Hip- and Thigh-Muscle Activation During the Star Excursion Balance Test

Beth Norris and Elaine Trudelle-Jackson

Context: The Star Excursion Balance Test (SEBT) is often used to train and assess dynamic balance and neuromuscular control. Few studies have examined hip- and thigh-muscle activation during the SEBT. Objective: To quantify hip- and thigh-muscle activity during the SEBT. Design: Repeated measures. Setting: Laboratory. Participants: 22 healthy individuals, 11 men and 11 women. Methods: EMG measurements were taken as participants completed 3 trials of the anterior (A), medial (M), and posteromedial (PM) reach directions of the SEBT. Main Outcome Measures: Mean EMG data (% maximal voluntary isometric contraction) from the gluteus medius (Gmed), gluteus maximus (Gmax), and vastus medialis (VM) were measured during the eccentric phase of each SEBT reach direction. Test–retest reliability of EMG data across the 3 trials in each direction was calculated. EMG data from each muscle were compared across the 3 reach directions. Results: Test–retest reliability ranged from ICC3,1 values of .91 to .99. A 2-way repeated-measure ANOVA revealed a significant interaction between muscle activation and reach direction. One-way ANOVAs showed no difference in GMed activity between the A and M directions. GMed activity in the A and M directions was greater than in the PM direction. There was no difference in GMax and VM activity across the 3 directions. Conclusion: GMed was recruited most effectively when reaching was performed in the A and M directions. The A, M, and PM directions elicited similar patterns of muscle recruitment for the GMax and VM. During all 3 SEBT directions, VM activation exceeded the 40–60% threshold suggested for strengthening effects. GMed activity also exceeded the threshold in the M direction. GMax activation, however, was below the 40% threshold for all 3 reach directions, suggesting that performing dynamic lower extremity reaching in the A, M, and PM directions may not elicit strengthening effects for the GMax.

Keywords: gluteus medius, gluteus maximus, vastus medius, balance

Dynamic postural control has been acknowledged as essential for return to function and sport after lower extremity injury.1–3 Unilateral weight-bearing exercises are often used to train and assess dynamic postural control. During the performance of unilateral weight-bearing exercises, proximal stability is required at the trunk and pelvis while movement is coordinated between multiple joints of the lower extremity.4,5 The Star Excursion Balance Test (SEBT) is a clinical test of...
dynamic postural control in which an individual balances on 1 leg while reaching the other in each of 8 different directions. Previous research has focused on the SEBT’s effectiveness as a screening tool that may be used both after lower extremity injury and to predict lower extremity injury. There has been less investigation regarding the kinematic requirements, such as muscle-activation patterns, necessary to complete the SEBT dynamic reaching tasks.

The single-limb squat (SLS) and the step-down are unilateral weight-bearing exercises similar to the SEBT in that each involves a minisquat movement of the weight-bearing lower extremity. In contrast to the SEBT, there has been considerable research identifying muscle-activation patterns during the SLS and step-down. In those studies, quantification of muscle activity through electromyography (EMG) has allowed an estimation of exercise intensity, with greater EMG-activation levels suggesting greater intensity. In addition, a threshold of muscle activity that is 40% to 60% of maximal effort has been previously suggested as necessary to elicit a strengthening stimulus. Muscle activity of less than 25% maximal voluntary isometric contraction (MVIC), however, may indicate that the muscle is functioning to maintain stability. Collectively, this knowledge of muscle activation contributes to understanding neuromuscular control during dynamic weight-bearing activities and helps clinicians assess, select, and progress therapeutic exercises.

Neuromuscular control during the SEBT is reflected by the distance reached in each direction, with an increase in reach distance reflecting greater neuromuscular control. Recent research has examined lower extremity kinematics in an attempt to identify factors that underlie neuromuscular control during SEBT performance. Research in this area has focused primarily on angular displacements at the hip and knee, with only 1 study examining muscle activity during SEBT reach directions. Gribble et al reported decreased SEBT reach distances and corresponding decreases in sagittal-plane knee and hip flexion when the SEBT was performed after fatiguing tasks. Although muscle activation was not measured in those studies, the authors suggest that proximal muscle activation may have been altered after the fatiguing tasks, leading to decreases in range of motion at the knee and hip and subsequent decreases in reach distance. Other researchers have reported increases in SEBT reach distance after 8 weeks of neuromuscular training focused on improving trunk control and hip strength. The findings of Gribble et al and Filipa et al suggest that alterations in muscle performance, through fatigue or training, may affect performance on the SEBT.

