunk, hip, and knee muscles during four commonly-prescribed unilateral lower extremity weight bearing exercises. Findings from this investigation showed that trunk muscle activation was very low and would not benefit individuals with AO, LE, and GMX weakness. Any of the exercises would be appropriate for GM neuromuscular re-education and endurance, with the wall squat being the most challenging. All of the unilateral weight bearing exercises would benefit individuals in need of improved VM strength, especially for those treated for rehabilitation.

## Declaration of interest

The authors declare no conflict of interest.

## References


Andersen LL, Magnusson SP, Nielsen M, Haleem J, Poulsen K, Aagaard P 2006 Neuromuscular activation in conventional therapeutic exercises and heavy resistance exercises: Implications for rehabilitation. Physical Therapy 86: 683–697.

Anderson KG, Behm DG 2004 Maintenance of EMG activity and loss of force output with instability. Journal of Strength and Conditioning Research 18: 637–640.

Ayotte NW, Stetts DM, Keenan G, Greenway EH 2007 Electromyographical analysis of selected lower extermity muscles during 5 unilateral weight-bearing exercises. Journal of Orthopaedic and Sports Physical Therapy 37: 48–55.

Bamman MM, Ingram SG, Caruso JF, Greenisen MC 1997 Evaluation of surface electromyography during maximal voluntary contraction. Journal of Strength and Conditioning Research 11: 68–72.

Blanpied PR 1999 Changes in muscle activation during wall slides and squat-machine exercise. Journal of Sport Rehabilitation 8: 123–134.

Bohannon RW 1997 Reference values for extremity muscle strength obtained by hand-held dynamometry from adults aged 20 to 79 years. Archives of Physical Medicine and Rehabilitation 78: 26–32.

Bolgla LA, Keskula DR 1997 Reliability of lower extremity functional performance tests. Journal of Orthopaedic and Sports Physical Therapy 26: 138–142.

Bolgla LA, Malone TR, Umberger BR, Uhl TL 2010 Reliability of electromyographic methods used for assessing hip and knee neuromuscular activity in females diagnosed with patellofemoral pain syndrome. Journal of Electromyography and Kinesiology 20: 142–147.

Bolgla LA, Shaffer SW, Malone TR 2008 Vastus medialis activation during knee extension. Journal of Sport Rehabilitation 16: 1–10.

Bolgla LA, Uhl TL 2005 Electromyographic analysis of hip rehabilitation exercises in a group of healthy subjects. Journal of Orthopaedic and Sports Physical Therapy 35: 487–494.

Boren K, Conrey C, Le Coguic J, Paprocki L, Voight M, Robinson TK 2011 Electro-myographic analysis of gluteus medius and gluteus maximus during rehabilitation exercises. International Journal of Sports Physical Therapy 6: 206–223.

Boudreau SN, Dwyer MK, Mattacola CG, Lattermann C, Uhl TL, McKeon JM 2009 Hip-muscle activation during the lunge, single-leg squat, and step-up-and-over exercises. Journal of Sport Rehabilitation 18: 91–103.

Bouillon LE, Wilhelm J, Eisel P, Wiesner J, Rachow M, Hatteberg L 2012 Electro-myographic assessment of muscle activity between genders during unilateral weight-bearing tasks using adjusted distances. International Journal of Sports Physical Therapy 7: 595–605.

Campenella B, Mattacola CG, Kimura IF 2000 Effect of visual feedback and verbal encouragement on concentric quadriceps and hamstrings peak torque of males and females. Isokinetics and Exercise Science 8: 1–6.

Cowan SM, Bennell KL, Hodges PW 2000 The test-retest reliability of the onset of concentric and eccentric vastus medialis obliquus and vastus lateralis electro-myographic activity in a stair stepping task. Physical Therapy in Sport 1: 129–136.

Cram JR, Kasman GS 1998 Introduction to surface electromyography. Gaithersburg, MD, Aspen Publishers, Inc.

Criswell E 2011 Cram's introduction to surface electromyography, 2nd edn. Sudbury, MA, Jones and Bartlett Publishers.

Distefano LJ, Blackburn JT, Marshall SW, Padua DA 2009 Gluteal muscle activation during common therapeutic exercises. Journal of Orthopaedic and Sports Physical Therapy 39: 532–540.

Dwyer MK, Boudreau SN, Mattacola CG, Uhl TL, Lattermann C 2010 Comparison of lower extremity kinematics and hip muscle activation during rehabilitation tasks between sexes. Journal of Athletic Training 45: 181–190.

Earl JE, Hoch AZ 2011 A proximal strengthening program improves pain, function, and biomechanics in women with patellofemoral pain syndrome. American Journal of Sports Medicine 39: 154–163.

Ekstrom R, Donatelli RA, Carp K 2007 Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. Journal of Orthopaedic and Sports Physical Therapy 37: 754–762.

Ekstrom RA, Osborn RW, Goehner HM, Moen AC, Ommen BM, Mefferd MJ, Bergman TR, Molencamp TB, Kelsey SA 2012 Electromyographic normalization procedures for determining exercise intensity of closed chain exercises for strengthening the quadriceps femoris muscles. Journal of Strength and Conditioning Research 26: 766–771.

Escamilla RF, Lewis C, Bell D, Bramblet G, Daffron J, Lambert S, Pecson A, Imamura R, Paulos L, Andrews JR 2010 Core muscle activation during Swiss ball and traditional abdominal exercises. Journal of Orthopaedic and Sports Physical Therapy 40: 265–276.

