

ORIGINAL RESEARCH

THE RELIABILITY OF AN INSTRUMENTED DEVICE FOR MEASURING COMPONENTS OF THE STAR EXCURSION BALANCE TEST

Phillip J. Plisky, PT, DSc, OCS, ATC^a

Paul P. Gorman, PTA, ATC^a

Robert J. Butler, PhD^b

Kyle B. Kiesel, PT, PhD, ATC^b

Frank B. Underwood, PT, PhD, ECS^b

Bryant Elkins, DPT^a

ABSTRACT

Background. The Star Excursion Balance Test (SEBT) is a dynamic test that requires strength, flexibility, and proprioception and has been used to assess physical performance, identify chronic ankle instability, and identify athletes at greater risk for lower extremity injury. In order to improve the repeatability in measuring components of the SEBT, the Y Balance Test™ has been developed.

Objective. The purpose of this paper is to report the development and reliability of the Y Balance Test™.

Methods. Single limb stance excursion distances were measured using the Y Balance Test™ on a sample of 15 male collegiate soccer players. Intraclass Correlation Coefficients (ICC) were used to determine the reliability of the test.

Results. The ICC for intrarater reliability ranged from 0.85 to 0.91 and for interrater reliability ranged from 0.99 to 1.00. Composite reach score reliability was 0.91 for intrarater and 0.99 for interrater reliability.

Discussion. This study demonstrated that the Y Balance Test™ has good to excellent intrarater and interrater reliability. The device and protocol attempted to address the common sources of error and method variation in the

SEBT including whether touch down is allowed with the reach foot, where the stance foot is aligned, movement allowed of the stance foot, instantaneous measurement of furthest reach distance, standard reach height from the ground, standard testing order, and well defined pass/fail criteria.

Conclusion. The Y Balance Test™ is a reliable test for measuring single limb stance excursion distances while performing dynamic balance testing in collegiate soccer players.

Key Words: Y Balance Test, lower extremity, postural stability

CORRESPONDENCE

Phillip J. Plisky

Residency Program Director

ProRehab, PC

5011 Washington Ave, Suite 1

Evansville, IN 47715

e-mail: phil@prorehab-pc.com

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^a ProRehab, PC
Evansville, IN

^b University of Evansville
Evansville, IN

BACKGROUND

Unilateral balance and dynamic neuromuscular control are required for sport. Dysfunctional unilateral stance has been prospectively identified as a risk for injury in sport.^{1,6} Recent discussion in the literature has occurred regarding the importance of assessing dynamic neuromuscular control for injury prediction using body relative movement testing.⁷ The Star Excursion Balance Test (SEBT) is a dynamic test that requires strength, flexibility, and proprioception. The goal of the SEBT is to maintain single leg stance on one leg while reaching as far as possible with the contralateral leg.^{8,9} The SEBT has been used to measure physical performance, compare balance ability among different sports, and identify individuals who have chronic ankle instability.¹⁰⁻¹³ Recently, the test has been used to identify athletes at greater risk for lower extremity injury.¹ Researchers have suggested using the SEBT as a screening tool for sport participation and as a post-rehabilitation test to ensure dynamic functional symmetry.¹¹ Further, researchers have shown that SEBT performance improves after training.^{10,14}

The test originally incorporated reaching in eight directions while standing on each foot,⁹ but factor analysis indicated that one reach direction (posteromedial) was able to accurately identify individuals with chronic ankle instability as well as performing all eight directions.¹⁵ Further, Plisky et al¹ reported that the sum of three reach directions (anterior, posteromedial, and posterolateral), as well as asymmetry between legs in anterior reach distance, were predictive of lower extremity injury in high school basketball players. Hubbard et al¹² reported that the anterior and posteromedial reach directions identified persons with chronic ankle instability. In a second study, these same authors found that hip abduction strength was correlated with the posteromedial reach distance, and hip extension strength correlated with posterolateral reach distance on the SEBT.¹⁶

For clinical use and screening purposes, the test needs to capture the greatest amount of information in the shortest amount of time. Thus, the anterior, posteromedial, and posterolateral directions appear to be important to identify individuals with chronic ankle instability and those at greater risk of lower extremity injury.