To date, there has been only 1 study investigating muscle activation as a factor that may contribute to neuromuscular control during the SEBT. Earl et al examined muscle activity of the vastus medialis oblique, vastus lateralis, medial hamstring, biceps femoris, anterior tibialis, and gastrocnemius in 10 healthy subjects during the performance of all 8 directions of the SEBT. They reported that muscle activity for all but the gastrocnemius is direction dependent. They concluded that information regarding muscle activation during the SEBT may help clinicians select SEBT reach directions to use when rehabilitating specific injuries and during specific phases of rehabilitation.

To most effectively use the SEBT in the assessment and training of dynamic balance and muscle dysfunction, additional information regarding muscle-activity requirements, particularly of proximal musculature, during the SEBT is warranted. The primary purpose of this study was to quantify and compare muscle activity...
of the hip and thigh during the performance of lower extremity reaching in 3 directions of the SEBT. A secondary purpose was to determine the reliability of muscle-activity assessment using normalized EMG-signal amplitudes during the SEBT. Specifically, we examined muscle activity of the gluteus medius (GMed), gluteus maximus (GMax), and vastus medialis (VM) during the eccentric phase of lower extremity reaching in the anterior, medial, and posteromedial directions of the SEBT.

**Methods**

**Design**

A repeated-measures design was used to assess hip- and thigh-muscle activity during the performance of lower extremity reaching in 3 directions of the SEBT. The dependent variable was root-mean-square muscle activation represented as a percentage of MVIC for the GMed, GMax, and VM. The independent variable was SEBT reach direction with 3 levels (anterior, medial, and posteromedial).

**Participants**

Twenty-two volunteers (11 men and 11 women) age 22–38 years participated in this study. Potential participants were excluded from the study based on any of the following findings during a preparticipation screening examination conducted by one of the investigators: limitations of lower extremity active range of motion determined by visual observation, limitations in lower extremity strength noted during manual muscle testing, presence of a visible contralateral pelvic drop during single-leg stance, inability to maintain single-leg stance for 20 seconds, inability to perform 10 repetitions of an SLS without loss of balance or the verbalization of pain, or occurrence of pain in the back, hip, knee, ankle, or foot within the last 14 days. None of the participants had a history of lower extremity orthopedic surgery or chronic ankle instability. All gave informed consent as approved by Texas Woman’s University’s institutional review board before participating in the study.

On the day of testing, participants first underwent a screening examination for exclusion criteria, including observation of single-leg balance, SLS ability, and assessment of gross lower extremity strength and active range of motion. Leg length was also measured for the purpose of standardizing reach distances. All screening tests were performed using the participant’s dominant lower extremity. Given our intent to examine muscle activity of the lower extremity that provides proximal neuromuscular control during unilateral weight-bearing activities, we defined the dominant lower extremity as the leg participants would stand on to kick a ball. After the screening examination, the participants were oriented to the testing protocol. The protocol proceeded as follows: electrode placement, MVIC testing, and SEBT testing.

**Electrode Placement and Instrumentation**

Bipolar and preamplified electrodes with a fixed distance of 1 cm were used to record the muscle activity of the GMed, GMax, and VM. Surface EMG signal from the GMed, GMax, and VM were collected with a Delsys EMG system (Delsys,
Muscle Activation During the SEBT

Inc, Boston, MA). Unit specifications of the EMG system included an amplifier gain of 1000 and a band-pass filter of 20 to 450 Hz. EMG data were sampled at 1024 Hz. The EMG machine was connected to a laptop computer where data were stored for analysis. Delsys EMGworks 3.5 software was used for signal acquisition and analysis.

Each participant’s skin was cleaned with alcohol wipes before electrode placement. Electrodes were positioned using the procedure described by Cram et al. For the GMax the electrode was placed one third of the distance from the second sacral vertebrae to the greater trochanter. The GMed electrode was placed one third of the distance from the greater trochanter to the iliac crest. The VM electrode was placed approximately 2 in. from the superior boarder of the patella toward the medial aspect of the thigh. All electrodes were placed in parallel with the muscle fibers, and a reference electrode was placed over the midsacrum. The same tester positioned all electrodes to maintain consistency.

