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Hip and Trunk Muscle Activity During the Star Excursion Balance Test in Healthy Adults

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Context: Dynamic balance is a measure of core stability. Deficits in the dynamic balance have been related to injuries in the athletic populations. The Star Excursion Balance Test (SEBT) is suggested to measure and improve dynamic balance when used as a rehabilitative tool. ***Objective:*** To determine the electromyographic activity of the hip and the trunk muscles during the SEBT. ***Design:*** Descriptive. ***Setting:*** University campus. ***Participants:*** Twenty-two healthy adults (11 males and 11 females; 23.3 [3.8] y, 170.3 [7.6] cm, 67.8 [10.3] kg, and 15.1% [5.0%] body fat). ***Intervention:*** Surface electromyographic data were collected on 22 healthy adults of the erector spinae, external oblique, and rectus abdominis bilaterally, and gluteus medius and gluteus maximus muscle of the stance leg. A 2-way repeated measures analysis of variance was used to determine the interaction between the percentage maximal voluntary isometric contraction (%MVIC) and the reach directions. The %MVIC for each muscle was compared across the 8 reach directions using the Sidak post hoc test with α at .05. ***Main Outcome Measures:*** %MVIC. ***Results:*** Significant differences were observed for all the 8 muscles. Highest electromyographic activity was found for the tested muscles in the following reach directions—ipsilateral external oblique (44.5% [38.4%]): anterolateral; contralateral external oblique (52.3% [40.8%]): medial; ipsilateral rectus abdominis (8% [6.6%]): anterior; contralateral rectus abdominis (8% [5.3%]): anteromedial; ipsilateral erector spinae (46.4% [20.2%]): posterolateral; contralateral erector spinae (33.5% [11.3%]): posteromedial; gluteus maximus (27.4% [11.7%]): posterior; and gluteus medius (54.6% [26.1%]): medial direction. ***Conclusions:*** Trunk and hip muscle activation was direction dependent during the SEBT. This information can be used during rehabilitation of the hip and the trunk muscles.

Keywords: electromyography, core, dynamic balance, SEBT

Dynamic balance (DB) is the ability to maintain the center of mass over a stable base of support while performing a task. Core stability is considered an important aspect of DB,[1,2] and deficits in DB have been related to injuries in the athletic populations.[3] The Star Excursion Balance Test (SEBT), developed originally as a rehabilitative tool, is a functional screening tool used to assess lower-extremity (LE) DB.[4,5] The SEBT has been shown to have moderate to high intratester (intraclass coefficient = .67–.97), intertester (ICC =.81–1.0), and test–retest (intraclass coefficient = .84–.93) reliability, and low measurement error (2.2%–2.9%) when assessing DB in the healthy adults.[3,6–8]

The SEBT has been used to identify athletes who are at risk for LE injuries and also to identify deficits following LE injuries in athletes.[3,9–11] It has also been used to monitor rehabilitation progress and neuromuscular training.[12–15] Neuromuscular training programs have been shown to increase core stability and DB leading to a reduction in athletic injuries.[13–15] Successful performance on the SEBT requires a combination of DB and neuromuscular characteristics, such as LE flexibility, strength, proprioception, and coordination.[11,14–16] The SEBT has also been used as a training tool to improve neuromuscular control and core strength.[16,17] Four weeks of training on the SEBT showed improvement in core muscle strength and reduction in the Oswestry Disability Index Score.[17]

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However, it can be time consuming when evaluating or rehabilitating a patient in the clinic with the recommended number of repetitions in each of the 8 directions of the SEBT.[6] Researchers have attempted to simplify the SEBT by reducing the number of reach directions, and repetitions needed to stabilize the reach distance before the actual assessment.[3,10,18,19] Various authors have recommended different directions based on the sample population used in the study.[3,9,10,18] However, in the last few years, several authors have used 3 specific directions (anterior, posteromedial, and posterolateral) of the SEBT, because it was reported that these 3 directions measure the same constructs as the other 5 directions of the SEBT. However, the recommendation was not based on the electromyographic (EMG) data.[3,10] So far the muscle activation of the LE during all the 8 directions of the SEBT was shown to be direction dependent.[20–22] This means that one direction was not sensitive enough to identify deficits for various muscle groups and each direction of the SEBT can stimulate different muscles at various levels.

To our knowledge, only one study has measured the hip muscle activity in the 3 reach directions (anterior, medial, and posteromedial) of the SEBT.[22] These authors did not use the commonly used directions (anterior, posteromedial, and posterolateral) of the SEBT. No study has measured the hip muscle activity in the other 5 directions of the SEBT and trunk muscle activity in all the 8 reach directions of the SEBT. The purpose of this study was to identify the EMG activity of the hip and the trunk muscles during the SEBT performance in the 8 reach directions in healthy adults. We chose to measure all the 8 directions instead of choosing directions because we intended to establish a comprehensive knowledge about the EMG activity for the SEBT and to verify if the anterior, posteromedial, and posterolateral directions of the

SEBT have the same EMG activity as the other 5 directions of the SEBT. Clinicians can thus use this information when using the SEBT for rehabilitation. The research hypothesis was that the eccentric muscle activity of the hip and the trunk muscles would be significantly different for the 8 reach directions of the SEBT.