The intrarater reliability of the SEBT has been reported as moderate to good (ICC 0.67- 0.97),^{8,11,17} and interrater reliability has been reported as poor to good (0.35-0.93).¹⁷

Because this balance test is dynamic, difficulty can occur in attempting to accurately assess the farthest reach point and what criteria constitutes a successful reach (e.g. how much movement of the stance foot is allowed or if the reach foot is allowed to touch down). Thus, there have been many protocols utilized for the test (*Table 1*) with the primary variations in protocol being whether the reach foot touches the floor. Touching down with the reach foot introduces error by making it difficult to quantify the amount of support gained from that touchdown. If touchdown is not allowed, standardizing the distance from the ground that the person reaches is difficult, as well as instantaneously marking the farthest reach point. In addition, it is difficult for examiners to determine how much movement of the stance foot is allowed. Precise determination of the heel or forefoot lift off from the surface is difficult due to the contours of the foot and the rapid position changes due to co-contraction of the lower limb muscles during unilateral stance.

Another disparity in SEBT protocols is where the stance foot is aligned to determine starting position. The starting point has been reported to be at the bisection of the lateral malleolus,¹⁸⁻²¹ most distal aspect of the toes,²² center of the foot,^{11,18,23-32} and varied according to reach direction.^{9,33}

The Y Balance Test™ (FunctionalMovement.com, Danville, VA) is an instrumented version of components of the SEBT developed to improve the repeatability of measurement and standardize performance of the test. The device utilizes the anterior, posteromedial, and posterolateral components of the SEBT. Therefore, a testing protocol was developed to address potential sources of error and to describe standard testing procedure so that results can be compared among studies as well as among clinicians. This device and protocol attempt to address the common sources of error and method variation including whether touchdown is allowed with the reach foot, where the stance foot is aligned, movement allowed of the stance foot, instantaneous measurement of furthest reach distance, standard reach height from the ground, standard testing order, and well defined pass/fail criteria.

METHODS

Subjects

Fifteen male collegiate soccer players (mean 19.7 ± 0.81 years) participated in the study. Subjects were excluded from participation in the study for lower extremity amputation; vestibular disorder; lack of medical clearance for