**MVIC Testing**

EMG surface electrodes were placed as previously described, and participants completed 3 MVICs for each muscle of the dominant lower extremity. Each trial lasted 5 seconds, with a 1-minute rest between trials. Verbal encouragement was given while the participant performed each trial of MVIC. Participants were given a 5-minute rest between MVIC testing and SEBT testing.

MVIC for the GMed was tested in side lying on the nondominant side. Pillows and a foam wedge were placed between the participant’s legs so that the dominant hip was held in 12° of abduction as measured with a goniometer. The hip and knee of the nondominant leg were flexed, and the hip of the dominant leg was in neutral alignment for flexion/extension. A strap was placed around the plinth and the participant’s thigh. The strap was positioned just above the lateral femoral condyle, and a small towel was placed between the strap and participant’s leg for comfort. During testing, the participant was instructed to raise the dominant leg up against the strap while maintaining the knee in extension and toes pointing forward to elicit maximal contraction of the GMed (Figure 1).

![Figure 1 — Participant position for testing of the maximal isometric voluntary contraction of the gluteus medius.](image-url)
MVIC for the GMax was performed in the prone position with the knee of the dominant leg flexed to 90°. The participant’s hips were maintained in a neutral position during testing. A strap was placed around the plinth and the participant’s thigh. The strap was positioned above the femoral condyles, and a towel was placed between the strap and the participant’s leg for comfort. During MVIC testing, the participant was instructed to contract the buttocks while lifting the dominant leg toward the ceiling against the strap to elicit isometric contraction of the GMax (Figure 2).

MVIC for the VM was performed in a seated position with the hips in 90° of flexion. The participant sat on the plinth with both knees flexed to 80° and both legs hanging off the edge of the plinth. A strap was placed around the participant’s lower leg and the leg of the plinth. The strap was positioned 2 in. above the medial and lateral malleoli, and a towel was placed under the knee and between the strap and ankle for comfort. During MVIC testing, the participant was instructed to push the lower leg toward extension against the strap to elicit isometric contraction of the VMO (Figure 3).

**Figure 2** — Participant position for testing of the maximal isometric voluntary contraction of the gluteus maximus.

**Figure 3** — Participant position for testing of the maximal isometric voluntary contraction of the vastus medialis.
Muscle Activation During the SEBT

SEBT Testing Protocol

For the SEBT, we chose to examine the anterior, medial, and posteromedial directions. Although recent research has recommended simplifying the SEBT to the anterior, posteromedial, and posterolateral directions, this recommendation was based on research on individuals with chronic ankle instability.24 Our intent was to examine muscle activity of healthy individuals (without chronic ankle instability) during reach directions that require sagittal- and frontal-plane stability of the stance lower extremity. Thus, we chose to examine only the anterior, medial, and posteromedial directions of the SEBT because reaching in these directions is especially challenging in terms of maintaining a level pelvis on the stance leg. The inability to maintain a level pelvis on the stance leg has been associated with alterations of neuromuscular control at the hip that, in turn, may contribute to patellofemoral dysfunction25 and increased risk of ACL injury.26 Because we were interested in dynamic postural control during sagittal- and frontal-plane stability, we chose proximal muscles in the hip and thigh that contribute to sagittal-plane stability—GMax and VM—and a proximal muscle in the hip that contributes to frontal-plane stability—GMed.

SEBT procedures began with the participant standing on a functional testing grid (EFI Sports Medicine, San Diego, CA) with the heel of the dominant lower extremity aligned in the center of the grid and the great toe aligned along the anteriorly projecting line. All testing was performed barefoot with EMG electrodes attached for the duration of testing. Instructions were given for the participant to shift his or her weight to the dominant leg, reach the opposite lower extremity as far as possible along the specified line (either anterior, medial, or posteromedial), lightly touch the toe of the reaching leg on the line without coming to rest, and return to the center of the star. The trial was discarded if the participant lifted the heel of the dominant leg off the mat, lost balance, came to rest at maximal reach distance, or could not return to the beginning position. Three trials were performed for each reach direction. During each trial, the examiner marked the point of maximal reach on the mat. At the conclusion of the SEBT, the examiner measured the distance from the center of the mat to each marked point with a tape measure and calculated the mean reach distance for each direction. Mean reach distance was expressed as a percentage of leg length. We included the variable of mean reach distance to allow a comparison of distances attained by our participants with values reported by other investigators and to determine whether reach distances differed between the 3 SEBT directions. A metronome was used at a rate of 60 beats/min to ensure consistent timing of each SEBT trial. Participants were given 2 beats (2 seconds) during the eccentric phase (from initial stance to maximum reach) with the reaching leg lightly touching the mat on the second beat. They were instructed to perform the concentric phase (from maximum reach to bilateral stance) at their own controlled pace.

