Original Research

The Reliability and Validity of Star Performer™ a Computerized tool for Quantifying the Star Excursion Balance Test

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Background

The Star Excursion Balance Test (SEBT) is well recognized in both clinical and research settings as a reliable, valid, and responsive assessment. However, the SEBT is time consuming and inconvenient. To address this limitation, a new device called the Star Performer™ has been developed to improve the efficiency of SEBT.

Purpose

To investigate the test-retest reliability of Star Performer™ device and compare its validity to traditional SEBT methods.

Study Design

Cross-sectional study

Methods

Twenty-five subjects with lower extremity injuries participated in this study. Each subject performed the SEBT twice, with approximately seven days between tests. The Star Performer™ device and a tape measure were used to record three test trials for each test direction with the average of the three reach distances being used for analysis. Test-retest reliability was evaluated by calculating the intra-class correlation coefficients (ICC 3,1) between the average reaching distance for each SEBT direction across the two testing sessions. To assess the validity of the Star Performer™ device, the averaged reaching distance for each SEBT direction was compared with the measurements obtained from the tape measure.

Results

Seventeen females (68%) and eight males (32%) with lower extremity injuries (mean age= 23.6 years, SD=3.9, range from 19-35) participated. The Star Performer™ demonstrated excellent test-retest reliability, with ICC 3,1 values ranging from 0.85 to 0.93 for the eight SEBT directions. The minimal detectable change at the 95% confidence level (MDC95) ranged from 2.56 to 5.37% for the eight directions. The Pearson correlation coefficients between the Star Performer™ and tape measure recordings ranged from 0.90 to 0.94 for the eight directions.

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Conclusion

This study provides evidence supporting the test-retest reliability and validity of the Star Performer™ for assessing SEBT performance. These findings suggest that Star Performer™ offers a precise and efficient approach to evaluate SEBT performance in individuals with lower extremity injuries.

Level of Evidence

Level 3b

INTRODUCTION

Over one million sports-related lower extremity injuries are estimated to occur every year.[1] These lower extremity injuries can adversely impact performance and lead to disability due to pain, weakness, loss of motion, impaired balance, and diminished neuromuscular control.[2-7] The American Physical Therapy Association clinical practice guidelines recommend functional performance tests for assessing impairments of body function and for predicting lower extremity injuries.[2-7] Among these tests, the Star Excursion Balance Test (SEBT) is commonly used by researchers and clinicians.[7-9]

The SEBT is a functional test that requires components such as strength, range of motion, balance, and neuromuscular control, with evidence supporting its reliability, validity, and responsiveness.[8-16] The SEBT has been found to be useful for assessing functional performance in individuals with groin pain, femoroacetabular impingement (FAI), hip arthroscopic surgery, great trochanteric pain syndrome, anterior cruciate ligament (ACL) injuries, patellar tendinopathy, patellar femoral pain, ankle sprain, and plantar fasciitis.[10-16] It is also used to differentiate reach distance values between injured and uninjured population.[8,9,12,17-60] Traditional methods measure an individual's performance on the SEBT utilizing a standard tape measure which require the clinician to assume a hands-and-knees position to record each of the reach distances based on visual assessment.[8,9] This method, given the multiple recordings in each direction, is time-intensive and inefficient. Additionally, visual assessment may cause potential errors due its inherent imprecision. Therefore, a computerized version of the SEBT would facilitate efficient and precise measurements and allow it to be more practical for use in clinical practice.

A new device called the Star Performer™ (GDE Technologies; Townsend, DE) **(Figures 1 and 2)** has been developed as a computerized version of the SEBT. The Star Performer™ automates the measurement process with real-time continuous data collection, data storage, and visual feedback displays. Additionally, the software can present graphs of reach distances, including radial plots, that allow for comparison of the reach distances on each leg to facilitate interpretation of an individual's performance. By improving the convenience and precision of the SEBT, the Star Performer™ holds promise for broader clinical use.

While the Star Performer™ theoretically has significant advantages, there is no current evidence to support its usefulness. Therefore, the purpose of this study was to investigate the test-retest reliability of Star Performer™ device and compare its validity to traditional SEBT methods. It
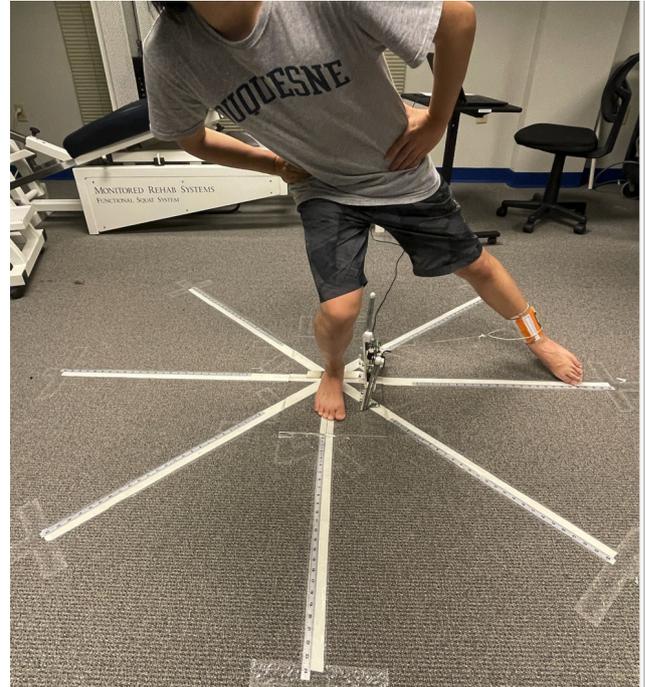

Figure 1. SEBT Performed Using the Star Performer™

Figure 2. Star Performer™

was hypothesized that the Star Performer™ will have excellent test-retest reliability and strong correlation with the traditional SEBT methods in individuals with lower extremity injuries.