Methods

Participants

A total of 22 healthy adults (11 males and 11 females) were recruited to participate in the study. Their mean (SD) age, height, weight, and body fat percentage was 23.3 (3.8) years, 170.3 (7.6) cm, 67.8 (10.3) kg, and 15.1% (5.0%), respectively. The study was approved by the institutional review board of the Rocky Mountain University of Health Professions and Saginaw Valley State University.

Protocol

The participants signed the informed consent before starting the test protocol. The participants were screened for the inclusion/exclusion criteria (Table 1).[22] Lange® skin folds calipers (model no. 68902; Fitness Mart®, division of Country Technology, Inc, Gays Mills, WI) and 3 site formula regression equations for men (chest, abdomen, and thigh) and women (triceps, suprailiac, and abdomen) were used to assess body composition.[23] Skin folds measurements were taken by the guidelines provided by the *ACSM's Guidelines for Exercise Testing and Prescription*[23] at the sites mentioned above for both the men and the women. The body composition of the participants was assessed to achieve most accurate surface EMG signal by reducing the effects of body fat on the surface EMG signal.[24]

The Biopac MP 36 System (Biopac Systems Inc, Santa Barbara, CA) was used to collect all the EMG data.[25,26] Surface EMG was collected from the erector spinae (ES), external oblique (EOB), and rectus abdominis (RA) bilaterally (ipsilateral and contralateral side of the stance leg), and gluteus medius (GMED) and gluteus maximus (GMAX) muscle of the stance leg using 10-mm-contact-area Ag–AgCl disposable electrodes (Trace Rite®; Bio-Detek Inc, Pawtucket, RI). The analog signals were amplified, converted to digital, and were analyzed using Biopac Student Laboratory Pro Software, version 4.0 (Biopac Systems Inc). The following EMG parameters were used: input impedance = 2 M (differential), common mode rejection ratio = 110 dB, maximum input voltage = ±10 V, and gain = 1000. These parameters were based on the previous muscle activation studies for the SEBT.[21] A skin impedance of less than 20 k was accepted.[27] The skin was cleaned with a skin prep pad, and participants shaved the area if body hair were present. The electrodes were placed according to the procedure described by Cram and Criswell[27] (Figure 1). The participants performed light jumping jacks for 30 seconds for warm-up.[28] For normalization of the EMG data, maximum voluntary isometric contractions (MVICs) were performed for each muscle. The MVIC test positions were consistent with those demonstrated by Kendall et al[29] and previous research.[22,30,31] Proper electrode placements were also confirmed by observing the EMG amplitudes during the manual muscle tests before testing the MVIC. The participants were asked to perform primary muscle action of the neighboring muscles to assess for crosstalk. Manual pressure was gradually increased until maximum resistance was applied and then held for 5 seconds using a metronome. Each muscle test was repeated 3 times with a 15-second rest between contractions. Two minutes of rest was provided between the MVIC testing of different muscles.

Table 1 Inclusion/Exclusion Criteria of the Study

Inclusion criteria	Exclusion criteria
• Age = 18–40 y • Age-related body composition (%body fat) between fair to very lean, as reported in *ACSM's Guidelines for Exercise Testing and Prescription*	• History of CAI of the stance leg (the leg participants would stand on to kick a ball) • Upper-extremity or LE injury within last 6 mo • History of upper-extremity surgery within last 6 mo and neck, back, or LE surgery • Currently experiencing pain anywhere in the body • Difficulty maintaining single-leg stance for 10 s on either leg • Visible contralateral pelvic drop during single-leg stance • History of head injury • Or any other disorder affecting their balance

Abbreviations: CAI, chronic ankle instability; LE, lower-extremity.

Star Excursion Balance Testing

The SEBT required participants to perform a reaching task with one lower limb while maintaining balance on the stance leg (Figure 1).[6–8] The preferred stance leg was defined as the leg participant would stand on to kick a ball, because it would simulate unilateral weight-bearing activities of the participants and also to make comparisons with previous EMG studies performed during the SEBT.[22] The task of the SEBT was explained to the participants. Participants placed the foot of their

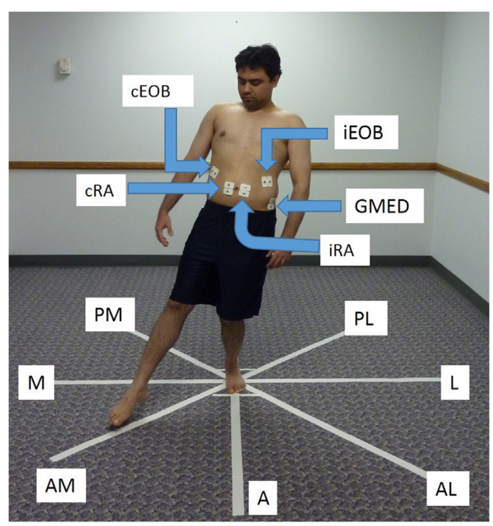

Figure 1 — Participant demonstrating The Star Excursion Balance Test in the AM direction. A indicates anterior; AL, anterolateral; AM, anteromedial; cEOB, contralateral external oblique; cRA, contralateral rectus abdominis; GMED, gluteus medius; iEOB, ipsilateral external oblique; iRA, ipsilateral rectus abdominis; L, lateral; M, medial; PL, posterolateral; PM, posteromedial.