Each participant was provided a visual demonstration of the testing procedure. Before the initiation of the testing, the participant performed 6 practice trials in each of the 3 directions to reduce any potential learning effect.6 After the completion of the practice trials, the participant rested 5 minutes before beginning the SEBT. To minimize the occurrence of fatigue during the performance of the SEBT, a 15-second rest period between trials and 1 minute of rest between directions were
EMG Analysis

EMG data were rectified and processed using the root-mean-square method with a 50-millisecond time constant. The middle 3 seconds of each MVIC trial were visually selected, and peak root-mean-square EMG amplitude during this time period was calculated for each of the 3 MVIC trials for each muscle. The mean root-mean-square EMG of the 3 MVIC trials for each muscle was used for normalization purposes.12

Mean EMG-signal amplitudes were calculated for each muscle during the 2-second eccentric phase of each SEBT trial. For each reaching direction, these 3 trial means were averaged, then normalized to the MVIC (MVIC%).

Statistical Analysis

Repeated-measures analysis of variance (ANOVA) was conducted on EMG measurements across 3 trials in each reach direction for each muscle, and intraclass correlation coefficients (ICC3,1) were calculated to assess test–retest reliability. A 1-way ANOVA with repeated measures was used to determine differences in mean reach distance among reaching directions. A 2-way repeated-measures ANOVA with 2 repeated factors, muscle (3 levels) and reach direction (3 levels), was used to determine differences in %MVIC. A significant interaction effect (muscle by reach direction) was followed with separate 1-way repeated-measures ANOVAs to assess the simple effect of reach direction. A significant simple effect of reach direction was followed with Bonferroni post hoc tests. An alpha level of .05 was used to determine statistical significance for all tests. SPSS Version 12.0 (SPSS Inc, Chicago, IL) was used for all statistical analysis.

Results

Test–retest reliability calculated across the 3 trials for each muscle and reach direction resulted in ICC3,1 values that ranged from .91 to .99. Table 1 summarizes the reliability analysis of normalized muscle activity for each reach direction. Mean

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Anterior ICC3,1</th>
<th>95% CI</th>
<th>Medial ICC3,1</th>
<th>95% CI</th>
<th>Posteromedial ICC3,1</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gluteus medius</td>
<td>.98</td>
<td>.95–.99</td>
<td>.94</td>
<td>.86–.97</td>
<td>.97</td>
<td>.93–.99</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>.99</td>
<td>.97–.99</td>
<td>.98</td>
<td>.97–.97</td>
<td>.97</td>
<td>.93–.99</td>
</tr>
<tr>
<td>Vastus medialis</td>
<td>.94</td>
<td>.87–.97</td>
<td>.94</td>
<td>.89–.96</td>
<td>.91</td>
<td>.81–.96</td>
</tr>
</tbody>
</table>

ICC, intraclass correlation coefficient; CI, confidence interval.
reach distances, expressed as percentage of leg length, were 87%, 89%, and 91% for the anterior, medial, and posteromedial directions, respectively. The 1-way ANOVA revealed that these reach distances were not significantly different among the 3 directions ($P = .086$).

The 2-way repeated-measures ANOVA showed a significant reach-direction-by-muscle interaction ($P = .016$), indicating that differences in EMG activity between muscles depend on the reach direction. The 1-way ANOVAs analyzing simple effects of direction revealed significant differences between reach directions for the GMed ($P = .001$) but not for GMax ($P = .430$) and VM ($P = .063$; Table 2). Further exploration of the significant GMed test was conducted using pairwise comparisons to identify which of the 3 directions had significant differences in EMG activity. The Bonferroni post hoc tests used to make these comparisons while controlling for Type I error revealed no significant differences in GMed activity between the anterior and medial directions but significantly greater GMed activity in the anterior and medial directions than in the posteromedial direction ($P \leq .017$; Table 2).

