



Original Article

Effects of posture and lower limb muscle strength on the results of the Star Excursion Balance Test

YASUHIRO ENDO, RPT, PhD^{1)*}, MASASHI MIURA, RPT, PhD¹⁾

¹⁾ Department of Rehabilitation, Sendai Seiyō Gakuin College: 4-3-55 Nagamachi, Taihakuku, Sendai 982-0011, Japan

Abstract. [Purpose] This study aimed to clarify the relationship between the distance measurements in the Star Excursion Balance Test and participants' posture and lower limb muscle strength. [Participants and Methods] Nine healthy male college students participated in this study. Star Excursion Balance Test distance was measured in both lower limbs by performing anterior, posterolateral, and posteromedial trials; measuring the maximum reach; and performing three-dimensional motion analysis to determine the posture at maximum reach. Isokinetic muscle strength for knee flexion/extension, hip flexion/extension, and hip adduction/abduction were measured using an isokinetic machine. [Results] The hip extension strength, reach side ankle dorsiflexion angles, stance side knee flexion, reach side knee flexion, and knee flexion strength were selected as significant explanatory variables in the anterior direction. For the posteromedial direction, hip adduction and hip extension strength, reach side hip flexion angle, and stance side hip flexion angle were selected. For the posterolateral direction, reach side knee flexion angle and stance side ankle dorsiflexion, knee flexion strength and reach side hip flexion angle were selected. [Conclusion] The related factors differed between the dominant and non-dominant legs even in the same reach direction.

Key words: Dynamic balance, Posture, Strength

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INTRODUCTION

Dynamic balance performance has previously been associated with increased injury risk¹⁻⁴⁾ and is necessary for improving the performance of athletes as well as for rehabilitation after injury⁵⁾ in varied populations. The Star Excursion Balance Test (SEBT) has been used to evaluate dynamic balance and is a useful screening tool for risk of lower limb disorders^{1, 3, 6, 7)}. Poor SEBT performance has been noted to predict increased lower-extremity injury risk in multiple sports^{3, 6)}. As a result of SEBT, the risk of failure increases when it decreases the reach distance of the lower limb length or when the difference between the left and right is 4 cm or more³⁾.

Dynamic balance involves neurological factors, visual acuity, sensation, muscular strength, and coordination, but it is not clear which factor is specifically evaluated in SEBT. Several studies have reported that different individual muscles are utilized in different tested reach directions⁸⁻¹⁰⁾. Most of them were examined using isometric muscle strength, and there were few reports on the relationship between posture and muscle strength during SEBT.

This study aimed to clarify the relationship between SEBT distance and posture and lower limb muscle strength. We hypothesized that SEBT reach distance would be associated with lower limb muscle strength and posture.

*Corresponding author. Yasuhiro Endo (E-mail: yasundo18@gmail.com)

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PARTICIPANTS AND METHODS

Nine healthy male college students participated in this study (age: 20.4 ± 0.5 years, height: 170.7 ± 4.7 cm, weight: 66.1 ± 13.9 kg, body mass index: 22.7 ± 4.9). The inclusion criteria for the subjects were no history of orthopedic or neurological diseases that affected balance and muscle strength in the past 6 months. Those who developed pain during SEBT and muscle strength measurements were excluded from analysis. All participants provided a voluntary signed informed consent form; this study was approved by the ethics review committee of the Sendai Seiyō Gakuin College (Approval No. 0101). This observational study was designed as a cross-sectional study.

Participants completed the SEBT in a manner previously described in literature^{3, 11, 12}. The participants stood with one leg, the stance leg, on the starting block and used their opposite leg to push the reach indicator box as far as possible in the anterior, posteromedial, and posterolateral directions (Fig. 1). Attempts did not count if the participants were unable to maintain a single-leg stance throughout the entire movement, rested the left foot on top of the indicator box while reaching, kicked the indicator box forward in an attempt to gain extra distance, or did not return to center with maintained balance. Each participant completed two testing trials in each direction with each leg after enough practice trials. We investigated each subject's ball-kicking foot, which was defined as the dominant leg. SEBT was performed by standing on the dominant as well as the non-dominant leg. The participants' lower-extremity lengths in the supine position were measured bilaterally from the anterior superior iliac spine to the medial malleolus for normalization using a tape measure. For data analysis, the reach distance in each direction was normalized using the following formula: $(\text{reach distance}/\text{lower-extremity length}) \times 100^{12}$.