METHODS

SUBJECTS

A sample size of 26 was calculated using methods described by Bonett et al,[61] with values as follows: ICC=0.85, w=0.2, k=2 and $z\alpha/2$ =1.96. Accounting for potential dropouts, 30 participants were included in the study. Participants were eligible if they were aged between 18 and 45 years and had sustained a lower extremity injury (hip, knee, foot, or ankle) in the prior six months, as diagnosed by an athletic trainer, physician, or physical therapist. Exclusion criteria included weight bearing limitations, a neurological disorder, pain with walking, and/or conditions that prevented the ability to stand on one leg. Subjects who sustained injuries or underwent balance training during the one-week test interval were also excluded. Of the 30 initial participants, five did not complete the study. Three participants withdrew between the first and second visits due to injuries, while the other two participated in balance related training during the one-week follow-up interval. Therefore, a total of 25 injured legs were included in this study. Written informed consent and authorization to disclose protected health information for a research study were obtained from all participants in accordance with the Ethics Committee of the Duquesne University.

DATA COLLECTION

Subjects completed the Lower Extremity Functional Scale (LEFS), University of California at Los Angeles (UCLA) Activity Scale and Visual analog scale (VAS) prior to testing. The LEFS is a 20-question patient-reported outcome measure that assesses an individual's ability to participate in everyday activities with activities ranked on a 4-point scale from "unable to perform" to "no difficulty" with total scores ranging from 0 to 80. The LEFS has appropriate psychometric properties for assessing lower extremity functional performance.[62-64] The UCLA Activity Scale is a 10-point activity scale that evaluates a patient's activity level from 1 (low) to 10 (high) that has appropriate psychometric properties for assessing physical activity levels.[65-67] The pain Visual Analogue Scale (VAS) is a 10-cm line, which represents a continuum from "no pain" to "worst pain imaginable.[68] Each participants' lower limb length was measured from the anterior superior iliac spine to the most distal portion of the medial malleolus with a standard tape measure.[8,9] A metric tape measure was adhered on each direction of SEBT.[8,69,70] (Figure 2) The distance from the center of the circle to the point where the subjects' toe touched each line was recorded by the same examiner. The SEBT performance was measured with the traditional tape measure method while the Star Performer™ simultaneously collected and recorded data.

SEBT

The SEBT was performed as described by Olmsted et al.[71] In summary, the SEBT was made with four strips of athletic tape 244cm in length. All lines were separated from each
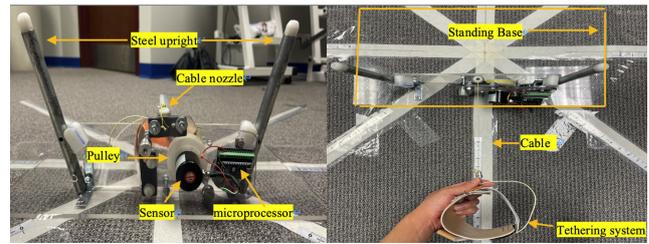

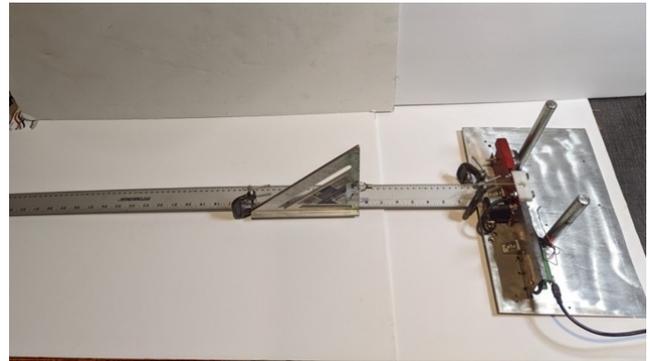**Figure 3. Star Performer™ components**

Figure 4. Calibration of the Star Performer™

other by a 45° angle forming the shape of a star. Directions of anterior, anteromedial, anterolateral, medial, lateral, posterior, posteromedial, and posterolateral were defined by the stance leg. Tape measures were adhered on each direction of the SEBT.

STAR PERFORMER™

The Star Performer™ (Figure 3) electronically measured the maximum reach distance in all eight directions of the SEBT while collecting real time distance, speed, and acceleration of movement data. The device is composed of a standing base, tethering system, cable, pulley, sensor, and microprocessor. (Figure 3) The Star Performer™ measures and records distance using a custom preprogrammed microprocessor and customized Star Performer software™ with data stored and displayed on a laptop computer. Measurements taken by the Star Performer™ were calibrated and accuracy prior to the study and confirmed using a standard aluminum meter stick. (Figure 4)

The Star Performer™ records data directly into the Star performer software™ in real time and simultaneously graphs the subjects' reach during each maneuver. (Figure 5). When the test is completed, the reach distances can be graphed (Figure 6) and a comparison of the bilateral legs' reaching distances represented in a radar plot (Figure 7).

SEBT AND STAR PERFORMER™ PROCEDURES

During the test process, the Star Performer™ was performed concurrently with the standard measurements of the SEBT. The Star Performer™ calculates the distance from the lateral ankle to the center of the ground and the tape measure method of SEBT measures from the point
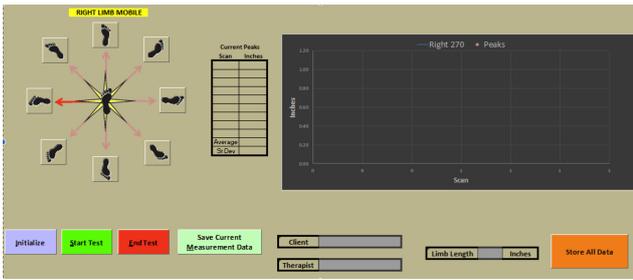
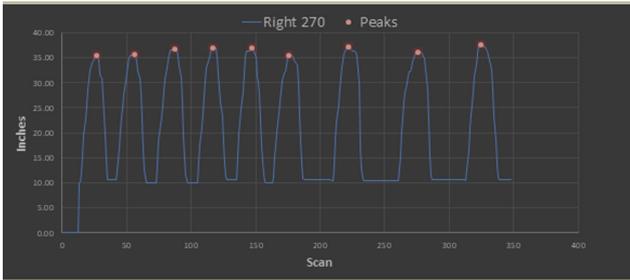**Figure 5. Star performer Software™ Interface**