TABLE 1. Comparison of Methods Used in Previous Studies

Study	Sample Size	Reach Foot Touch Down	Stance Foot Alignment	Stance Foot Movement Allowed	Average or Greatest reach	Testing Directions*	Limb Length Measured	Attempts allowed / trials	Shoes on /off
Gray ⁹	NA†	No, within 3 inch of test vector	Varied to direction of reach	No	Greatest (unit of measure unspecified)	AL A AM M PM P PL L	No	Not specified	Pictured with shoes on
Kinzey and Armstrong ²⁴	20	No	Center box	No	Average of 3 greatest (cm)	AM, PM	No	5	Not controlled
Hertel et al ¹⁷	16	Yes	Center of grid	No	Avg of 1-3;4-6;7-9;10-12 trial (cm)	AL A AM M PM P PL L	No	1 practice followed by 3 trials	Pictured with shoes on
Earl and Hertel ²⁵	10	Yes	Varied to direction of reach	Not specified	With-in 1 mm of precision	A AM M Pm P PL L AL	No	6 practice / 5 trials/ last 3 marked	Pictured with shoes on
Olmsted et al ²⁵	40	Yes	Center of grid	No	Avg of 3 greatest (cm)	A AM M Pm P PL L AL	No	6 practices /then till 3 good reaches met	Pictured with shoes off
Gribble and Hertel ²⁶	30	Yes	Center of grid	No	Mean of 3 trials (cm)	A AM M Pm P PL L AL	Yes/ASIS to mid ipsilateral medial malleolus	6 practice / 3 trials	Pictured with shoes off
Gribble et al ²⁰	30	Yes	Center of grid	No	Mean of 3 trials (cm)	A, M, P	Yes/ASIS to mid medial malleolus bilateral	6 practice / 3 trials	Pictured with shoes off
Cote et al ³¹	48	Yes	Center of grid	No	Mean of 3 trials (cm)	A AM M Pm P PL L AL	No/ normalized to height	1 practice/3 trials	Not specified
Lanning et al ¹¹	105	No	Center of Box	No	Greatest (cm)	AM, PM	Yes / ASIS to mid medial malleolus bilateral	6 practice / 3 trials	With the shoes on
Plisky et al ²²	235	No	Center of grid with most distal aspect of great toe at start line	No	Greatest of 3 trials (cm), & sum of each direction greatest (composite)	A, PM, PL	Inferior aspect of ASIS to distal lateral malleolus, after clearing of the hips	6 practice / 3 trials	Great toe at line, pictured with shoes off
Hertel et al ²⁰	87	Yes	Geometric center of the foot on cross-hairs in center of grid	No	Mean of 3 trials (cm)	A AM M Pm P PL L AL	Yes/ ASIS to distal tip medial malleolus	6 practice / 3 trials	Geometric center of foot/ pictured with shoes off
Gribble et al ¹⁸	30	Yes	Foot bisected equally in all planes	No; Hands on iliac crests	Avg of 3 reaches (unit not specified)	A	Yes/ ASIS to distal medial malleolus	6 practice / 3 trials	Pictured shoes off
Sawkins et al ³³	30	Yes	Varied to direction of reach	No	Greatest	A, P, PM	Not specified	6 practice (prior to taping)/ 3 trials	Shoes off
Bressel et al ²¹	34	Yes	Middle of grid with center of foot on small dot	Cited "as Gribble" ²⁶	Avg of 3 trials(cm & mm used)	A AM M Pm P PL L AL	Yes/ ASIS to medial malleolus (nearest mm) Both lower extremities	180seconds of practice prior to testing, 3 trials	Not specified
Hubbard et al ¹²	60	Yes	Not specified	Not specified	Avg of 3 (cm)	A, PM, PL	Yes/ "Gribble" ²⁶	6 practice / 3 trials	Not specified
Hubbard et al ¹⁶	30	Yes	Not specified	Not specified	Avg of 3 (cm)	A, PM, PL	Yes/ "Gribble" ²⁶	6 practice / 3 trials	Not specified
Gribble et al ¹⁸	30	Yes	Middle of grid	No; Hands on hips	Mean of 3 trials (unit not specified)	A, M, P	Yes/ ASIS to distal med malleolus	6 practice / 3 trials	Not specified (kinematic markers placed)
English and Howe ³²	3	Methods cited as Kinzey et al ²⁴ , with touchdown	Center of box	Not specified	Mean of 3 trials (cm)	Reported as: Right anterior and posterior; Left anterior and posterior; (AM, PM)	Not specified	6 practice / 3 trials	Pictured with shoes on
Hale et al ¹⁰	67	Yes	Not specified	Not specified; hands on hips	Mean of 3 trials (unit not specified)	A AM M Pm P PL L AL	Not specified	6 practice / 3 trials	Not specified

*A= Anterior, AM= Anterior Medial, M= Medial, PM= Posterior Medial, P= Posterior, PL= Posterior Lateral, L= Lateral, AL= Anterior Lateral, ASIS= Anterior Superior Iliac Spine,
 † NA = Not Applicable

participation; injury; current or undergoing treatment for inner ear, sinus, upper respiratory infection, or head cold; or cerebral concussion within the previous three months. Prior to participation all subjects read and signed an informed consent form approved by the University of Evansville's Institutional Review Board.

Testing Device

The Y Balance Test Kit™ consists of a stance platform to which three pieces of PVC pipe are attached in the anterior, posteromedial, and posterolateral reach directions (Figure 1). The posterior pipes are positioned 135 degrees from the anterior pipe with 45 degrees between the posterior pipes. Each pipe is marked in 5 millimeter increments for measurement. The subject pushes a target (reach indicator) along the pipe which standardizes the reach height (i.e. how far off the ground the reach foot is), and the target remains over the tape measure after performance of the test, making the determination of reach distance more precise.