Additionally, a 3-dimensional quantitative SEBT evaluation was performed at our institution. SEBT was measured in both lower limbs by performing anterior (ANT), posteromedial (PM), and posterolateral (PL) trials, measuring the maximum reach and performing three-dimensional motion analysis to determine the posture at maximum reach. We securely placed 18 reflective markers on the skin, bilaterally, overlying anatomical landmarks of the trunk, pelvis, thigh, shank, and foot. Videos were captured from four cameras (Go pro Hero7, Gopro Inc., CA, USA, 120 fps) placed around the subject. The videos were analyzed using 3-dimensional motion analysis software, Kineanalyzer (Kisei Comtech, Tokyo, Japan). Angles were calculated for hip flexion, hip abduction, knee flexion, and ankle dorsiflexion. Joint angles of the lower limbs were calculated on both the stance and reach sides.

Isokinetic muscular strength was measured using an isokinetic machine (Biodex System3, BIODEX Medical, NY, USA) for knee flexion/extension, hip flexion/extension, and hip adduction/abduction. Bilateral isokinetic strength was measured at 120degree/sec. Each measurement was performed five times, the maximum torque was measured, and the maximum torque was divided by body weight. Muscle strength measurements were taken on a separate day within 1 week of the SEBT measurements.

After testing the normal distribution of each item, the laterality of each item was examined by the Wilcoxon signed-rank test. The stepwise multiple regression analysis was performed with reach distance as the dependent variable and muscle strength of the stance side limb and joint angle as explanatory variables. Statistical analysis was performed using SPSS ver.27, and a p-value of <0.05 was considered statistically significant in all analyses.

RESULTS

Results of the SEBT reach distance and muscle strength measurements are shown in Table 1, and joint angles for maximum reach of SEBT are shown in Table 2. There was no significant difference between the dominant leg and non-dominant leg in reach distance and muscle strength. Regarding the relationship between reach distance and muscle strength, the results



Fig. 1. Star Excursion Balance Test (SEBT).

differed between the dominant and non-dominant legs.

In multiple regression analysis results, the hip extension strength was selected as a significant explanatory variable in the ANT direction of the dominant side. For the ANT direction of the non-dominant side, reach side ankle dorsiflexion angle, stance side knee flexion angle, reach side knee flexion angle, and knee flexion strength were selected. For the PM direction of the dominant side, hip adduction strength and reach side hip flexion angle were selected. For the PM direction of the non-dominant side, stance side hip flexion angle and hip extension strength were selected. For the PL direction of the dominant side, reach side knee flexion angle and stance side ankle dorsiflexion were selected. For the PL direction of the non-dominant side, knee flexion strength and reach side hip flexion angle were selected (Table 3).

DISCUSSION

In this study, the hip extension muscle strength was involved in the dominant side, while the reach distance, which is an index of dynamic balance ability, was involved in the ANT direction. On the non-dominant side, the knee flexion strength on the stance side, the larger ankle plantar flexion on the reach side, and the knee flexion on the smaller stance side were associated with the reach distance. Previous studies have shown that the SEBT ANT score correlates with hip extension/flexion muscle strength¹³). However, during ANT reach, the hip extensor muscle activity is about 10% of the maximum isometric muscle strength⁹). The hamstrings have the functions of the hip extensor muscle and the knee flexor muscle. This result suggested that there is a possibility that the gluteus maximal muscle strength and hamstrings as hip extensor muscles and hamstrings as knee flexion muscles are essential for stabilizing pelvic, hip, and knee joints on the stance side when maintaining a dynamic balance. As a characteristic of the movement, moving the opposite lower limb forward while controlling the knee flexion of the stance side enables a further reach movement. At this time, it may be necessary to stabilize the pelvis and femur by the hip extensor muscles. Simultaneously, it seems that the reach side ankle joint should be more plantarflexed.