stance leg in the middle of the SEBT so that equal halves of the length of the foot was in the anterior and posterior halves. Participants completed the test barefoot. As a guide for maintaining foot position, marks were made behind the heel and in front of the toes on the anteroposterior tape measures. Participants were instructed to keep their arms by the side, so their shoulder flexion and abduction do not exceed 45° while performing the SEBT. No specific instructions were provided for the trunk motion. Participants were instructed to toe touch before beginning to reach, marking the beginning of the single-leg stance phase. The toe touch event was recognized on the EMG data using a toe sensor that showed as a spike on the computer screen. Participants made a maximum reach with the opposite leg in a specified reach direction, performed a light touch on the floor with the great toe of the reaching foot and successfully returned to the double-leg stance. They were asked to toe touch marking the end of the single-leg stance phase before putting any weight on the reaching leg. A metronome was used at a rate of 30 beats per minute (equates to 2 s) to ensure consistent timing and speed of each of the SEBT trials where each reaching phase (from initial stance to maximum reach) and recovery phase (from maximum reach to bilateral stance) were performed during one beat.[22] Verbal cueing was provided to the participants during the SEBT to synchronize their toe touch with the metronome beat.

Maximum reach distances were recorded at the touchdown point. The reach distance was normalized by participants' leg length measured from the anterior superior iliac spine to the end of the medial malleolus.[32] Participants completed 6 practice trials in each of the 8 reach directions of the SEBT. The 5-minute break was provided between the practice trials and the data collection. Fifteen seconds of recovery time was given between test trials to reduce the risk of fatigue. A 60-second recovery time was utilized between reach directions, and the order of the reach directions was randomized. The trial was discarded if the heel of the stance leg lifted off the ground, participant putting weight on the reaching leg during maximal reach, lost balance even if the heel remained on the ground, could not return to the starting position, and did not match the metronome speed. If the trial was discarded, additional trials were performed until the participant completed 3 good trials in each direction.

Data Processing

The EMG data were collected using a sampling frequency of 1000 Hz from all the muscles during each of the MVICs and the SEBT. The raw data were band-pass filtered between 10 Hz and 500 Hz.[21] The electrocardiogram data from the trunk muscles were removed using high-pass digital filtering (finite impulse response using a Hamming window and fourth-order Butterworth filter) at 30 Hz cutoff frequency.[33] The raw data were integrated to remove the baseline, and the root mean square (RMS) was calculated over a 50-sample period.[22] The 3 trials of the MVIC for each muscle were calculated for 5-second period. However, the middle 3 seconds of each MVIC trial were averaged to calculate the peak RMS, and the mean of the peak RMS value of the 3 trials was used for normalization purposes.

Mean RMS value of the EMG signal of each muscle for each direction during the SEBT was calculated during the 2 seconds reaching (eccentric) phase of the each SEBT trial. The reaching phase was measured from the beginning of the unilateral stance to the maximal reach identified by the toe sensor. The EMG of the reaching phase was calculated to be consistent with the prior literature.[21,22] The RMS value of the reaching phase of the 3 trials was averaged for each muscle to be normalized to its respective MVIC value and represented as a percentage of the MVIC (%MVIC).

Statistical Analysis

A 2-way repeated-measures analysis of variance (ANOVA) with 2 repeated factors, muscle (8 levels) and reach direction (8 levels), was used to determine the differences in the %MVIC and the interaction between the %MVIC and the reach directions. A significant interaction effect (muscle by reach direction) was followed with separate 1-way repeated-measures ANOVAs to compare the normalized EMG values of the same muscle during the 8 directions. Separate ANOVAs were run on each muscle tested. In the event of a significant ANOVA, the Sidak post hoc test was used to identify significant differences in the normalized EMG activity of the muscle between specific directions. The level of significance was preset at .05, and SPSS version 18.0 (IBM, Armonk, NY) was used for all the statistical analyses.

Results

The 2-way repeated-measures ANOVA was statistically significant ($P < .001$) showing that the muscle activity changes with the change in the direction of the SEBT. For nomenclature, ipsilateral (i) side was the same side, and contralateral (c) sides was the opposite side of the stance leg during the SEBT. One-way repeated-measures ANOVAs showed significant differences for all the 8 reach directions of the SEBT for the iEOB ($P \leq .001$), cEOB ($P \leq .001$), iRA ($P \leq .01$), cRA ($P \leq .001$), iES ($P \leq .001$), cES ($P \leq .001$), GMAX ($P \leq .001$), and GMED ($P \leq .001$). Pairwise comparisons that were statistically significant were reported in Tables 2–4 along with the effect size.[34] The effect size was calculated using Morris and DeShon's[34] Equation (8). The effect sizes observed were between 0.8 and 2.5, which is considered a large effect size.[34]

Discussion

Based on the results, we accepted the proposed research hypothesis that the muscle activity of the hip and the trunk muscles was significantly different for the 8 reach directions of the SEBT, and each muscle showed the highest activation in one specific direction of the SEBT (Figure 2).