Y Balance Test™ Protocol

The subjects viewed an instructional video which demonstrated the test and testing procedure as explained by Plisky et al.¹ Hertel et al.¹⁷ found a significant learning effect with the SEBT where the longest reach distances occurred after six trials followed by a plateau. Therefore, the subjects practiced six trials on each leg in each of the three reach directions prior to formal testing. The subjects were tested within 20 minutes of practicing. All subjects wore athletic shoes during the performance of the test. The subject stood on one leg on the

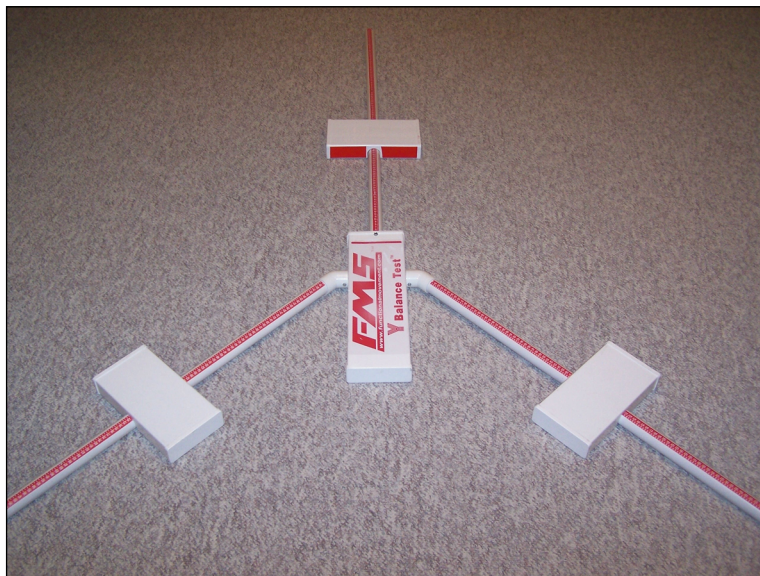


Figure 1. Y Balance Test Kit™

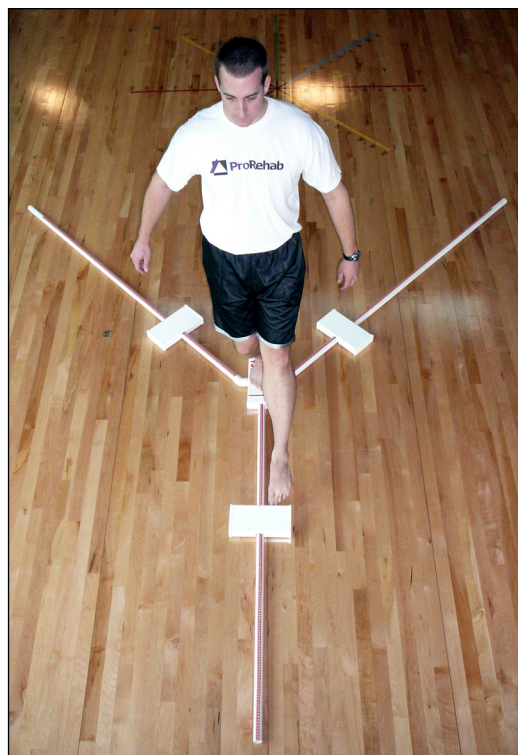


Figure 2. Anterior reach using the Y Balance Test Kit™

center foot plate with the most distal aspect of the athletic shoe at the starting line. While maintaining single leg stance, the subject was asked to reach with the free limb in the anterior (Figure 2), posteromedial (Figure 3), and posterolateral (Figure 4) directions in relation to the stance foot. In order to improve the reproducibility of the test and establish a consistent testing protocol, a standard testing order was developed and utilized. The testing order

was three trials standing on the right foot reaching in the anterior direction (right anterior reach) followed by three trials standing on the left foot reaching in the anterior direction. This procedure was repeated for the posteromedial and the posterolateral reach directions.