**Discussion**

The primary purpose of this study was to evaluate hip- and thigh-muscle activity during the performance of lower extremity reaching in 3 directions of the SEBT. We used EMG to compare muscle activity across the 3 reach directions. The primary finding in our study was that only 1 muscle, the GMed, demonstrated differences in muscle activation across the reach directions.

**Reach Distance**

Reach distances attained by participants in our study were similar to those for the same SEBT directions reported by other investigators using healthy, unimpaired participants.$^{24,27}$ This suggests that muscle-activation levels in our participants could not be attributed to shorter reach distances than were previously reported.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Reach Direction, Mean (SD)</th>
<th>Statistics</th>
<th>Multiple Comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Anterior (1)</td>
<td>Medial (2)</td>
<td>Posteromedial (3)</td>
</tr>
<tr>
<td>Gluteus medius</td>
<td>38 (23)</td>
<td>49 (21)</td>
<td>22 (15)</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>21 (32)</td>
<td>25 (20)</td>
<td>22 (24)</td>
</tr>
<tr>
<td>Vastus medialis</td>
<td>70 (27)</td>
<td>77 (35)</td>
<td>69 (28)</td>
</tr>
</tbody>
</table>

*Significant difference between the means of the indicated pair of reach directions.
addition, our participants demonstrated consistent reach distances in each direction. This finding minimizes the likelihood that differences in reach distances may have contributed to the differing patterns of muscle activation in each SEBT direction.

**GMed**

GMed muscle activity in our study ranged from 22% to 49% MVIC. These levels are similar to findings reported by Ayotte et al\(^\text{12}\) for the unilateral minisquat (36% ±17% MVIC) and Boudreau et al\(^\text{13}\) for the SLS (30.1% ± 9.1% MVIC). In contrast, Distefano et al\(^\text{4}\) reported GMed EMG amplitudes of 64% ±24% MVIC for the SLS. Although the procedures for MVIC testing and the timing of the phases of each exercise (2 s) were similar in our study and the study by Distefano et al,\(^\text{4}\) instructions for completing the study-specific exercise differed. Distefano et al instructed participants to perform the SLS to a depth that allowed the middle finger to touch the ground. Our instructions were for participants to reach the non-weight-bearing lower extremity as far as possible in a specific direction without loss of balance. Thus, the depth of the squat may have differed between the 2 studies, resulting in the differing EMG amplitudes. In addition, Distefano et al\(^\text{4}\) analyzed mean EMG amplitudes over the combined concentric and eccentric phases, whereas we analyzed EMG amplitudes during the eccentric phase only. EMG amplitudes have been reported to be lower during eccentric muscle contractions than with concentric and isometric contractions when external loading and contraction velocities are held constant.\(^\text{28,29}\) Thus, the analysis of eccentric muscle activity may provide another explanation for the lower levels of GMed activity reported in our study.

We found the level of GMed muscle recruitment to be greater in the anterior and medial directions than in the posteromedial direction. During the medial direction of the SEBT, GMed EMG amplitude was 48% MVIC, which fell within the 40% to 60% threshold of muscle activity previously suggested as necessary to elicit a strengthening stimulus.\(^\text{16}\) During the anterior and posteromedial reaching directions, however, EMG amplitudes were 38% MVIC and 22% MVIC, respectively. These findings suggest that only the medial direction results in providing a potential strengthening stimulus for the GMed, whereas the anterior and posteromedial directions may be more effective when the goal of the therapeutic exercise is to promote pelvic stability.\(^\text{17}\) When prescribing the SEBT as a therapeutic intervention to address muscle-performance deficits of the GMed, clinicians may first use the posteromedial direction during the early stages of rehabilitation, progressing to the anterior direction. As neuromuscular control improves, the medial direction of the SEBT may be added as a strengthening stimulus for the GMed.

**GMax**

EMG activity of the GMax was consistent across all 3 reach directions, suggesting that participants were using a similar movement strategy when performing the 3 directions of the SEBT. Although we did not examine kinematics at the trunk, hip, and knee during the SEBT, there was no difference in maximum reach distance between the 3 directions. EMG activity of the GMax reported in our study (21% to 25% MVIC) was lower than values reported by Ayotte et al (57% ± 44% MVIC),\(^\text{12}\) Boudreau et al (35.2% ± 24% MVIC),\(^\text{13}\) and Distefano et al (59% ± 27% MVIC).\(^\text{4}\)
Factors that might influence the recruitment of the GMax during the SEBT include the amount of sagittal-plane flexion of the trunk and hip and methodological differences between the studies.