Ferber R, Noehren B, Hamill J, Davis IS 2010 Competitive female runners with a history of iliotibial band syndrome demonstrate atypical hip and knee kinematics. Journal of Orthopaedic and Sports Physical Therapy 40: 52–58.

Fredericson M, Cookingham CL, Chaudhari AM, Dowdell BC, Oestreicher N, Sahrmann SA 2000 Hip abductor weakness in distance runners with iliotibial band syndrome. Clinical Journal of Sport Medicine 10: 169–175.

Fredericson M, Weir A 2006 Practical management of iliotibial band friction syndrome in runners. Clinical Journal of Sport Medicine 16: 261–268.

Fukuda TY, Melo WP, Zaffalon BM, Rossetto FM, Magalhães E, Bryk FF, Martin RL 2012 Hip posterolateral musculature strengthening in sedentary women with patellofemoral pain syndrome: A randomized controlled clinical trial with 1-year follow-up. Journal of Orthopaedic and Sports Physical Therapy 42: 823–830.

Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR 1999 The effect of neuromuscular training on the incidence of knee injury in female athletes. American Journal of Sports Medicine 27: 699–705.

Holm S 1979 A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics 6: 65–70.

Ireland ML 1999 Anterior cruciate ligament injury in female athletes: Epidemiology. Journal of Athletic Training 34: 150–154.

Kendall FP, McCreary EK, Provance P, Rodgers MM, Romani WA 2005 Muscle testing and function with posture and pain, 5th edn. Baltimore, MD, Lippincott Williams & Wilkins.

Khayambashi K, Fallah A, Movahedi A, Bagwell J, Powers C 2014 Posterolateral hip muscle strengthening versus quadriceps strengthening for patellofemoral pain: A comparative control trial. Archives of Physical Medicine and Rehabilitation 95: 900–907.

Krause DA, Jacobs RS, Pilger KE, Sather BR, Sibunka SP, Hollman JH 2009 Electro-myographic analysis of the gluteus medius in five weight-bearing exercises. Journal of Strength and Conditioning Research 23: 2689–2694.

Mohr KJ, Kvitne RS, Pink MM, Fideler B, Perry J 2003 Electromyography of the quadriceps in patellofemoral pain with patellar subluxation. Clinical Orthopaedics and Related Research 415: 261–271.

Natri A, Kannus P, Jarvinen M 1998 Which factors predict the long-term outcome in chronic patellofemoral pain syndrome? A 7-yr prospective follow-up study. Medicine and Science in Sports and Exercise 30: 1572–1577.

Neumann DA 2010 Axial skeleton: Muscle and joint interactions. In: Neumann DA (ed) Kinesiology of the musculoskeletal system, pp 379–422. St. Louis, Mosby.

Niemuth PE, Johnson RJ, Myers MJ, Thieman TJ 2005 Hip muscle weakness and overuse injuries in recreational runners. Clinical Journal of Sport Medicine 15: 14–21.

Noehren B, Davis I, Hamill J 2007 Prospective study of the biomechanical factors associated with iliotibial band syndrome. Clinical Biomechanics 22: 951–956.

Noehren B, Schmitz A, Hempel R, Westlake C, Black W 2014 Assessment of strength, flexibility, and running mechanics in men with iliotibial band syndrome. Journal of Orthopaedic and Sports Physical Therapy 44: 217–222.

Pfile KR, Hart JM, Herman DC, Hertel J, Kerrigan DC, Ingersoll CD 2013 Different exercise training interventions and drop-landing biomechanics in high school female athletes. Journal of Athletic Training 48: 450–462.

Portney LG, Watkins MP 2009 Foundations of clinical research. Applications to practice, 3rd edn. Upper Saddle River, NJ, Prentice Hall Health.

Powers CM 2010 The influence of abnormal hip mechanics on knee injury: A bio-mechanical perspective. Journal of Orthopaedic and Sports Physical Therapy 40: 42–51.

Prins MR, van der Wurff P 2009 Females with patellofemoral pain syndrome have weak hip muscles. A systematic review. Australian Journal of Physiotherapy 55: 9–15.

Rainoldi A, Melchiorri G, Caruso I 2004 A method for positioning electrodes during surface EMG recordings in lower limb muscles. Journal of Neuroscience Methods 134: 37–43.

Reiman MP, Bolgla LA, Loudon JK 2012 A literature review of studies evaluating gluteus maximus and gluteus medius activation during rehabilitation exercises. Physiotherapy Theory and Practice 28: 257–268.

Selseth A, Dayton M, Cordova ML, Ingersoll CD, Merrick MA 2000 Quadriceps concentric EMG activity is greater than eccentric EMG activity during the lateral step-up exercise. Journal of Sport Rehabilitation 9: 124–134.

Souza GM, Baker LL, Powers CM 2001 Electromyographic activity of selected trunk muscles during dynamic spine stabilization exercises. Archives of Physical Medicine and Rehabilitation 82: 1551–1557.

Wilk KE, Macrina LC, Cain EL, Dugas JR, Andrews JR 2012 Recent advances in the rehabilitation of anterior cruciate ligament injuries. Journal of Orthopaedic and Sports Physical Therapy 42: 153–171.

Zazulak BT, Cholewicki J, Reeves NP 2008 Neuromuscular control of trunk stability: clinical implications for sports injury prevention. Journal of the American Academy of Orthopaedic Surgeons 16: 497–505.

Zazulak BT, Hewett TE, Reeves N, Goldberg B, Cholewicki J 2007 Deficits in neuro-muscular control of the trunk predict knee injury risk: A prospective biomechanical-epidemiological study. American Journal of Sports Medicine 35: 1123–1130.