The subject was instructed by one rater (PPG) to stand on the platform with toes behind the line and to push the reach indicator in the red target area in the direction being test. These were the only instructions given to the subject during testing. All testing was observed and scored by two raters (inter-rater reliability) simultaneously that were blinded to each others scoring. Rater #1 was a physical therapist assistant and certified athletic trainer with with 10 years of experience,

and Rater #2 (BE) was a physical therapist with 7 years of experience. The raters independently determined if a successful trial was completed (i.e. that the foot was positioned correctly behind the line and that all of the criteria were met for a successful trial). To reduce bias, the rater recorded the reach distance regardless whether he thought the trial was successful. After three trials in one

reach direction, the raters were asked if they had a least one successful trial. If they did not, the subject was asked to perform an additional trial until a successful reach was completed. If the subject was unable to perform the test according to the above criteria in six attempts, the subject failed that direction.

The maximal reach distance was measured by reading the tape measure at the edge of the reach indicator, at the point where the most distal part of the foot reached. The trial was discarded and repeated if the subject: 1) failed to maintain unilateral stance on the platform (e.g. touched down to the floor with the reach foot or fell off the stance platform), 2) failed to maintain reach foot contact with the reach indicator on the target area while it was in motion (e.g. kicked the reach indicator), 3) used the reach indicator for stance support (e.g. placed foot on top of reach indicator), or 4) failed to return the reach foot to the starting position under control. The starting position for the reach foot is defined by the area immediately between the standing platform and the pipe opposite the stance foot. The process was repeated while standing on the other leg.

The specific testing order was right anterior, left anterior, right posteromedial, left posteromedial, right posterolateral, and left posterolateral. The greatest successful reach for each direction for each rater was used for analysis of the reach distance in each direction. Also, the greatest reach distance from each direction was summed to yield a composite reach distance for analysis of overall performance on the test. The testing procedure was repeated approximately 20 minutes later using a single rater (PPG) and

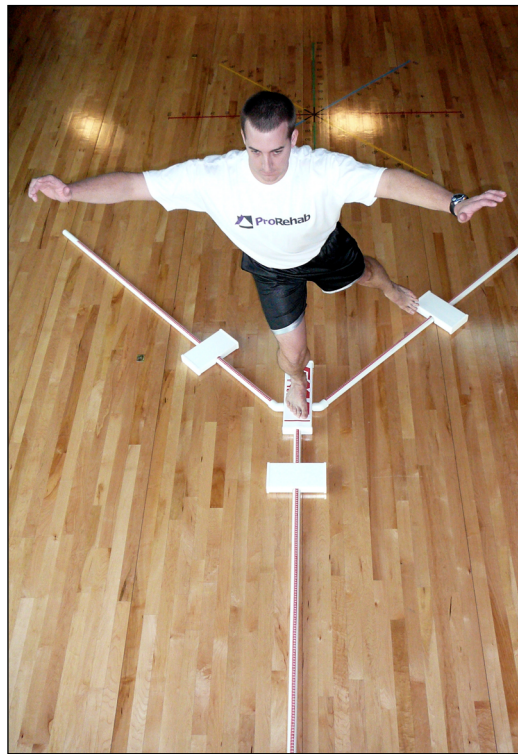


Figure 3. Posteromedial reach using the Y Balance Test Kit™

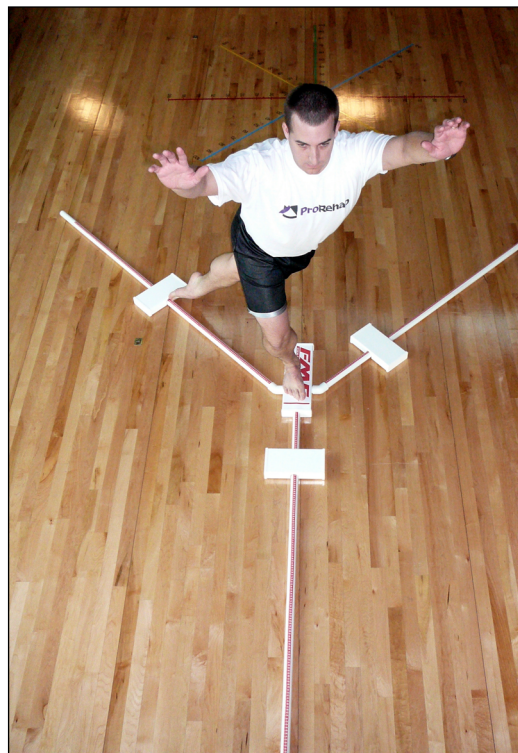


Figure 4. Posterolateral reach using the Y Balance Test Kit™

measuring the same subjects right stance limb (to measure intra-rater reliability).