In the PM direction, the results suggested that the hip adduction muscle strength and hip joint extension muscle strength on the stance side, and the hip flexion on the stance side and the hip extension on the reach side as postures might be involved in the reach distance. In the reach motion to PM, it is considered that the center of gravity of the supporting lower limbs and the upper body needs to be moved more forward as the center of gravity of the lower limbs on the reach side moves posteromedial with the reach. During this movement, the knee and hip joints flexion, and the trunk tilts forward. Also, Jatin et

Table 1. Results of SEBT and muscle strength

		Dominant	Non dominant
SEBT	Anterior (%)	82.3 ± 7.2	84.1 ± 12.2
	Posteriomedial (%)	101.2 ± 13.7	98.8 ± 19.6
	Posteriolateral (%)	90.6 ± 14.9	87.7 ± 20.6
Knee extension	120 deg/sec (Nm/kg)	228.3 ± 30.5	234.9 ± 32.9
Knee flexion	120 deg/sec (Nm/kg)	112.4 ± 14.2	119.0 ± 21.1
Hip extension	120 deg/sec (Nm/kg)	216.1 ± 80.0	211.9 ± 73.3
Hip flexion	120 deg/sec (Nm/kg)	206.4 ± 42.8	189.5 ± 40.9
Hip abduction	120 deg/sec (Nm/kg)	184.4 ± 44.6	149.8 ± 53.7
Hip adduction	120 deg/sec (Nm/kg)	147.3 ± 68.7	157.7 ± 56.0

Mean ± SD.

Table 2. Results of motion analysis to assess posture at maximal reach for the Star Excursion Balance Test

		Anterior		Posteromedial		Posterolateral	
		Dominant	Non dominant	Dominant	Non dominant	Dominant	Non dominant
Stance side	Hip flexion (°)	22.9 ± 14.6	24.6 ± 12.8	93.6 ± 24.9	97.9 ± 20.3	88.2 ± 22.5	83.8 ± 28.2
	Hip abduction (°)	-16.1 ± 6.1	-10.6 ± 9.0	-19.9 ± 9.5	-14.9 ± 8.0	-19.4 ± 9.1	-11.8 ± 4.6
	Knee flexion (°)	70.0 ± 15.7	70.5 ± 18.9	70.7 ± 12.0	70.1 ± 12.3	62.9 ± 11.1	59.2 ± 10.8
	Ankle dorsiflexion (°)	37.7 ± 10.1	36.4 ± 5.9	24.9 ± 10.7	24.3 ± 6.8	34.6 ± 8.8	30.4 ± 6.2
Reach side	Hip flexion (°)	48.5 ± 13.5	38.9 ± 17.8	19.6 ± 8.8	23.7 ± 8.3	34.3 ± 11.0	31.6 ± 13.3
	Hip abduction (°)	4.8 ± 16.7	-2.1 ± 11.6	17.2 ± 4.9	21.3 ± 9.3	-12.9 ± 10.2	-5.0 ± 10.6
	Knee flexion (°)	6.1 ± 3.2	7.8 ± 2.8	20.3 ± 11.7	15.1 ± 7.6	23.8 ± 15.3	24.3 ± 13.7
	Ankle dorsiflexion (°)	-45.1 ± 8.4	-41.5 ± 10.5	-20.6 ± 27.9	-25.6 ± 17.3	-37.7 ± 16.2	-40.7 ± 14.4

Mean ± SD.

Table 3. Results of the multiple regression analysis

		B	p value	R ²
Dominant side	ANT			0.567
		Hip extension strength	0.068	0.019
	PM			0.842
		Hip adduction strength	0.162	0.008
		Reach side hip flexion angle	-0.692	0.036
	PL			0.861
		Reach side knee flexion angle	-0.676	0.004
		Stance side ankle dorsiflexion angle	0.801	0.024
Non-dominant side	ANT			0.986
		Reach side ankle dorsi flexion angle	-1.04	0.002
		Stance side knee flexion angle	-0.242	0.018
		Reach side knee flexion angle	1.392	0.006
		Knee flexion strength	0.185	0.032
	PM			0.906
		Stance side hip flexion angle	0.612	0.009
		Hip extension strength	0.11	0.048
	PL			0.881
			Knee flexion strength	1.039
		Reach side hip flexion angle	0.753	0.023