Reach Distance

To corroborate that the EMG activity collected during various reach directions was indeed a result of participant's maximum reach distance, the EMG data were not collected until the reach distance was stabilized during the practice trials. Additionally, the maximum reach distances achieved by our participants in all the 8 directions were similar to the results of the previous studies where maximum reach distances for healthy adults were reported.[11,19,35] We used a similar methodology to normalize reach distances as reported in these studies. Reach distances achieved in our study were within ±6% range compared with the previous studies.[11,19,35] This further leads us to the conclusion that the EMG activity produced by the participants in our study was, therefore, due to achieving their maximum reach distance (Table 5).

Table 2 Pairwise Comparisons of the 8 Directions of the SEBT for the Anterior Trunk Muscles That Were Statistically Significant Along With Their ES

		P value	ES
cEOB			
M	PL	.001	2.3
M	AL	.002	1.57
M	L	.01	1.3
M	PM	.01	1.07
M	P	.03	1.01
AM	PL	.001	1.44
AM	L	.004	1.26
AM	AL	.04	0.8
PM	PL	.01	1.91
PM	L	.04	1.11
P	PL	.02	1.39
P	L	.04	1.12
iRA			
AL	P	.02	1.182
AL	PL	.047	0.99
AL	L	.047	0.98
M	P	.002	1.12
cRA			
A	L	.01	1.15
A	PL	.02	1.01
AM	L	.01	1.12
AM	PL	.01	1.04
M	PL	.004	2.13
M	P	.001	2.09
M	L	.01	1.76
AL	L	.02	1.0
AL	PL	.04	0.87
PM	L	.001	1.67
PM	PL	.003	1.25
iEOB			
AL	PM	<.001	1.76
AL	P	.002	1.38
AL	L	.01	1.46
AL	PL	.004	1.2
AL	M	.02	1.0
A	PM	.02	0.93
PL	PM	.03	0.97

Abbreviations: A, anterior; AL, anterolateral; AM, anteromedial; cEOB, contralateral external oblique; cRA, contralateral rectus abdominis; ES, effect size; iEOB, ipsilateral external oblique; iRA, ipsilateral rectus abdominis; L, lateral; M, medial; P, posterior; PL, posterolateral; PM, posteromedial; SEBT, Star Excursion Balance Test.

Table 3 Pairwise Comparisons of the 8 Directions of the SEBT for the Posterior Trunk Muscles That Were Statistically Significant Along With Their ES

		P value	ES
iES			
PL	A	<.001	2.3
PL	AM	<.001	2.16
PL	M	<.001	2.05
PL	PM	<.001	1.92
PL	AL	<.001	1.57
PL	P	.002	1.28
L	A	<.001	2.5
L	AM	<.001	2.08
L	M	<.001	1.83
L	AL	<.001	1.58
L	PM	<.001	1.49
P	A	<.001	2.05
P	AM	<.001	1.76
P	M	<.001	1.59
P	PM	<.001	1.43
P	AL	<.001	1.24
AM	AL	.002	1.1
A	AL	<.001	1.4
cES			
PM	A	<.001	2.42
PM	AM	<.001	2.07
PM	M	<.001	1.54
PM	AL	<.001	1.35
PM	L	.01	0.9
P	A	<.001	2.4
P	AM	<.001	1.7
P	AL	<.001	1.34
P	L	.002	1.05
P	PL	.003	1.02
PL	A	<.001	1.95
PL	AM	<.001	1.31
PL	AL	.01	0.9
M	A	<.001	1.5
M	AM	<.001	1.4
L	A	<.001	2.01
L	AM	.001	1.2
AL	A	.002	1.24

Abbreviations: A, anterior; AL, anterolateral; AM, anteromedial; cES, contralateral erector spinae; ES, effect size; iES, ipsilateral erector spinae; L, lateral; M, medial; P, posterior; PL, posterolateral; PM, posteromedial; SEBT, Star Excursion Balance Test.

External Oblique

The EMG activity of the iEOB for the 8 directions of the SEBT in our study ranged from 27.5% (28.2%) to 44.5% (38.4%) MVIC (Table 6). The iEOB EMG activity was highest in the anterolateral direction. It might be because of the trunk rotation to the opposite side of the stance leg to counterbalance the reaching leg. The EMG activity of the cEOB for the 8 directions of the SEBT ranged from 18% (9.8%) to 52.3% (40.8%) MVIC (Table 6). The cEOB muscle has the highest muscle activation in the medial direction because instead of performing lateral flexion, the participants probably chose to perform trunk rotation toward the stance leg to counterbalance the reaching leg.

Table 4 Pairwise Comparisons of the 8 Directions of the SEBT for the Hip Muscles That Were Statistically Significant Along With Their ES

		P value	ES
GMAX			
P	AL	<.001	2.35
P	A	<.001	2.2
P	AM	<.001	1.38
P	L	.002	1.07
P	PL	.02	0.86
PM	A	<.001	1.88
PM	AL	<.001	1.79
PM	AM	.001	1.23
M	A	<.001	1.68
M	AM	<.001	1.64
M	AL	.001	1.49
PL	AL	<.001	1.65
PL	A	.001	1.4
PL	AM	.04	0.82
L	AL	.001	1.65
L	A	.01	1.1
GMED			
M	L	<.001	2.16
M	PM	.003	1.16
M	PL	.001	1.2
M	AM	.046	0.8
AL	L	.001	1.57
AM	L	<.001	1.45
P	L	.001	1.59
A	L	.001	1.4
PM	L	<.001	1.8
PL	L	<.001	1.68

Abbreviations: A, anterior; AL, anterolateral; AM, anteromedial; ES, effect size; GMAX, gluteus maximus; GMED, gluteus medius; L, lateral; M, medial; P, posterior; PL, posterolateral; PM, posteromedial; SEBT, Star Excursion Balance Test.