In a weight-bearing position, an increase in trunk flexion increases the flexion moment at the hips, which is balanced by contraction of the hip extensors. Conversely, maintaining a more vertical trunk may decrease the flexion moment at the hip, placing less torque demand on the hip extensors. In addition, the moment arm for the GMax is greatest at 0° of hip flexion and decreases as hip flexion increases to 90°. In studies investigating the SLS or minisquat, instructions regarding movement execution may have resulted in participants’ using greater hip flexion. Thus, the amount of hip flexion used during the SEBT may have been less than that demonstrated in studies investigating the SLS or minisquat, contributing to the lower GMax muscle activity reported in our study. Again, investigating trunk and lower extremity kinematics during the SEBT may provide more insight regarding GMax muscle activity.

These differences in GMax activity between our study and the aforementioned studies may also be attributable to methodological differences. As previously mentioned, we recorded EMG activity during the eccentric phase of the SEBT, compared with the concentric phase in the study by Ayotte et al and both the concentric and eccentric phases in the study by Distefano et al. Another methodological factor may be the procedures for MVIC testing. MVIC testing for the GMax was conducted in the standing position in the study by Boudreau et al, compared with the prone position in our study, thus limiting a direct comparison between the 2 studies. A third methodological difference between our study and studies involving the SLS or minisquat is the definition of dominant lower extremity to determine the lower extremity that was used to assess muscle activity. We defined dominant lower extremity as the leg the participant would stand on to kick a ball. Ayotte et al, Boudreau et al, and Distefano et al defined the dominant lower extremity as the leg used to kick a ball. This difference in the definition of dominant lower extremity may have contributed to differences in muscle activity of the GMax. Finally, instructions requiring participants to touch their middle finger to the floor may have resulted in greater hip flexion in the study by Distefano et al, thus placing greater demands on the GMax.

In our study, GMax EMG amplitude was below the 40% to 60% threshold in all 3 directions, suggesting that the SEBT may not be an appropriate stimulus for GMax strengthening. However, the SEBT may be used to promote muscle stability or endurance, which necessitates lower levels of strength. Because GMax activity was similar between the 3 directions, clinicians may use any of the directions as a rehabilitation exercise to promote the use of the GMax as a pelvic stabilizer. In addition, given the low levels of GMax activation observed in the 3 directions of the SEBT, clinicians may use these components of the SEBT in the early phase of rehabilitation before progressing to exercises that require a higher level of muscle activity.

**VM**

VM amplitudes reported in our study ranged from 69% to 77% MVIC, and, similar to findings for the GMax, they were consistent across the 3 reach directions. Ayotte
et al\textsuperscript{12} reported VM EMG activity of 60% MVIC during the concentric phase of a unilateral minisquat. The depth of the squat in their study was limited to 15.24 cm vertical descent, whereas the depth of the squatting movement during the SEBT in our study was not controlled. Our VM amplitudes can best be compared with the findings reported by Earl and Hertel,\textsuperscript{21} who examined lower extremity muscle activity, including that of the VM, during all 8 directions of the SEBT. They reported VM MVIC of greater than 100% for the anterior, medial, and posteromedial directions. Although the instructions for performing the SEBT were similar between the 2 studies, Earl and Hertel did not control the timing of the concentric and eccentric phases of the SEBT. The speed of lengthening during an eccentric contraction and the speed of shortening during a concentric contraction will affect a muscle’s force potential. To reduce the potential effect that the speed of lengthening might have during an eccentric contraction, we instructed participants to perform the eccentric phase of the SEBT over a 2-second period and used a metronome to provide auditory pacing. Another difference between our study and that of Earl and Hertel was the method of EMG-data analysis. Earl and Hertel analyzed peak activity during each trial, concentric and eccentric phases combined, whereas we analyzed the mean EMG activity only during the eccentric phase. Peak muscle activity would be greater than mean muscle activity, possibly explaining the greater VM muscle activity reported by Earl and Hertel.\textsuperscript{21}

The VM amplitudes in our study were above the 40% to 60% threshold, suggesting that the anterior, medial, and posteromedial directions of the SEBT may be equally effective for VM strengthening. This finding supports the use of the anterior, medial, and posteromedial directions as potential strengthening exercises to target muscle-performance impairments of the quadriceps. Given the high level of VM recruitment found during the SEBT, however, clinicians may consider using the SEBT during the later stages of rehabilitation.

