Lower-Extremity Muscle Activation During the Star Excursion Balance Tests

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Objective: To identify integrated EMG (I-EMG) activity of 6 lower-extremity muscles during the 8 Star Excursion Balance Tests (SEBTs).

Design and Setting: Repeated measures, laboratory setting.

Subjects: 10 healthy young adults.

Interventions: The SEBTs require the subject to balance on the stance leg and maximally reach with the contralateral foot along each of 8 lines extending from a common axis at 45° intervals.

Measures: I-EMG activity of the vastus medialis obliquus (VMO), vastus lateralis (VL), medial hamstring (MH), biceps femoris (BF), anterior tibialis (AT), and gastrocnemius.

Results: Significant differences were found in all muscles (P < .05) except the gastrocnemius (P = .08). VMO and VL activity tended to be greatest with anteriorly directed excursions, whereas the MH and BF activity were greatest with posteriorly directed excursions. AT activity was lowest with the lateral excursion.

Conclusions: Performance of the different SEBTs results in different lower-extremity muscle-activation patterns.

Key Words: closed kinetic chain, neuromuscular control, quadriceps, hamstrings


Squatting exercises are commonly included in lower-extremity rehabilitation programs in an effort to improve strength, balance, and neuromuscular control.1-2 Recently, a more complex squatting task to train and assess lower-extremity balance and neuromuscular control has been reported.3-4 The Star Excursion Balance Tests (SEBTs) are a series of unilateral minisquats performed while attempting with the opposite leg to reach as far as possible in a given direction. A large “asterisk” with 8 rays at 45° angles to one another is placed on the floor (Figure 1). The athlete stands on 1 leg in the center and attempts to reach as far as possible with the other leg in each direction. Increasing the excursion distance is thought to require greater range of motion (ROM) and neuromuscular control at the hip, knee, and ankle.

The SEBTs are quantified by measuring the distance from the center of the star to the farthest point reached in each direction. The farther the excursion distance the greater the demand on the balance and neuromuscular-control systems. Studies have demonstrated high intratester and intertester reli-

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ability\textsuperscript{4-5} when using the SEBT as an assessment of dynamic balance. There is a significant learning effect when performing the SEBTs; therefore, at least 6 practice trials are necessary before evaluating a subject’s performance.\textsuperscript{5}

Muscle-activation patterns during different excursion directions have not previously been described. When one sees the exercises being performed, it is visually obvious that each direction places different demands on the lower extremity. The purposes of this investigation were to identify differences in (1) muscle activity and (2) ROM of the knee and ankle among the different excursion directions.

**Methods**

**Subjects**

Ten recreational athletes were used as subjects (5 men, 5 women, age = 24.9 ± 4.2; mass = 72.2 ± 17.2kg; height = 152.6 ± 7.9 cm). Subjects were excluded if they had a history of serious injury to the lower extremity or were currently experiencing any pain in the hip, knee, or ankle. Subjects who had recently suffered from a head injury or balance disorder were
also excluded. At the beginning of the session subjects read and signed an informed consent form approved by the Institutional Review Board at Pennsylvania State University.

**Instrumentation**

The Biopac MP100 System (Biopac Systems Inc, Santa Barbara, Calif) was used to collect all EMG and ROM data. Surface EMG was collected from the vastus medialis obliquus (VMO), vastus lateralis (VL), medial hamstrings (MH), biceps femoris (BF), anterior tibialis (AT), and gastrocnemius using 10-mm-contact-area Ag-AgCl disposable electrodes (Biopac). The analog signals were amplified, converted to digital, and analyzed using AcqKnowledge Software, version 3.5 (Biopac). The following EMG parameters were used: Bandwidth = 10–500 Hz, input impedance = 2 MΩ (differential), common mode rejection ratio = 110 dB, maximum input voltage = ±10 V, sampling rate = 1000 Hz, and gain = 1000.

Electrogoniometers (Penny and Giles Biometrics Ltd, Gwent, UK) were used to monitor the knee and ankle ROM of the stance leg. At the knee, the stationary arm was aligned with the femur and the telescopic arm was fixed to the lateral aspect of the fibula. At the ankle, the stationary arm was fixed to the distal posterior calf and the telescopic arm was fixed to the posterior calcaneus.