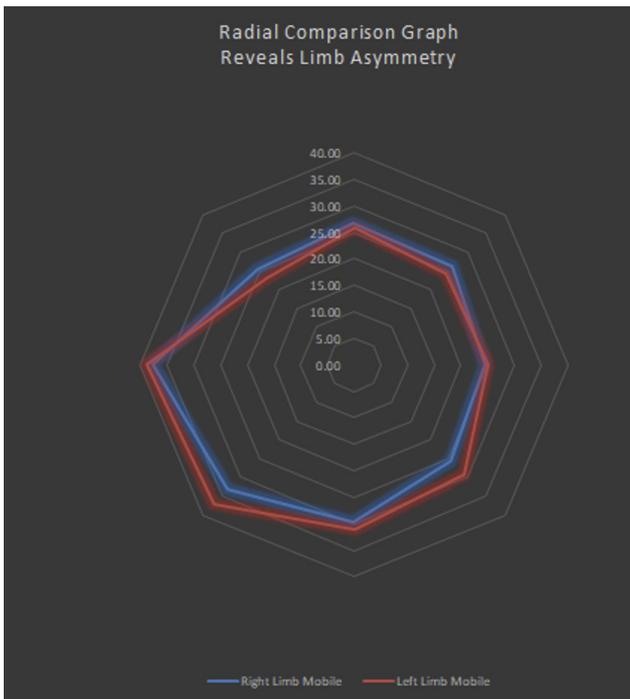**Figure 6. Star Performer™ Software Reach Distance Graph**

Figure 7. Star Performer™ Software Radar Plot

where the toe touches the ground to the center of the SEBT. The SEBT was performed twice by each subject, separated by approximately seven days, using established methods on the affected lower extremity.[12,13,16,69,70,72-74] Participants were given identical verbal instruction on how to perform the SEBT to ensure consistency in testing methods. The investigator also demonstrated how to perform test. As instructed, participants performed the test barefoot, with the foot positioned by aligning the heel at the intersection point of the eight lines. Participants were asked to maintain a single-leg stance on the test leg while reaching the opposite leg to touch as far as possible along each of the eight directions with the most distal part of their foot. The sequence of the eight directions was determined using a random number generator. To be successful, each attempt must have met the following criteria: 1) participants' hands remained on their hips and balance maintained while reaches were completed; 2) the reach leg was not to be in contact with the floor for more than one second and 3) the heel of the stance leg remained in position in the center of the grid. If the participant was unable to complete the above requirements as determined by the investigator, the performance in that direction was discarded and the attempt was repeated. As described by prior methods,[73,74] each participant was asked to perform six successful practice attempts in each test direction to minimize the influence of the learning effect. Participants were then asked to perform three test trials in each direction, with each trial being separated by five seconds of rest.[75] One minute of recovery was given between each reach direction and when switching legs.[69] Before analysis the reaching distance on the anterior, posterior, lateral, anterolateral, posterolateral directions of the Star Performer™ was calibrated. The figures and functions of how calibration was done are shown in **Appendix A**.

DATA ANALYSIS

The average reach distances (normalized by leg length) from three successful trails in each direction using both Star Performer™ and tape measure methods were used for analysis. Reaching distances were normalized to leg length by calculating (Reaching Distance / Leg Length) × 100.[8,9] A two-way mixed model was used to generate intra-class correlation coefficients (ICC 3,1) of consistency. Interpretation of ICC value was made according to the scale described by Koo et al.[76] (i.e., poor reliability 0–0.50; moderate reliability 0.50-0.75; good reliability 0.75-0.9 and excellent reliability 0.9-1). The SEM values were calculated as follows: $SEM = SD_{diff}\sqrt{(1-ICC)}$ with SD_{diff} representing the standard deviation of mean difference between two measurements.[77,78][ref] The minimal detectable change at the 95% confidence level (MDC_{95}) were calculated as follows: $MDC = $ z-score (95% CI) × SEM × $\sqrt{2}$.[79] The Pearson correlation was utilized between with normalized reaching distances of Star Performer™ and tape measure method during the first visit. The Pearson correlation coefficient (r) was interpreted as indicating weak, moderate, or strong relationships at values of 0.10, 0.30, and 0.50, respectively.[80]

RESULTS

Demographic information and the average reach distances (normalized by leg length), along with the range (minimum to maximum) measured by the Star Performer™ during the first visit is presented in Table 1. The average reach distances measured by the tape measure method and the Star

Table 1. Demographic information for subjects

Variable	Value
N	25
Age	23.6years (SD=3.9)
Height	166 cm (SD=7)
Weight	63.6(10.7)
Female Male	17(68%) 8(32%)
Pain VAS	2.6 (SD=2.2)
LEFS	65.7(3.9)
Right leg involved	14 (56%)
Left leg involved	11 (44%)
Reaching distance	Average % of leg length (with range)
Anterior	62.4% (50.2-74.2%)
Anteromedial	66.9% (53.1-79.3%)
Medial	67.9% (47.3-82.3%)
Posteromedial	68.2% (45.7-84.6%)
Posterior	65.4% (44.9-84.9%)
Posterolateral	55.1% (25.1-88.2%)
Lateral	63.5% (34.8-91.9%)
Anterolateral	46.5% (32.1-64.1%)
UCLA level	
0-3	4 (16%)
4-6	11(44%)
8-10	10(40%)
Region of injury	
Intra-articular hip	4(16%)
Extra-articular hip	1(4%)
Intra-articular knee	2(8%)
Extra-articular knee	7(28%)
Foot and ankle	11(44%)

LEFS: Lower Extremity Functional Scale, UCLA: University of California at Los Angeles Activity Scale, VAS: Visual Analogue Scale

Performer™ during the first and second visits are presented in the Appendix. Test-retest reliability of normalized distance was good to excellent for each direction of Star Performer™ ($ICC_{3,1}$= 0.85-0.93) and tape measure ($ICC_{3,1}$= 0.85-0.93). The results with ICC and MDC_{95} for normalized distance are shown in Table 2. The correlation between the normalized distance measured by Star Performer™ and tape measure was strong (r= 0.90-0.94), as presented in Table 3.