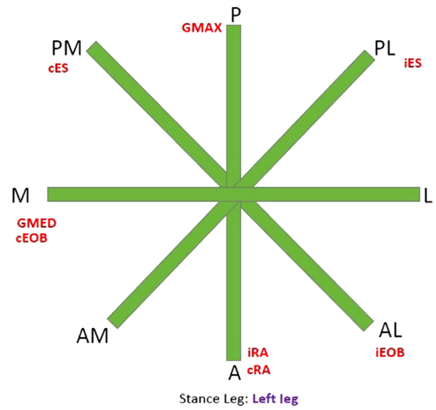

Figure 2 — The Star Excursion Balance Test directions and muscles with highest activity. A indicates anterior; AL, anterolateral; AM, anteromedial; cEOB, contralateral external oblique; cES, contralateral erector spinae; cRA, contralateral rectus abdominis; GMAX, gluteus maximus; GMED, gluteus medius; iEOB, ipsilateral external oblique; iES, ipsilateral erector spinae; iRA, ipsilateral rectus abdominis; L, lateral; M, medial; P, posterior; PL, posterolateral; PM, posteromedial.

Table 5 Normalized Reach Distance During the SEBT

Directions	Mean (SD) (%leg length)
A	81 (7)
AL	70 (9)
AM	86 (7)
P	82 (12)
PL	75 (13)
PM	86 (10)
M	88 (9)
L	64 (15)

Abbreviations: A, anterior; AL, anterolateral; AM, anteromedial; L, lateral; M, medial; P, posterior; PL, posterolateral; PM, posteromedial; SEBT, Star Excursion Balance Test.

To our knowledge, no previous studies have measured the EOB muscle activity for the SEBT. However, there are studies that have measured the EOB activity during the single-leg squat (SLS).[36,37] The EMG activity reported in the current study was higher than that reported in the previous studies. It might be because in those studies, the participants were asked to perform a step-down or a mini squat which does not require large trunk motions. Whereas, in the current study, the participants were asked to reach as far as possible in the 8 directions of the SEBT, which was possible only by performing large trunk motion to counterbalance the reaching leg producing higher EMG activity than that reported in the previous studies.[36,37]

Rectus Abdominis

The muscle activity of the iRA and the cRA were low (between 3.6% [2.0%] and 8.0% [6.6%] MVIC; Table 6) in all the 8 directions of the SEBT. The muscle activation of less than 10% MVIC has been deemed important for maintaining trunk stability when the task does not require active trunk flexion–extension motion.[31,38,39] The EMG activity for the RA muscle in our study was lower than previously reported by the Zeller et al[40] study. The reason for the difference in the RA EMG activity might be that their participants were instructed to squat as far down as possible potentially producing cocontraction between the ES and the RA muscles to maintain the upright posture causing higher muscle activity in the RA compared with the current study. While in our study, participants were asked to reach as far as possible without any instructions for the depth of squatting. As evident from the EOB activation, the participants might have chosen to perform trunk rotation opposite to the stance leg, instead of leaning backward, to counterbalance the reaching leg, which might have led to lower muscle activation of the iRA and the cRA muscles compared with the Zeller et al[40] study. Another difference was that Zeller et al[40] reported the combined EMG activity for both the concentric and the eccentric phases, whereas in the current study, EMG activity was reported only for the eccentric phase of the SEBT. It has been reported in the literature that the EMG activity

Table 6 EMG Activity of Each Muscle Represented by %MVIC

	Muscles							
Directions	iRA Mean (SD)	cRA Mean (SD)	iEOB Mean (SD)	cEOB Mean (SD)	iES Mean (SD)	cES Mean (SD)	GMAX Mean (SD)	GMED Mean (SD)
A	8.0 (6.6)[a]	8.0 (5.6)[a]	40.1 (35.0)	40.8 (35.0)	16.3 (10.3)	12.3 (6.4)	11.7 (6.5)	42.9 (22.8)
AM	7.0 (7.7)	8.0 (5.3)	33.0 (26.0)	47.3 (31.7)	16.4 (11.3)	13.9 (7.8)	13.9 (8.3)	44.4 (22.5)
AL	6.8 (4.4)	5.9 (3.5)	44.5 (38.4)[a]	34.0 (27.7)	23.5 (13.5)	18.6 (9.4)	10.8 (5.5)	47.0 (25.7)
P	3.8 (1.8)	4.9 (3.7)	29.8 (28.8)	37.6 (30.2)	38.0 (15.9)	31.1 (10.8)	27.4 (11.7)[a]	44.3 (24.5)
PM	4.5 (2.8)	5.0 (3.0)	27.5 (28.2)	41.3 (33.7)	23.4 (12.0)	33.5 (11.3)[a]	24.0 (11.1)	43.9 (20.6)
PL	4.0 (1.8)	3.9 (2.3)	32.6 (31.4)	24.9 (18.1)	46.4 (20.2)[a]	26.7 (10.6)	21.9 (12.1)	36.6 (19.6)
M	4.5 (2.0)	6.2 (4.4)	31.9 (29.6)	52.3 (40.8)[a]	18.4 (12.1)	25.3 (11.4)	22.6 (12.5)	54.6 (26.1)[a]
L	3.9 (1.7)	3.6 (2.0)	28.4 (25.4)	18.0 (9.8)	43.0 (18.9)	23.7 (10.7)	18.6 (11.0)	26.3 (13.4)