Shaving and vigorous cleaning of the area with an alcohol pad prepared the skin. All electrodes were placed over the area of greatest muscle bulk. For the hamstrings this was proximal to the palpable tendons. For the quadriceps the knee was placed in approximately 45° of flexion when the electrodes were attached. This was done to ensure that the electrodes were over the muscle belly while the exercises were being performed. All electrodes were aligned parallel to the assumed direction of the muscle fibers, with the exception of the gastrocnemius, and secured with tape and elastic wraps. For recording gastrocnemius activity, 1 electrode was applied to each head. Although the electrodes were not parallel to the muscle fibers, this is an accepted way of recording generalized gastrocnemius activity. The Cybex II Isokinetic Dynamometer (Cybex Inc, Bay Shore, NY) was used to facilitate the maximal voluntary isometric contractions (MVICs).

**Procedures**

After the electrodes were applied bilaterally, subjects performed a 5-minute, submaximal warm-up on a stationary bicycle. The left leg was tested first in all subjects. Before the MVIC was collected from each muscle group, subjects performed warm-up contractions at 25%, 50%, and 75% of perceived maximal effort. Data were then collected during three 3-second MVICs during which verbal encouragement was provided. For the quadriceps and hamstrings, the subject was seated in approximately 90° of hip flexion and 60° of knee flexion and secured with Velcro® straps across the thigh and
hips. For the AT, the subject remained in the same position, except the knee was supported in full extension. For this muscle only, subjects performed 5-second contractions against manual resistance. The first 2 seconds were used to “ramp up” to maximum contraction, which was maintained for the last 3 seconds. This was done to establish better resistance for the tester. For the gastrocnemius, the subject remained in the same position. The ankle was positioned perpendicular to the shank, and the subject held both ends of a towel looped around the forefoot. The subject was instructed to plantar flex with maximal effort while maintaining the position of the joint by resisting with the arms and trunk. Because of the ease of data collection, the ankle goniometer was attached after the MVICs were collected.

The goniometers were calibrated while the subject stood in a quiet, 2-legged stance. Full extension of the knee and the standing angle of the ankle were set to 0°.

For the SEBTs, EMG and ROM data were collected only from the stance leg. Each subject performed 5 trials in each direction in the following order: anterior (A), anteromedial (AM), medial (M), posteromedial (PM), posterior (P), posterolateral (PL), lateral (L), and anterolateral (AL; Figure 1). Directions were labeled with respect to the stance leg. For the 3 anterior directions, subjects stood with the crosshair just in front of the second toe. For the medial direction, subjects placed the crosshair at the midpoint on the medial side of their foot. For the 3 posterior directions, subjects stood with the crosshair at the back of the heel. For the lateral directions subjects placed the crosshair at the midpoint on the lateral side of their foot.

Instructions were given to each subject in the same manner as in previous studies involving the SEBTs. Subjects were instructed to stand on 1 leg and attempt to reach as far as possible and touch the floor lightly with the opposite foot. No further instructions about technique or position were given, and movements of the trunk and upper extremities were not constrained. Subjects performed 6 practice trials in each direction, with adequate rest before testing began. Five consecutive trials were performed in each direction. The excursion distance was marked with ink on the floor during the last 3 trials. It was measured from the crosshair at the center of the star to the mark with 1 mm of precision. The MVIC and star-trial procedure were then repeated on the right leg.

Data Acquisition

EMG data were collected from all muscles during each of the MVICs. EMG and ROM data were collected simultaneously during the star trials. The raw signal was low-pass filtered at 500 Hz and high-pass filtered at 10 Hz. The raw data were integrated to remove the baseline, and the root mean square (RMS) was calculated over a 10-sample period. The average RMS value was calculated from a 1-second window about the peak for the MVICs. The average RMS value was calculated from a 100-millisecond window about the peak for the SEBT trials. The average for the SEBT trials was taken over a smaller window because of variation in the speed with which the subjects
performed the motion. The average RMS value for each muscle for each trial was normalized to its respective MVIC value and served as the dependent variable. The maximum knee-flexion and dorsiflexion angles were averaged across the last 3 trials and served as additional dependent variables.