ICC: Intra-class correlation coefficients; MDC: Minimal Detectable Change; SEM: Standard Error of Mean

DISCUSSION

The primary findings of this study provided evidence for good to excellent test-retest reliability and concurrent validity of the Star Performer™ (normalized by leg length) compared to traditional SEBT measurements methods in individuals with lower extremity injuries in prior six months. The Star Performer™ exhibited smaller MDC_{95} values of normalized distance, ranging from (2.56-5.37%), compared with the traditional SEBT tape measure method (4.34-5.86%) over a one-week period of time. The results of this study support the use of Star Performer™ as a precise outcome instrument to assess SEBT performance in individuals with lower extremity injuries. Using its computerized device and software, the Star Performer™ addresses the identified inefficiencies of the SEBT and has potential for broader clinical use.

This study found good to excellent test-retest reliability of both Star Performer™ and tape measure method for the SEBT. The ICC values for normalized distance of the Star Performer™ ranged from 0.85-0.93, aligning closely with the tape measure method which ranged from 0.85-0.93 in the current study. Both normalized distance of ICC values from the Star Performer™ and the tape measure method found in this current study were similar with previous stud-

Table 2. The Test-retest Reliability of normalized Star Performer™ and Tape Measure Method

	Tape Measure			Star Performer		
Direction	ICC (95%CI)	SEM	MDC95%	ICC (95%CI)	SEM	MDC95%
Anterior	0.85 (0.69-0.93)	1.86	5.17	0.90 (0.81-0.96)	0.96	2.67
Anteromedial	0.86 (0.72-0.94)	1.56	4.34	0.87 (0.73-0.94)	1.34	3.74
Medial	0.85 (0.69-0.93)	2.12	5.9	0.85 (0.69-0.93)	2.07	5.76
Posteromedial	0.89 (0.76-0.95)	1.97	5.47	0.93 (0.86-0.97)	0.92	2.56
Posterior	0.91 (0.81-0.96)	1.88	5.22	0.93 (0.86-0.97)	0.93	2.58
Posterolateral	0.93 (0.85-0.97)	1.57	4.36	0.93 (0.83-0.95)	1.53	4.27
Lateral	0.91 (0.81-0.96)	2.11	5.86	0.91 (0.80-0.96)	1.93	5.37
Anterolateral	0.86 (0.72-0.94)	1.72	4.77	0.90 (0.80-0.95)	1.31	3.66

Table 3. Correlation between normalized Tape measure and Star Performer measurements

Direction	Pearson correlation coefficient (95% CI)
Anterior	0.92 (0.84-0.96)
Anteromedial	0.91 (0.83-0.96)
Medial	0.91 (0.85-0.96)
Posteromedial	0.90 (0.80-0.95)
Posterior	0.93 (0.86-0.96)
Posterolateral	0.94 (0.88-0.97)
Lateral	0.94 (0.87-0.97)
Anterolateral	0.91(0.84-0.96)

ies (Table 4).[10,13-16,72] Pierobon et al[15] reported ICC values of test-retest reliability from 0.72-0.93 in all eight directions in patients with lateral ankle sprain over a 24-72 hour interval. Five studies all investigated the test-retest reliability ranging from 30 seconds to one week on three directions of SEBT and found ICC values ranging from 0.89-0.99 on anterior direction, from 0.93-0.99 on posteromedial and from 0.51-0.96 on posterolateral direction for those with greater trochanteric pain, ACL injury, chronic ankle sprain, and general lower extremity injuries, as well as a healthy population.[10,13,14,16,72] Variation in reliability may be attributed to factors such specific diagnosis, retest interval, and test protocol variation including instruction of leg position, number of practice trials, and rest time.

In the current study, the MDC$_{95}$ values of normalized distance for the Star Performer™ ranged from 2.56-5.37% and the tape measure method ranged from 4.34-5.86%. The normalized distance for Star Performer™ demonstrated smaller MDC$_{95}$ values across seven of eight directions compared to the tape measure method. This indicates that the Star Performer™ has reduced measurement error in SEBT over a one-week period compared to the traditional tape measure method. The MDC value offers clinicians the smallest change score that can differentiate between actual clinical changes and variations that might arise from random measurement variability. Visual assessments are inherently prone to human biases and errors. Rapid reaching movements can be challenging for clinicians to accurately observe and measure, leading to potential discrepancies with the tape measure method. Variability in observation positions across the eight directions also causes biases, as maintaining a consistent observation point is impractical.

Comparatively, previous studies have reported varying MDC values of normalized distance in SEBT (Table 5).[13-16] Pierobon et al.[15] determined MDC$_{95}$ values of normalized distance in SEBT spanning 8.56-13.36% across all eight directions for lateral ankle sprains assessed between a 24–72-hour interval. Three other studies investigated the anterior, posteromedial, and posterolateral directions.[13,14,16] Ferrer-Peña et al.[14] reported MDC$_{90}$ values of normalized distance in SEBT between 2.8-10.4% for greater trochanteric pain syndrome assessed between trials, while Shi et al.[16] found MDC$_{90}$ values of normalized distance in SEBT ranging from 4.5-47.3% for chronic ankle sprains over a one-week interval. Dobija et al.[13] indicated MDC$_{95}$ values of normalized distance in SEBT between 5.92-8.36% for ACL injuries with a 30-second interval between assessments. Previous studies focused on specific diagnoses and examined three of eight directions on SEBT, differing from the current study, making direct comparisons challenging.[13,14,16] Variation in MDC values can be attributed to factors such as the specific diagnosis, test protocol, interval between tests, and the chosen cutoff for defining MDC.