al. reported that PM excursion during the SEBT was correlated with hip extensor strength¹³). Studies of muscle activity have reported that hip extensor muscle at about 24% of maximum isometric strength⁹). Due to the characteristics of this movement, it is considered that the hip flexion angle of the stance side and the hip extension angle of the reach side at the maximum reach are related to the reach distance. Also, for the stability of the hip joint on the stance side, the hip extensor muscles may be active and involved in the reach distance. Jatin et al. showed that the PM reach distances on SEBT were correlated with hip abductor strength¹³). According to muscle activity measurements, the hip abductor muscle is 44% active in maximum isometric muscle strength⁹). Hip abductor muscle activity is less in the PM direction than in the ANT and Medial directions¹⁰). In this study, the strength of the hip adductor muscle, which is the hip abductor's antagonist muscle, was significantly associated with the reach distance. From these, it was considered that to support the lower limbs against the movement of the center of gravity to the outside; it is necessary to stabilize the hip joint by the co-contraction of the abductor and adductor muscles during movement rather than the absolute muscle strength.

For the dominant side, the smaller knee flexion angle of the reach side and the larger ankle dorsi flexion of the stance side were associated with the PL direction's reach distance. It was suggested that the PL direction score on the non-dominant side might be related to the knee flexor strength on the stance side and the hip flexion angle on the reach side. In the movement of reaching the contralateral lower limb to cross the supporting side lower limb, it is considered that the lower leg was tilted forward by the dorsiflexion of the ankle joint on the stance side, and the knee and hip joints were performing coordinated flexion movements. The more the knee joint on the reach side is in the extended position, the longer the lower limb length is increasing the reach distance in the PL direction. Knee flexor strength was considered necessary for stabilizing the hip and knee joints by the hamstrings in the PL as well as ANT direction. The reach side hip flexion angle may also reflect the trunk flexion angle.

From these results, there was a difference in the relationship between reach distance, muscle strength, and posture depending on each reach direction of SEBT, and their influence was not considerable. These results are similar to those of previous studies¹³).

Dynamic balance is associated with many factors. SEBT also requires lower-extremity strength, motion range, and coordination to assess balance, which may increase its sensitivity to predict injuries³). Plisky et al. suggested that SEBT may be a useful measure that can help identify a component of the neuromuscular differences between boys and girls because of the differences in the association between SEBT and lower limb injuries³). According to this study's results, SEBT may be significantly affected by factors other than muscle strength and posture. The core plays a vital role in stabilizing the lower extremity and knee movement during activity^{14, 15}). Thus, the role of the core muscles may also be considered.

In terms of the relationship between SEBT and injury, Robert et al. suggested that low SEBT scores could be a risk of non-contact injury in collegiate American football players⁶). Conversely, others have found a good balance to be a risk factor for injury^{7, 16}). Reach asymmetry on the SEBT and previous injury did not assist with identifying athletes at risk of an injury⁶). Plisky et al.³) observed that >4 cm asymmetry on the anterior reach was associated with elevated injury risk. Therefore, there

may be a need for population-specific cut-off points to be developed to screen for injury risk in athletes⁶). For any lower limb injury, risk factors included greater SEBT anterior reach distance, Ankle injury risk factors included smaller SEBT anterior reach distance¹⁷). In this study, related factors of muscle strength and posture differed between the dominant and non-dominant legs, even in the same reach direction. It is necessary to evaluate laterality of reach distance from the perspective of injury prevention, and it is important that interpretations are made on the assumption that factors differ between dominant and non-dominant legs. However, the cause of the laterality could not be clarified in this study, and additional research is needed.

This study's limitation is that the number of participants was small and comprised only Japanese male college students. Future studies on a larger number of subjects are warranted.

Additionally, isometric muscle strength was measured in previous studies; however, the isokinetic strength measurement used in this study may have contributed to the difference in reach distance.

Furthermore, in this study, the characteristics of SEBT's reach distance were not clarified; this problem may be solved by conducting a larger-scale study from a biomechanical viewpoint.

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Conflict of interest

The authors have no financial conflicts of interest to disclose concerning this study.

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