**Statistical Analysis**

Six 1-within-factor ANOVAs were run to compare the normalized EMG values during the 8 excursion directions. A separate ANOVA was run on each muscle tested. In the event of a significant ANOVA, Tukey post hoc tests were run to identify significant differences in normalized I-EMG activity between specific directions of excursion. Two 1-within-factor ANOVAs were run to compare the knee-flexion and ankle dorsiflexion angles during the 8 directions. Post hoc comparisons were again made to identify significant differences in ROM between specific directions of excursion. The level of significance was preset at .05 for all analyses.

**Results**

Significant differences in EMG activity among the different excursion directions were found for all muscles ($P < .05$) except the gastrocnemius ($P = .08$). EMG activity of the thigh and leg musculature during the different directions is illustrated in Figures 2 and 3, respectively. VM activity was found to be greater during the anterior excursion than during any other direction ($P = .037$). The lateral and anterolateral excursions produced lower VM activity than any other direction except the anterolateral; posterior comparison was not significant. VL activity was significantly lower during the lateral excursion than during all other directions ($P = .001$), and

![Figure 2](image)

**Figure 2** Normalized EMG activity of the quadriceps and hamstrings for each of the 8 excursion directions. VMO indicates vastus medialis obliquus; VL, vastus lateralis; MH, medial hamstring; and BF, biceps femoris.
MH activity was significantly higher during the anterolateral excursion than during the lateroanterior, anteromedial, and medial excursions \((P < .005)\). The BF activity was higher during the posterior, posterolateral, and lateral excursions than during the anterior and anteromedial excursions. The posterior and lateral excursions were also greater than the medial and anterolateral excursions \((P < .03)\). AT activity was significantly higher during the posteromedial, posterior, posterolateral, and lateral excursions than during the anterior (not significantly different than lateral), anteromedial, medial, and anterolateral \((P < .005; \text{Figure 4})\).

Significant differences in ROM among the different directions were found at the ankle and the knee \((P < .05)\). The highest knee flexion occurred during the anteromedial excursion, which was significantly greater than the anterior excursion. The anterior, anteromedial, medial, and posteromedial directions produced more knee flexion than the anterolateral direction did. Knee flexion was significantly lower during the posterolateral and lateral directions than during any other except the anterolateral. The anterior, anteromedial, and medial directions produced greater ankle dorsiflexion than all other directions did \((P < .0005)\), except that the medial and lateral excursions were not significantly different. Knee and ankle ROM values with the different excursion directions are illustrated in Figure 5.

**Comments**

Results indicate that, with the exception of the gastrocnemius, muscle activation of the lower extremity during the SEBTs is direction dependent. A closer examination of the specific differences in the following paragraphs...
might provide clinicians with a rationale as to which directions are best suited for isolating particular muscle-recruitment patterns during rehabilitation.

Although it is still necessary to eliminate inflammation and restore full strength and pain-free ROM, the ability to perform functional tasks such as the SEBTs demonstrates that the neuromuscular-control mechanism is
working properly. After injury the mechanical stability of a joint is compro-
mised as a result of ligament or bone damage. It is up to the neuromuscular
system to compensate for the loss of mechanical stability by improving
functional stability. One begins in the early stages of rehabilitation by re-
gaining volitional muscle control and restoring protective reflex loops. Initial training includes proprioceptive activities that improve kinesthetic
awareness and stabilization after sudden perturbations. In a more functional
stage, programmed motor patterns must be relearned to allow coordination
of joint stabilizers during complex movements such as accelerating, decel-
erating, and cutting. Before an athlete can return to activity, both static
and dynamic stabilization must become subconscious to allow the athlete
to perform more complex activities.

The results of this experiment support the body of research that advocates
the use of closed-kinetic-chain (CKC) exercises to reestablish neuromuscular
control after injury. Whereas open-kinetic-chain (OKC) exercises isolate
muscle groups for selective strengthening, CKC exercises have been shown
to produce the cocontraction necessary for functional stabilization. Functional stabilization of a joint requires cocontraction of the agonist and
antagonist muscles that surround the joint.