The normalized distance of Star Performer™ exhibited a strong correlation (r=0.91-0.94) with the tape measure method across all eight directions of the SEBT. Any dis-

Table 4. Test-retest reliability with Intra-class correlation coefficients (ICC) values of normalized distance in Star Excursion Balance Test in lower extremity injuries

Direction	Current study		Pierobon 2020	Plisky 2006	Meardon 2016	Ferrer-Peña 2019	Dobija 2019	Shi 2023
	Tape measure	Star Performer						
Anterior	0.85	0.90	0.87	0.89	0.99	0.95	0.91	0.95
Anteromedial	0.86	0.87	0.87					
Medial	0.85	0.85	0.93					
Posteromedial	0.89	0.93	0.75	0.93	0.98	0.99	0.96	0.95
Posterior	0.91	0.93	0.72					
Posterolateral	0.93	0.93	0.78	0.91	0.99	0.79	0.96	0.51
Lateral	0.91	0.91	0.87					
Anterolateral	0.86	0.90	0.85					

Table 5. Minimal detectable change (MDC) of normalized distance in Star Excursion Balance Test for lower extremity injuries

Direction	Current study		Pierobon 2020	Ferrer-Peña 2019	Dobija 2019	Shi 2023
	Tape measure	Star Performer				
	MDC_{95}	MDC_{95}	MDC_{95}	MDC_{90}	MDC_{95}	MDC_{90}
Anterior	5.17	2.67	8.56	5	5.93	4.5
Anteromedial	4.34	3.74	8.68			
Medial	5.9	5.76	6.73			
Posteromedial	5.47	2.56	13.36	2.8	7.08	5.6
Posterior	5.22	2.58	13			
Posterolateral	4.36	4.27	13.33	10.4	8.36	47.3
Lateral	5.86	5.37	12.17			
Anterolateral	4.77	3.66	9.69			

crepancy may be a result from the differences measurement techniques. The Star Performer™ calculates the distance from the lateral ankle to the center of the ground, while the tape measure method measures from the point where the toe touches the ground to the center of the SEBT. This kind of measurement technique difference introduces an error attributable to the subject's foot size. Although SEBT protocol recommends normalizing the subject's leg length, from the anterior superior iliac spine to the medial malleolus's most distal portion, this approach doesn't account for foot size. Consequently, the Star Performer™ may offer greater accuracy as it excludes the foot during reach distance calculations, ensuring consistent reach endpoints across subjects.

The Star Performer™ not only offers a more precise assessment compared to the traditional SEBT but also enhances the efficiency of data collection and provides real-time interpretation. With the tape measure method, clinicians must use a hands-and-knees position to record each reach distance. Throughout the eight directions of the test, the clinician must change positions multiple times to record the patient's outcome, making the process cumbersome. The Star Performer™, with its ability to automatically record and output data, effectively addresses this problem. The Star Performer™ requires less time compared to the tape measure method when testing the same subject across eight directions. Furthermore, the immediate output from the Star Performer™ aids clinicians in real-time interpretation. The radial plot of the Star Performer™ provides clinicians with a direct means to contrast the SEBT performance of the affected side against the unaffected side. Additionally, the reach distance graph acts as a valuable visual feedback tool for patients during SEBT training. Beyond its precision, the Star Performer™ stands out as a more efficient and user-friendly tool compared to the traditional tape measure method in SEBT.

LIMITATIONS

This study has limitations. It included only young and active participants with diverse lower extremity injuries, potentially limiting the findings to this specific demographic. Additionally, the test-re-test reliability outcomes are con-

strained to a one-week timeframe, making them unsuitable for long-term clinical follow-up.

CONCLUSION

This study introduces the Star Performer™, a novel computerized device and software for evaluating the SEBT in patients with lower extremity injuries. The findings demonstrate good to excellent test-retest reliability and strong concurrent validity when compared to the traditional tape measure method used for data collection in the SEBT. The Star Performer™ offers a more convenient, precise, and efficient assessment method for evaluating patients with lower extremity injuries than previous SEBT methodologies.

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REFERENCES

1. Sheu Y, Chen LH, Hedegaard H. Sports- and Recreation-related injury episodes in the United States, 2011-2014. *Natl Health Stat Report*. 2016;(99):1-12.

2. Arundale AJH, Bizzini M, Dix C, et al. Exercise-based knee and anterior cruciate ligament injury prevention. *J Orthop Sports Phys Ther*. 2023;53(1):Cpg1-cpg34. doi:10.2519/jospt.2023.0301

3. Cibulka MT, White DM, Woehrle J, et al. Hip pain and mobility deficits--hip osteoarthritis: clinical practice guidelines linked to the international classification of functioning, disability, and health from the orthopaedic section of the American Physical Therapy Association. *J Orthop Sports Phys Ther*. 2009;39(4):A1-25. doi:10.2519/jospt.2009.0301

4. Enseki KR, Bloom NJ, Harris-Hayes M, et al. Hip pain and movement dysfunction associated with nonarthritic hip joint pain: a revision. *J Orthop Sports Phys Ther*. 2023;53(7):Cpg1-cpg70. doi:10.2519/jospt.2023.0302

5. Logerstedt DS, Snyder-Mackler L, Ritter RC, Axe MJ, Godges JJ. Knee stability and movement coordination impairments: knee ligament sprain. *J Orthop Sports Phys Ther*. 2010;40(4):A1-a37. doi:10.2519/jospt.2010.0303

6. Martin RL, Chimenti R, Cuddeford T, et al. Achilles pain, stiffness, and muscle power deficits: midportion achilles tendinopathy revision 2018. *J Orthop Sports Phys Ther*. 2018;48(5):A1-a38. doi:10.2519/jospt.2018.0302

7. Martin RL, Davenport TE, Fraser JJ, et al. Ankle stability and movement coordination impairments: lateral ankle ligament sprains revision 2021. *J Orthop Sports Phys Ther*. 2021;51(4):Cpg1-cpg80. doi:10.2519/jospt.2021.0302

8. Gribble PA, Hertel J, Plisky P. Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *J Athl Train*. 2012;47(3):339-357. doi:10.4085/1062-6050-47.3.08

9. Powden CJ, Dodds TK, Gabriel EH. The reliaiblity of the Star Excursion Balance test and Lower Quarter Y-balance test in healthy adults: a systematic review. *Int J Sports Phys Ther*. 2019;14(5):683-694. doi:10.26603/ijspt20190683

10. Meardon S, Klusendorf A, Kernozek T. Influence of injury on dynamic pstrual control in runners. *Int J Sports Phys Ther*. 2016;11(3):366-377.