Lower Limb Length

On a mat table with the subject supine, the subject lifted the hips off the table and returned them to starting position. Then, the examiner passively straightened the legs to equalize the pelvis. The subject's right limb length was then measured in centimeters from the anterior superior iliac spine to the most distal portion of the medial malleolus with a cloth tape measure.

Data Analysis

The data were analyzed for each subject for the right limb in the anterior, posterolateral, and posteromedial reach directions. Means and standard deviations were calculated for the reach distance in each direction and limb length. Paired sample t-test was used to determine if there was a difference between the performance of the right and left limb. Since reach distance is related to limb length, reach distance was normalized to limb length to allow future comparison among studies. To express reach distance as a percentage of limb length, the normalized value was calculated as reach distance divided by limb length then multiplied by 100.²² Composite reach distance was the sum of the three reach directions divided by three times limb length, and then multiplied by 100.²² An ICC (3,1) was used to evaluate intrarater reliability and ICC (2,1) was used to evaluate interrater reliability for each of the normalized reach distances.

RESULTS

Mean, standard deviation, median, and range of the average performance of the two limbs are reported in Table 2. Intrarater reliability for the

one tester ranged from 0.85 to 0.91 with anterior reach 0.91, posteromedial of 0.85, and posterolateral 0.90, and composite 0.91 (Table 3). Inter-rater reliability between the two testers ranged from 0.99 to 1.0 with anterior 1.0, posteromedial 0.99, posterolateral 0.99, and composite reach 0.99 (Table 4).

DISCUSSION

The intrarater reliability of the SEBT has been reported as moderate to good (ICC 0.67-0.97),^{8,11,17} and interrater reliability has been reported as poor to good (0.35-0.93).¹⁷ The variability in the ranges of previously reported reliability of the SEBT suggests the need to improve the accuracy of the testing methods and importance of a standardized testing protocol. The interrater reliability improved over the traditional SEBT testing methods when using the Y Balance Test™. Because the interrater reliability exceeds the intrarater reliability, the variability in subject performance on the test likely exceeds the variability in the measurement recorded by different raters (i.e. the precision in the device is greater than the precision in subject performance). This occurrence can be attributed to a more standardized scoring criteria and a more precise measurement device that also standardizes performance. Further, a standard testing order (i.e. right anterior, left anterior, right posteromedial, left posteromedial, right posterolateral, left posterolateral) allows for consistent performance of the test and attempts to minimize

TABLE 2. Results of Y Balance Test

	Mean reach in cm* (Standard Deviation)	Median Reach in cm* (range)	Normalized Mean†Reach (Standard Deviation)
Rater 1			
Anterior	71.5 (6.9)	70.8 (60.8 – 81.0)	76.7 (4.4)
Posteromedial	114.0 (7.1)	111.0 (100.8 -125.8)	122.5 (4.3)
Posterolateral	110.2 (7.2)	108.5 (101.3-120.8)	118.5 (5.0)
Composite	295.1 (19.8)	284.0 (268.5 – 328.5)	105.7 (3.4)
Rater 2			
Anterior	71.7 (7.1)	70.8 (60.8-81.5)	76.9 (4.4)
Posteromedial	114.0 (7.1)	111.0 (100.8 -125.8)	122.5 (4.3)
Posterolateral	110.3 (7.2)	108.8 (101.3-121.8)	118.5 (4.9)
Composite	296.7 (20.3)	288.3 (267.5 – 332.8)	106.2 (3.8)
Repeated Measurement			
Anterior	72.9 (5.8)	72.0 (66.0-83.5)	78.3 (3.9)
Posteromedial	114.9 (7.3)	114.0 (105.0 – 129.5)	123.5 (5.0)
Posterolateral	112.3 (6.5)	112.0 (102.5 -126.5)	120.8 (5.3)
Composite	300.1 (17.7)	289 (278.0 - 332.5)	107.5 (3.5)

* = centimeters

† = normalized to limb length expressed as a percentage

fatigue by alternating stance limbs.