Abbreviations: A, anterior; AL, anterolateral; AM, anteromedial; cEOB, contralateral external oblique; cES, contralateral erector spinae; cRA, contralateral rectus abdominis; EMG, electromyographic; GMAX, gluteus maximus; GMED, gluteus medius; iEOB, ipsilateral external oblique; iES, ipsilateral erector spinae; iRA, ipsilateral rectus abdominis; L, lateral; M, medial; %MVIC, percentage maximal voluntary isometric contraction; P, posterior; PL, posterolateral; PM, posteromedial.
[a]Direction with highest EMG activity.

for the eccentric phase is lower than that of the concentric phase.[37] Also, in our study, the dominant leg was the one participant stood to kick a ball, whereas in Zeller et al,[40] the dominant leg was the one the participant used to kick a ball, and this might have also led to the differences in the EMG activity.

Erector Spinae

The EMG activity of the iES ranged from 16.3% (10.3%) to 46.4% (20.2%) MVIC (Table 6) during the 8 directions of the SEBT. The highest EMG activity for the iES was in the posterolateral direction because participants might have actively extended and laterally flexed the trunk toward the stance leg against the external torque generated by the gravity to maintain the upright posture. The EMG activity of the cES ranged from 12.3% (6.4%) to 33.5% (11.3%) MVIC (Table 6) during the 8 directions of the SEBT. The highest EMG activity was in the posteromedial direction because participants might have actively extended and laterally flexed the trunk toward the reaching leg against the external torque generated by the gravity to maintain the upright posture.

Our results for the ES muscle activation were comparable to the Zeller et al[40] study. We observed that the ES muscle on both sides produced higher activity in all the posterior directions compared with all the anterior directions because the participants might have actively extended the trunk to maintain upright posture against the flexor moment generated by gravity.

Gluteus Maximus

The EMG activity of the GMAX ranged from 10.8% (5.5%) to 27.4% (11.7%) MVIC (Table 6) during the 8 directions of the SEBT. The posterior direction elicited the highest GMAX EMG activity because as the participant performed hip flexion during reaching, it would cause gravity to generate a flexion moment that would stimulate the GMAX to contract eccentrically to control hip flexion and prevent loss of balance.[41] The magnitude of the GMAX activation in the posteromedial and the medial directions was comparable to than those reported in the Norris and Trudelle-Jackson [22] study. However, the GMAX EMG activity in our study for the anterior direction was lower than reported in their study.[22] It is because participants in our study reached a mean distance of 81% of their leg length compared with 87% in the Norris and Trudelle-Jackson [22] study in the anterior direction. It is possible that the participants in our study might have performed less hip flexion compared with the participants in their study resulting in the lower EMG activity of the GMAX in the present study. As participants in our study elicited higher activity in the EOB muscles when reaching in the anterior direction, it is also possible that they chose to rotate from the trunk than flex the hip to complete the task. More hip flexion would have elicited higher EMG activity in the GMAX to control the motion in the anterior direction. Because Norris and Trudelle-Jackson[22] did not measure trunk muscle activation in their study, this explanation cannot be confirmed. The GMAX activity in our study was lower than that reported in the other studies that performed the SLS.[42–44] These differences might have occurred because the main task in the SEBT is to reach as far as possible with one leg while maintaining balance on the other leg, whereas, during the SLS, participants are instructed to perform a squat without having to reach in any specific direction. It might be that squatting caused greater hip flexion than the SEBT putting greater demand on the hip extensors to eccentrically control hip flexion leading to higher muscle activity. Another difference was that these studies reported the EMG activity for either the concentric phase or the combined EMG activity for both the concentric and the eccentric phases. While in the current study, EMG activity was reported only for the eccentric phase of the SEBT.[42–44] Also, these studies defined the dominant leg differently than us.[42–44] All these methodological differences could have led to differences in the EMG activity.