11. Almeida GPL, Monteiro IO, Marizeiro DF, Maia LB, de Paula Lima PO. Y balance test has no correlation with the stability index of the Biodex Balance System. *Musculoskel Sci and Pract*. 2017;27:1-6. doi:10.1016/j.msksp.2016.11.008

12. Jupil K, Rosen AB, Brown CN. Comparison between single and combined clinical postural stability tests in individuals with and without chronic ankle instability. *Clin J Sport Med*. 2017;27(4):394-399. doi:10.1097/JSM.0000000000000354

13. Dobija L, Reynaud V, Pereira B, et al. Measurement properties of the Star Excursion Balance Test in patients with ACL deficiency. *Phys Ther Sport*. 2019;36:7-13. doi:10.1016/j.ptsp.2018.12.010

14. Ferrer-Peña R, Moreno-López M, Calvo-Lobo C, López-de-Uralde-Villanueva I, Fernández-Carnero J. Relationship of dynamic balance impairment with pain-related and psychosocial measures in primary care patients with chronic greater trochanteric pain syndrome. *Pain Med*. 2019;20(4):810-817. doi:10.1093/pm/pny160

15. Pierobon A, Raguzzi I, Soliño S, et al. Minimal detectable change and reliability of the star excursion balance test in patients with lateral ankle sprain. *Physiother Res Inti*. 2020;25(4):e1850. doi:10.1002/pri.1850

16. Shi X, Ganderton C, Tirosh O, Adams R, Ei-Ansary D, Han J. Test-retest reliability of ankle range of motion, proprioception, and balance for symptom and gender effects in individuals with chronic ankle instability. *Musculoskel Sci Pract*. 2023;66. doi:10.1016/j.msksp.2023.102809

17. Clagg S, Paterno MV, Hewett TE, Schmitt LC. Performance on the modified star excursion balance test at the time of return to sport following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2015;45(6):444-452. doi:10.2519/jospt.2015.5040

18. Harput G, Howard JS, Mattacola C. Comparison of muscle activation levels between healthy individuals and persons who have undergone anterior cruciate ligament reconstruction during different phases of weight-bearing exercises. *J Orthop Sports Phys Ther*. 2016;46(11):984-992. doi:10.2519/jospt.2016.5896

19. Zult T, Gokeler A, Raay J, et al. An anterior cruciate ligament injury does not affect the neuromuscular function of the non-injured leg except for dynamic balance and voluntary quadriceps activation. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(1):172-183. doi:10.1007/s00167-016-4335-3

20. Cervenka JJ, Decker MN, Ruhde LA, Beaty JD, Ricard MD. Strength and stability analysis of rehabilitated anterior cruciate ligament individuals. *Int J Exerc Sci*. 2018;11(1):817-826. doi:10.70252/MUNO4563. PMID:29997727

21. Domingues PC, Serenza FDS, Muniz TB, et al. The relationship between performance on the modified star excursion balance test and the knee muscle strength before and after anterior cruciate ligament reconstruction. *Knee*. 2018;25(4):588-594. doi:10.1016/j.knee.2018.05.010

22. Salas-gómez D, Fernández-gorgojo M, Sánchez-juan P, et al. Measuring recovery and understanding long-term deficits in balance, ankle mobility and hip strength in people after an open reduction and internal fixation of bimalleolar fracture and their impact on functionality: a 12-month longitudinal study. *J Clin Med*. 2022;11(9). doi:10.3390/jcm11092539

23. Bastien M, Moffet H, Bouyer L, Perron M, Hébert LJ, Leblond J. Concurrent and discriminant validity of the star excursion balance test for military personnel with lateral ankle sprain. *J Sport Rehabil*. 2014;23(1):44-55. doi:10.1123/JSR.2012-0132

24. Bastien M, Moffet H, Bouyer LJ, Perron M, Hébert LJ, Leblond J. Alteration in global motor strategy following lateral ankle sprain. *BMC Musculoskelet Disord*. 2014;15(1). doi:10.1186/1471-2474-15-436

25. Doherty C, Bleakley C, Hertel JAY, Caulfield B, Ryan J, Delahunt E. Dynamic balance deficits 6 months following first-time acute lateral ankle sprain: a laboratory analysis. *J Orthop Sports Phys Ther*. 2015;45(8):626-633. doi:10.2519/jospt.2015.5653

26. Doherty C, Bleakley CM, Hertel J, Caulfield B, Ryan J, Delahunt E. Laboratory measures of postural control during the Star Excursion Balance Test after acute first-time lateral ankle sprain. *J Athl Train*. 2015;50(6):651-664. doi:10.4085/1062-6050-50.1.09

27. Kalichman L, Lachman H, Freilich N. Long-term impact of ankle sprains on postural control and fascial densification. *J Bodyw Mov Ther*. 2016;20(4):914-919. doi:10.1016/j.jbmt.2016.04.002

28. Pourkazemi F, Hiller C, Raymond J, Black D, Nightingale E, Refshauge K. Using balance tests to discriminate between participants with a recent index lateral ankle sprain and healthy control participants: a cross-sectional study. *J Athl Train*. 2016;51(3):213-222. doi:10.4085/1062-6050-51.4.11

29. Ko J, Rosen AB, Brown CN. Functional performance deficits in adolescent athletes with a history of lateral ankle sprain(s). *Phys Ther Sport*. 2018;33:125-132. doi:10.1016/j.ptsp.2018.07.010

30. Alghadir AH, Iqbal ZA, Iqbal A, Ahmed H, Ramteke SU. Effect of chronic ankle sprain on pain, range of motion, proprioception, and balance among athletes. *Int J Environ Res Public Health*. 2020;17(15):1-11. doi:10.3390/ijerph17155318

31. Fraser JJ, Koldenhoven RM, Jaffri AH, et al. Foot impairments contribute to functional limitation in individuals with ankle sprain and chronic ankle instability. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(5):1600-1610. doi:10.1007/s00167-018-5028-x

32. Nagamoto H, Yaguchi H, Takahashi H. History of ankle sprain affect the star excursion balance test among youth football players. *Foot Ankle Surg*. 2021;27(7):784-788. doi:10.1016/j.fas.2020.10.004

33. Chaiyakul S, Chaibal S. Physical performance and psychological status of professional football players with recurrent ankle sprains. *Sport Mont*. 2022;20(2):17-22. doi:10.26773/smj.220603