The Y Balance Test™ was developed to address some of the limitations of the traditional SEBT testing methods. A reach indicator, standard reach height from the ground, well defined pass/fail criteria, and the ability of the reach indicator to remain over the tape measure after performance improve the reproducibility of the reach measurement. These features also allow the rater to focus more

attention on observing the subject, and, therefore, better assess the subject's movement quality (Table 5). If examiners focused on monitoring stance foot movement, it was nearly impossible to simultaneously mark reach distance. In addition, during the development of the testing protocol for the device, it was difficult for examiners to determine how much movement of the stance foot was allowed in a successful trial (i.e. it was difficult to determine if/when the heel or forefoot actually lifted from the surface). Thus, the athlete was allowed to lift the heel off the ground to improve repeatability and standardize the testing procedures so that results can be

compared among studies as long as the toe remained aligned with the start stripe at the front of the stance platform.

Some limitations to this study should be noted. Error could have been introduced by fatigue,³⁰ practice effect,¹⁷ and re-measurement on the same day of initial testing. Future studies should be conducted with shoes off as many athletes attend

TABLE 3: Intrarater reliability (one rater) for the right stance limb for the Y Balance Test™

	ICC* (3,1)	95% CI†	SEM (cm)‡
Anterior	0.88	0.69-0.96	2.01
Posteromedial	0.85	0.62-0.95	2.83
Posterolateral	0.86	0.64-0.95	3.11
Composite	0.89	0.69-0.96	5.84

* Intraclass correlation coefficient

† 95% confidence interval

TABLE 4: Interrater reliability for the Y Balance Test™

		ICC* (2,1)	95% CI†	SEM (cm)‡
Anterior	Left	1.0	0.99-1.0	0.69
	Right	0.99	0.97-0.99	0.71
Posteromedial	Left	1.0	0.99-1.0	0.68
	Right	1.0	0.99-1.0	0.78
Posterolateral	Left	0.99	0.99-1.0	0.73
	Right	1.0	0.99-1.0	0.85
Composite	Left	0.97	0.92-0.99	3.31
	Right	0.99	0.96-0.99	2.08

* Intraclass correlation coefficient

† 95% confidence interval

TABLE 5. Recommendations for standardized protocol with the provided rationale for the recommendation.

Recommendation	Rationale
Shoes off	Individuals attend testing in a variety of footwear so it is difficult to standardize.
Six practice trials	Learning effect.
Video instruction	Increases efficiency of testing protocol and standardizes instruction.
Standard testing order	Minimize fatigue by alternating stance limbs. Improves consistency in administration of test.
Stance foot aligned at most distal aspect of toes	Keeps starting point in a uniform and reproducible position to which the reach foot can be referenced.
Stance foot movement is allowed	Difficult to reliably determine if heel/forefoot is lifted from the surface.
Body movement allowed under control	Difficult to standardize amount of movement allowed.
Normalized to limb length	Normalization standardizes measurement to each individual.
Standard reach height	Allows reach height to be uniform.

pre-participation physicals and rehabilitation sessions with a large variety of footwear, often not appropriate for sport. Future studies should utilize a similar, standardized testing protocol so that results may be compared across studies. In addition, only one limb (right) was measured twice by the first rater.

A need exists to collect normative data using the Y Balance Test™ on varied populations (e.g. collegiate, high school, basketball, hockey, elderly, firefighters, etc). With normative data and prospective studies, the Y Balance Test™ could be evaluated for prediction of injury in different populations and establish acceptable reach distances for each population.

CONCLUSION

The Y Balance Test™ has shown good to excellent reliability with the standardized equipment and methods. By establishing the reliability of the Y Balance Test™, sports medicine clinicians can better determine deficits and asymmetries in individuals, as well as assist in the return to play decision-making process.

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