Limitations

Although we found differences in the level of GMed muscle activation across the 3 reaching directions of the SEBT, our results should be interpreted with caution. A limitation to the use of EMG in general is the potential for crosstalk between adjacent muscles. We attempted to minimize this potential in our study by using standardized procedures for electrode placement and ensuring that electrodes were securely adhered to the skin. We achieved high levels of reliability for all EMG signals, providing positive support for our data-collection methodologies.

Another limitation of our study is that we only examined muscle activity of the dominant lower extremity, defined as the leg the participant would stand on to kick a ball. Our reasoning was to purposely examine muscle activity of the leg that provides postural control during unilateral weight-bearing activities. This may have contributed to differences in muscle activation in our study compared with those reported in studies involving the SLS\textsuperscript{4,13} and the minisquat\textsuperscript{12} that defined the dominant lower extremity differently. To better understand neuromuscular control during the SEBT, future research should examine muscle activity of both the stance lower extremity and the reaching lower extremity.

As previously mentioned, our findings for EMG muscle amplitude might be better interpreted if kinematics at the trunk and lower quarter were also assessed.
to quantify movement patterns. Although we did not collect kinematic data, we believe that we provided useful data regarding muscle activity during the SEBT that were lacking in the literature and that could be used when designing therapeutic exercise programs.

Finally, our results were obtained in a cohort of healthy, young adults without lower extremity pathology, during the eccentric phase of the SEBT. Future research should investigate muscle activity during the SEBT in individuals with selected lower extremity pathologies or muscle weakness and examine muscle activity during both eccentric and concentric phases.

**Clinical Implications**

The levels of muscle activation reported in our study may guide clinical decision making when one is considering using the SEBT as a rehabilitation exercise. If the goal of the therapeutic intervention is muscle strengthening, the medial direction may most effectively target the GMed, whereas all 3 directions (anterior, medial, and posteromedial) may be effective for the VM. Conversely, if the goal of the therapeutic exercise is muscle endurance or to enhance the stabilization function of a muscle, clinicians may consider using the anterior or posteromedial direction for the GMed and all 3 directions to target the GMax.

Clinicians may also use the findings reported in our study to help determine when in the course of rehabilitation to incorporate the SEBT as a therapeutic exercise. Given the high levels of VM activation during the anterior, medial, and posteromedial directions, the use of the SEBT as a strengthening stimulus for the VM may be delayed until the later stages of rehabilitation, when baseline strength of the VM has been established. In contrast, the low levels of GMax activation during the anterior, medial, and posteromedial directions suggest that these components of the SEBT may be used in the early phases of rehabilitation, when more demanding exercise that requires higher levels of muscle activity may be contraindicated based on the stage of tissue healing or may be precluded based on a patient’s initial level of strength.

Levels of muscle activation for the GMed show a more defined progression that may support the use of the anterior and posteromedial SEBT directions in the early phases of rehabilitation, followed by the use of the medial direction as neuromuscular control improves. Future research is needed, however, to investigate the effectiveness of the SEBT as a therapeutic exercise to enhance muscle-performance capacities of the hip and thigh muscles.

**Conclusions**

This study quantified muscle activity in 3 muscles during 3 directions of the SEBT. For 2 of these muscles (GMax and VM), activity was consistent across the 3 directions (anterior, medial, and posteromedial). In contrast, GMed muscle activity was similar in the anterior and medial directions but lower in the posteromedial direction. If the SEBT is to be used an exercise to promote muscle strengthening, clinicians may consider using the medial direction to target the GMed, whereas all 3 directions may be considered for the VM. Based on the lower levels of muscle
activity attained for the GMed in the anterior and posteromedial directions and for the GMax in all 3 directions, we recommend considering the use of these directions of the SEBT in the early phases of rehabilitation or when the goal is to promote stability or muscle endurance.

Acknowledgments

At time of the study, Beth Norris was with Texas Woman’s University, Dallas TX.

References


25. Willson JD, Davis IS. Lower extremity mechanics of females with and without patellofemoral pain across activities with progressively greater task demands. *Clin Biomech (Bristol, Avon).* 2008;23(2):203–211.