34. Pionnier R, Découfour N, Barbier F, Popineau C, Simoneau-Buessinger E. A new approach of the Star Excursion Balance Test to assess dynamic postural control in people complaining from chronic ankle instability. *Gait and Posture*. 2016;45:97-102. doi:10.1016/j.gaitpost.2016.01.013

35. Kwon YU, Iiiblaise Williams DS, Blaise Williams DS 3rd. The effect of variable rest intervals and chronic ankle instability on triplanar ankle motion during performance of the Star Excursion Balance Test. *Hum Mov Sci*. 2017;52:143-150. doi:10.1016/j.humov.2017.01.013

36. McCann RS, Crossett ID, Terada M, Kosik KB, Bolding BA, Gribble PA. Hip strength and Star Excursion Balance Test deficits of patients with chronic ankle instability. *J Sci Med Sport*. 2017;20(11):992-996. doi:10.1016/j.jsams.2017.05.005

37. Jaber H, Lohman E, Daher N, et al. Neuromuscular control of ankle and hip during performance of the star excursion balance test in subjects with and without chronic ankle instability. *PLoS ONE*. 2018;13(8). doi:10.1371/journal.pone.0201479

38. Kwon YU, Arnold BL, Powell DW, Iiiwilliams DSB, Williams DSB 3rd. Influence of rest interval on foot-tibia coordination with chronic ankle instability during the Star Excursion Balance Test. *Hum Mov Sci*. 2018;58:239-247. doi:10.1016/j.humov.2018.02.009

39. Sierra-Guzmán R, Jiménez F, Abián-Vicén J. Predictors of chronic ankle instability: Analysis of peroneal reaction time, dynamic balance and isokinetic strength. *Clin Biomech (Bristol)*. 2018;54:28-33. doi:10.1016/j.clinbiomech.2018.03.001

40. Kosik KB, Johnson NF, Terada M, Thomas AC, Mattacola CG, Gribble PA. Decreased dynamic balance and dorsiflexion range of motion in young and middle-aged adults with chronic ankle instability. *J Sci Med Sport*. 2019;22(9):976-980. doi:10.1016/j.jsams.2019.05.005

41. DeJong AF, Mangum LC, Hertel J. Ultrasound imaging of the gluteal muscles during the Y-balance test in individuals with or without chronic ankle instability. *J Athl Train*. 2020;55(1):49-57. doi:10.4085/1062-6050-363-18

42. Fatima S, Bhati P, Singla D, Choudhary S, Hussain ME. Electromyographic activity of hip musculature during functional exercises in participants with and without chronic ankle instability. *J Chiropr Med*. 2020;19(1):82-90. doi:10.1016/j.jcm.2019.07.002

43. Hassanpour S, Daryabor A, Jamshidi A, Rezaei M. Efficacy of ankle supports on dynamic postural control in patients with chronic ankle instability. *Med Sci Sports Exerc*. 2020;32(3):194-202. doi:10.1097/JPO.0000000000000309

44. John C, Stotz A, Gmachowski J, et al. Is an elastic ankle support effective in improving jump landing performance, and static and dynamic balance in young adults with and without chronic ankle instability? *J Sport Rehabil*. 2020;29(6):789-794. doi:10.1123/jsr.2019-0147

45. Lee K, Kim YH, Lee S, Seo SG. Characteristics of the balance ability and isokinetic strength in ankle sprain. *Isokinet Exerc Sci*. 2020;28(3):239-245. doi:10.3233/IES-194223

46. Jaffri AH, Saliba S. Does verbal encouragement change dynamic balance? The effect of verbal encouragement on Star Excursion Balance Test performance in chronic ankle instability. *Braz J Phys Ther*. 2021;25(5):617-622. doi:10.1016/j.bjpt.2021.04.002

47. Mullins JF, Hoch MC, Kosik KB, et al. Effect of dry needling on spinal reflex excitability and postural control in individuals with chronic ankle instability. *J Manipulative Physiol Ther*. 2021;44(1):25-34. doi:10.1016/j.jmpt.2020.08.001

48. Thompson T, Suttmiller AMB, Ringle B, McCann RS. Corticomotor excitability of the gluteus maximus in individuals with chronic ankle instability: a pilot study. *Transl Sports Med*. 2021;4(1):65-71. doi:10.1002/tsm2.199

49. Kwon YU. Lower extremity muscle activation during the Star Excursion Balance Test in patients with chronic ankle instability and copers. *Medicina (Kaunas)*. 2023;59(6). doi:10.3390/medicina59061040

50. Ma T, Xu X, Li M, et al. Cortical activation during single-leg stance in patients with chronic ankle instability. *J Athl Train*. Published online 2023. doi:10.4085/1062-6050-0363.22

51. Miyachi R, Kanazawa Y, Fujii Y, Yamazaki T. Relationship between ankle-joint angle during dynamic balance task and ankle-joint proprioception in chronic ankle-instability individuals. *J Sports Med Phys Fitness*. 2023;63(1):121-128. doi:10.23736/S0022-4707.22.13985-X

52. Mohamadi S, Rahmani N, Ebrahimi I, Salavati M, Dadgoo M. The effect of leg dominance and group difference in Star Excursion Balance Test between individuals with chronic ankle instability, ankle sprain copers and healthy controls. *Arch Bone Joint Surg*. 2023;11(3):206-211. doi:10.22038/ABJS.2022.65920.3161

53. Chaari F, Boyas S, Sahli S, et al. Postural balance asymmetry and subsequent noncontact lower extremity musculoskeletal injuries among Tunisian soccer players with groin pain: a prospective case control study. *Gait and Posture*. 2022;98:134-140. doi:10.1016/j.gaitpost.2022.09.004

54. Choi M, Kim Y. Biomechanical asymmetry of strength and dynamic balance kinetics in middle-ages with adhesive capsulitis of the hip. *Int J Environ Res Public Health*. 2022;19(20). doi:10.3390/ijerph192013093

55. Johansson AC, Karlsson H. The Star Excursion Balance Test: criterion and divergent validity on patients with femoral acetabular impingement. *Man Ther*. 2016;26:104-109. doi:10.1016/j.math.2016.07.015

56. Mobarra T, Hojjat S, Rahimi A. Comparison of knee functional ability and static and dynamic postural control between female handball players with patellofemoral pain and healthy female handball players. *Sci J Kurdistan Univ Med Sci*. 2016;21(4):94-106.