Other studies have found that significant quadriceps activity is produced
during the seated leg press, standing squat, and OKC knee extension, but the hamstrings are significantly active only during the standing squat. Although the leg press and standing squat are similar activities, gravity affects the body differently in each position, and therefore the standing squat facilitates the quadriceps/hamstring cocontraction, whereas the leg press does not. The lateral step-up exercise also produces the beneficial
quadriceps/hamstring cocontraction, although the amount of hamstring
activity is small compared with the quadriceps activity.

The current investigation produced a similar result in that there was
cocoontrac tion of the quadriceps and hamstrings during all directions of
excursion. The quadriceps was most active during the 3 anteriorly directed
excursions. To perform the anterior excursions, subjects leaned backward,
extending the trunk, to maintain their balance. Gravity acting on the upper
body creates a large knee-flexion moment, which must be controlled by an
extension moment produced by the quadriceps (Figure 6).

High VL activity during the medial and posteromedial excursions might
be the result of muscular stabilization against the varus force created at the
knee with these directions. Therefore, performing anteriorly and medially
directed excursions would be an effective way to eccentrically strengthen
the quadriceps and improve functional stabilization in the late stages of
rehabilitation. On the other hand, if an athlete were recovering from a
quadriceps strain, it would be prudent to begin the SEBTs in the lateral
direction. In this case the athlete would benefit from the proprioceptive
training but not overload the quadriceps. As strength improves, the more
quadriceps-demanding directions can be added to the program.
CKC exercises also produce less patellofemoral stress than OKC exercises do and therefore might be more comfortable for patients with patellofemoral pain.\textsuperscript{2,11,18} Some studies have indicated that vastus medialis (VMO) activity is increased when hip extension is combined with knee extension compared with knee extension alone.\textsuperscript{17,19} Increasing VMO activity is one of the major goals of patellofemoral rehabilitation. Our results indicate that VMO activity is highest with anteriorly directed excursions.

During the SEBTs the biceps femoris was most active during the posterior, posterolateral, and lateral excursions. High activity during the 2 posterior excursions can be explained by gravity acting on the trunk, causing a hip-flexion moment (Figure 7). As the leg is extended backward the trunk flexes to maintain balance. The hamstrings must eccentrically contract to resist this hip-flexion moment. This finding is supported by previous research that indicated increased hamstring activity as the trunk angle increased.\textsuperscript{8} Extreme external rotation at the hip during the lateral excursion further increases biceps femoris activity as it functions to externally rotate the hip. High activity of the medial hamstrings during the anterolateral direction...
is believed to be caused by this muscle group’s functioning to internally rotate the hip to perform this excursion.

Another indication for the use of the SEBTs as a tool is ACL rehabilitation. During conservative and postoperative treatment of ACL-injured knees, the amount of strain placed on the ACL must be limited. OKC knee extensions place a high amount of shear force on the ACL and could be detrimental.\(^2\) Tibiofemoral compressive forces are greater during CKC exercise than during OKC exercise, and hamstring cocontraction during CKC knee extension reduces the strain on the ACL.\(^1,2,9,11,18\) In addition to increased hamstring activity, increased trunk flexion during squatting activities increases the posterior shear force on the tibiofemoral joint.\(^8,9\) This would be beneficial for early rehabilitation of ACL reconstruction, when CKC exercises are necessary but anterior shear at the tibiofemoral joint must be minimized.\(^8,9\)

The activity of the AT was highest during the 3 posteriorly directed excursions and during the lateral excursion. To perform these excursions, the center of mass shifts posteriorly on the foot (Figure 6). The AT must be active to keep the knee and leg over the center of pressure to prevent one from falling backward.

In conclusion, activation of muscles of the lower extremity during the SEBT depends partly on the excursion direction. This information is useful to clinicians when selecting rehabilitation exercises for a specific injury. The SEBTs are a useful set of exercises for reestablishing functional stabilization and eccentrically training the hamstrings and quadriceps. The posterior-di-
rection excursions can be safely performed early in the rehabilitation of ACL injuries, with later progression to the more demanding anterior and lateral directions. Further research is needed to explore the effects of rehabilitation programs using the SEBTs in treating specific lower-extremity injuries.

References

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