Gluteus Medius

The EMG activity of the GMED ranged from 26.3% (13.4%) to 54.6% (26.1%) MVIC (Table 6) during the 8 directions of the SEBT. The highest activity was observed in the medial direction because, during the task, the pelvis of the reaching side would have dropped. To maintain pelvic stability and keep the pelvis in neutral in the sagittal plane, the demand on the GMED muscle of the stance leg would probably be the greatest, eliciting the highest muscle activity in this direction. Our results were comparable to those reported in the Norris and Trudelle-Jackson[22] study for the M and the anterior directions. However, for the posteromedial direction, the participants in our study produced muscle activity 2 times greater than the participants in the Norris and Trudelle-Jackson[22] study. Probably in their study when the participants reached in the posteromedial direction, they might have laterally flexed the trunk toward the stance leg to counterbalance the reaching leg that might have put less demand on the stance leg GMED to keep their pelvis in neutral. On the other hand, the participants in our study might have kept their trunk upright. It is evident from the highest cES EMG activity in the posteromedial direction. This might have put higher demand on the stance leg GMED to maintain pelvic stability eliciting higher muscle activity than reported in the Norris and Trudelle-Jackson[22] study. Our results were comparable to the previous studies that measured GMED muscle activity during the SLS.[42,43] It is because both the SEBT and the SLS require participants to balance on one leg while maintaining pelvic stability. However, EMG activity of the GMED in our study was lower than those reported in the study by Distefano et al.[44] It might be because their participants were instructed to perform the task for a depth where the middle finger touches the ground which might have led to greater demand on the GMED compared with our study, eliciting higher muscle activity. Also, Distefano et al[44] reported the combined EMG activity for both the concentric and eccentric phases, while we reported EMG activity only for the eccentric phase of the SEBT. This might have also resulted in higher GMED activity in their study compared with the current study.

Limitations and Future Scope

Like other EMG studies, our results should be interpreted with caution. Incorrect conclusions could be drawn if the results of this study are generalized to a population outside the age group, with any pathology, or athletes. One limitation is that the EMG data in the current study were the combination of male and female healthy adults. Some studies have reported differences in the muscle activation patterns between the males and the females.[45,46] However, these studies did not normalize for participants height, and leg length during data collection and analysis and the activities tested were different from the one studied in the current study.[45,46] We found several studies that did not find EMG differences between the males and the females.[36,37,40,45,46] To our knowledge, there was no study that reported differences in the EMG between the males and the females during the SEBT. Also, surface EMG has the potential for cross talk between adjacent muscles, error during electrode positioning, and also a submaximal effort by the participant during MVIC testing.[27] We took appropriate steps to minimize cross talk by using standard procedures for the electrode placement. We also performed manual muscle tests after the electrode placement to confirm the correct position of the electrodes. During MVIC, verbal encouragement was given to the participants to achieve maximal effort. Another significant limitation was that we did not collect the kinematic and the kinetic data and that is why the description of the EMG patterns was based on the biomechanical explanations.

Future studies could consider correlating the kinematic and the kinetic data along with the EMG activity to clarify the neuromuscular control strategies while performing the SEBT. Also, we would recommend that the future studies could investigate the differences in the muscle activation patterns between both legs and between the reaching and the recovery phase of the SEBT. In addition, we recommend that the future studies report gender differences during the SEBT that would help clinicians to design rehabilitation plans specific to gender needs.

Clinical Application

Previously, the SEBT has been used as a rehabilitation tool to improve ankle stability and reduce disability among patients with low back pain.[16,17] Researches have suggested that activities that elicit EMG activation of more than 40% MVIC have been shown to improve muscle strength,[47–49] whereas muscle activation below 40% MVIC may have a role in the neuromuscular control to maintain DB during that activity.[31,38,39] The results of our study can be used to rehabilitate the hip and the trunk muscles to gain neuromuscular control and improve strength depending upon the reach direction chosen to perform the SEBT (Table 7). The results also indicated that most muscles produced EMG activity less than 40% MVIC (Figure 3), which means that the SEBT can primarily be used to gain neuromuscular control for the hip and the trunk muscles. However, we also observed EMG activity of more than 40% MVIC for a few muscles in some directions that could be used to gain strength. Our results showed a continuum of directions

Table 7 Continuum of Directions Based on the Mean %MVIC for Each Muscle During the SEBT

Muscles	More than 40% MVIC (stimulus for strengthening)	Less than 40% MVIC (stimulus for stability and neuromuscular control)
iEOB	AL > A >	AM > PL > M > P > L > PM
cEOB	M > AM > PM > A >	P > AL > PL > L
iRA		A > AM > AL > M > PM > PL > L > P
cRA		AM > A > M > AL > PM > P > PL > L
GMAX		P > PM > M > PL > L > AM > A > AL
GMED	M > AL > AM > P > PM > A>	PL > L
iES	PL > L >	P > AL > PM > M > AM > A
cES		PM > P > PL > M > L > AL > AM > A

Abbreviations: A, anterior; AL, anterolateral; AM, anteromedial; cEOB, contralateral external oblique; cES, contralateral erector spinae; cRA, contralateral rectus abdominis; GMAX, gluteus maximus; GMED, gluteus medius; iEOB, ipsilateral external oblique; iES, ipsilateral erector spinae; iRA, ipsilateral rectus abdominis; L, lateral; M, medial; MVIC, maximal voluntary isometric contraction; P, posterior; PL, posterolateral; PM, posteromedial; SEBT, Star Excursion Balance Test.