57. Goto S, Aminaka N, Gribble PA. Lower-extremity muscle activity, kinematics, and dynamic postural control in individuals with patellofemoral pain. *J Sport Rehabil*. 2018;27(6):505-512. doi:10.1123/jsr.2016-0100

58. Coelho VK, Gomes BSQ, Lopes TJA, Corrêa LAC, Telles GF, Nogueira LAC. Knee proprioceptive function and physical performance of patients with patellofemoral pain: a matched case-control study. *Knee*. 2021;33:49-57. doi:10.1016/j.knee.2021.08.031

59. Aguiar Gonçalves G, Harudy Kamonseki D, Reclusa Martinez B, Amaral Nascimento M, Lombardi Junior I, Liu Chiao Y. Static, dynamic balance and functional performance in subjects with and without plantar fasciitis. *Fisioterapia em Movimento*. 2017;30(1):19-27. doi:10.1590/1980-5918.030.001.AO02

60. Fendri T, Boyas S, Sahli S, et al. Patellar tendinopathy impairs postural control in athletes: a case-control study. *Phys Ther Sport*. 2022;53:14-20. doi:10.1016/j.ptsp.2021.10.014

61. Bonett DG. Sample size requirements for estimating intraclass correlations with desired precision. *Stat Med*. 2002;21(9):1331-1335. doi:10.1002/sim.1108

62. Mehta SP, Fulton A, Quach C, Thistle M, Toledo C, Evans NA. Measurement properties of the lower extremity functional scale: a systematic review. *J Orthop Sports Phys Ther*. 2016;46(3):200-216. doi:10.2519/jospt.2016.6165

63. Zhang Y, Zang Y, Martin RL. Clinically most relevant psychometric properties of the lower extremity functional scale: a systematic review. *Disabil Rehabil*. 2025;47(8):1932-1938. doi:10.1080/09638288.2024.2390051

64. Zhang Y, Ai D, Gao Y, et al. Test-retest reliability and responsiveness for the simplified chinese lower extremity functional scale in patients with lower extremity musculoskeletal injuries. *Orthop J Sports Med*. 2025;13(4):23259671251322906. doi:10.1177/23259671251322906

65. Naal FD, Impellizzeri FM, Leunig M. Which is the best activity rating scale for patients undergoing total joint arthroplasty? *Clin Orthop Relat Res*. 2009;467(4):958-965. doi:10.1007/s11999-008-0358-5

66. Terwee CB, Bouwmeester W, van Elsland SL, de Vet HC, Dekker J. Instruments to assess physical activity in patients with osteoarthritis of the hip or knee: a systematic review of measurement properties. *Osteoarthritis Cartilage*. 2011;19(6):620-633. doi:10.1016/j.joca.2011.01.002

67. Rolfson O, Eresian Chenok K, Bohm E, et al. Patient-reported outcome measures in arthroplasty registries. *Acta Orthop*. 2016;87 Suppl 1(Suppl 1):3-8. doi:10.1080/17453674.2016.1181815

68. Boonstra AM, Schiphorst Preuper HR, Reneman MF, Posthumus JB, Stewart RE. Reliability and validity of the visual analogue scale for disability in patients with chronic musculoskeletal pain. *Int J Rehabil Res*. 2008;31(2):165-169. doi:10.1097/MRR.0b013e3282fc0f93

69. Munro AG, Herrington LC. Between-session reliability of the star excursion balance test. *Phys Ther Sport*. 2010;11(4):128-132. doi:10.1016/j.ptsp.2010.07.002

70. Hertel J, Miller SJ, Denegar CR. Intratester and intertester during the Star Excursion Balance Tests. *J Sport Rehabil*. 2000;9(2):104. doi:10.1123/jsr.9.2.104

71. Olmsted LC, Carcia CR, Hertel J, Shultz SJ. Efficacy of the Star Excursion Balance Tests in Detecting Reach Deficits in Subjects With Chronic Ankle Instability. *J Athl Train*. 2002;37(4):501-506.

72. Plisky PJ, Rauh MJ, Kaminski TW, Underwood FB. Star excursion balance test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther*. 2006;36(12):911-919. doi:10.2519/jospt.2006.2244

73. Clark RC, Saxion CE, Cameron KL, Gerber JP. Associations between three clinical assessment tools for postural stability. *N Am J Sports Phys Ther*. 2010;5(3):122-130.

74. Hyong IH, Kim JH. Test of intrarater and interrater reliability for the star excursion balance test. *J Phys Ther Sci*. 2014;26(8):1139-1141. doi:10.1589/jpts.26.1139

75. Gribble PA, Kelly SE, Refshauge KM, Hiller CE. Interrater reliability of the star excursion balance test. *J Athl Train*. 2013;48(5):621-626. doi:10.4085/1062-6050-48.3.03

76. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med*. 2016;15(2):155-163. doi:10.1016/j.jcm.2016.02.012

77. de Vet HC, Terwee CB, Knol DL, Bouter LM. When to use agreement versus reliability measures. *J Clin Epidemiol*. 2006;59(10):1033-1039. doi:10.1016/j.jclinepi.2005.10.015

78. Stratford PW, Riddle DL. When minimal detectable change exceeds a diagnostic test-based threshold change value for an outcome measure: resolving the conflict. *Phys Ther*. 2012;92(10):1338-1347. doi:10.2522/ptj.20120002

79. Haley SM, Fragala-Pinkham MA. Interpreting change scores of tests and measures used in physical therapy. *Phys Ther*. 2006;86(5):735-743. doi:10.1093/ptj/86.5.735

80. Brydges CR. Effect Size Guidelines, Sample Size Calculations, and Statistical Power in Gerontology. *Innov Aging*. 2019;3(4):igz036. doi:10.1093/geroni/igz036

SUPPLEMENTARY MATERIALS

Appendix 1

Download: https://ijspt.scholasticahq.com/article/137953-the-reliability-and-validity-of-star-performer-a-computerized-tool-for-quantifying-the-star-excursion-balance-test/attachment/282670.docx