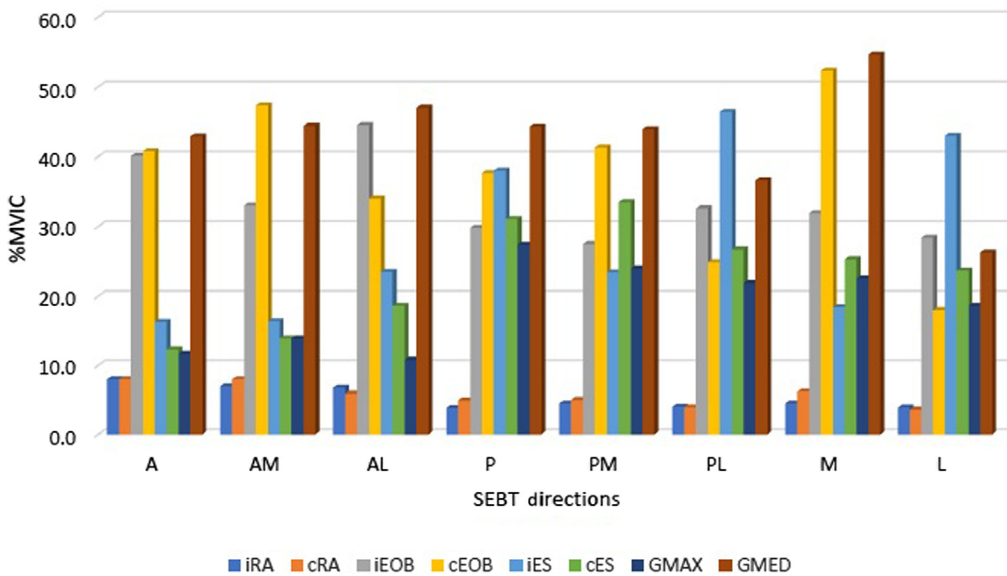

Figure 3 — EMG activity in the eight directions of the SEBT. A indicates anterior; AL, anterolateral; AM, anteromedial; cEOB, contralateral external oblique; cES, contralateral erector spinae; cRA, contralateral rectus abdominis; GMAX, gluteus maximus; GMED, gluteus medius; iEOB, ipsilateral external oblique; iES, ipsilateral erector spinae; iRA, ipsilateral rectus abdominis; L, lateral; M, medial; P, posterior; PL, posterolateral; PM, posteromedial; %MVIC, percentage maximal voluntary isometric contraction; SEBT, Star Excursion Balance Test.

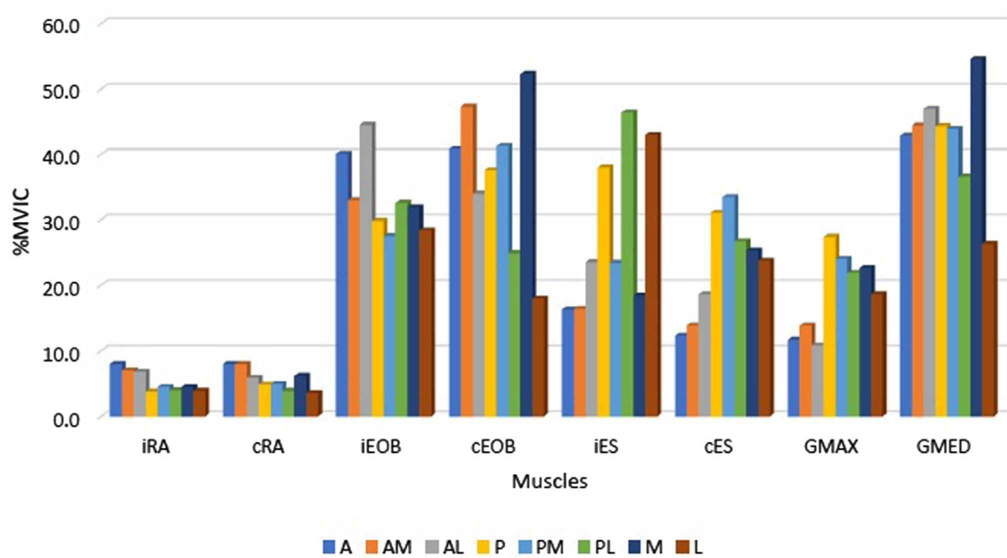

Figure 4 — EMG activity of each muscle during The Star Excursion Balance Test. A indicates anterior; AL, anterolateral; AM, anteromedial; cEOB, contralateral external oblique; cES, contralateral erector spinae; cRA, contralateral rectus abdominis; GMAX, gluteus maximus; GMED, gluteus medius; iEOB, ipsilateral external oblique; iES, ipsilateral erector spinae; iRA, ipsilateral rectus abdominis; L, lateral; M, medial; P, posterior; PL, posterolateral; PM, posteromedial; %MVIC, percentage maximal voluntary isometric contraction.

(Table 7) to achieve minimum to maximum effect for a given muscle (Figure 4). For example, in a patient with GMED weakness, the clinicians can start with the lateral and the posterolateral directions (Table 7) during the early stages of the rehabilitation to improve neuromuscular control and then progress the person from the anterior direction to the medial direction for strengthening.

Conclusions

Based on the results of our study, we conclude that each direction of the SEBT activates muscles differently. All the hip and the trunk muscles were activated during the 8 directions of the SEBT, but different activation patterns were seen in each of the directions. The specific directions of the SEBT could be used during rehabilitation both in the early stages when the goal may be to train the muscles to provide stability and neuromuscular control followed by strength improvement in the later stages.

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