Y-Balance Test: A Reliability Study Involving Multiple Raters

LTC Scott W. Shaffer, SP USA; LTC Deydre S. Teyhen, SP USA†; CPT Chelsea L. Lorenson, SP USA*; CPT Rick L. Warren, SP USA*; CPT Christina M. Koreerat, SP USA*; CPT Crystal A. Straseske, SP USA*; Lt Col John D. Childs, USAF BSC**

ABSTRACT The Y-balance test (YBT) is one of the few field expedient tests that have shown predictive validity for injury risk in an athletic population. However, analysis of the YBT in a heterogeneous population of active adults (e.g., military, specific occupations) involving multiple raters with limited experience in a mass screening setting is lacking. The primary purpose of this study was to determine interrater test–retest reliability of the YBT in a military setting using multiple raters. Sixty-four service members (53 males, 11 females) actively conducting military training volunteered to participate. Interrater test–retest reliability of the maximal reach had intraclass correlation coefficients (2,1) of 0.80 to 0.85 with a standard error of measurement ranging from 3.1 to 4.2 cm for the 3 reach directions (anterior, posteromedial, and posterolateral). Interrater test–retest reliability of the average reach of 3 trails had an intraclass correlation coefficients (2,3) range of 0.85 to 0.93 with an associated standard error of measurement ranging from 2.0 to 3.5cm. The YBT showed good interrater test–retest reliability with an acceptable level of measurement error among multiple raters screening active duty service members. In addition, 31.3% (*n* = 20 of 64) of participants exhibited an anterior reach asymmetry of >4cm, suggesting impaired balance symmetry and potentially increased risk for injury.

INTRODUCTION

Traumatic and overuse lower extremity injuries are common and unfortunately injury prediction is complex and multifactorial.[1–5] More than 10,000 Americans seek medical treatment for sports-, recreational-, and exercise-related injuries on a daily basis.[6] Researchers have estimated that 50% to 80% of injuries are overuse in nature and involve the lower extremity.[1,5,7] Overuse lower extremity injuries have a specific impact on U.S. military readiness, accounting for an estimated 3.8 million injury-related limited duty days in 2004.[8] The impact of lower extremity injuries in the military emphasizes the need for efficient and effective neuromusculoskeletal screening. Unfortunately, reliable and field-expedient injury screening tools used to screen large populations (athletes, military, and occupation specialties) in an efficient manner with multiple examiners are limited.[9]

Impaired balance is one of the several risk factors that have been associated with increased risk of lower extremity injuries.[10–12] Research suggests deficits in static and dynamic balance discern between individuals with a history of ankle sprains, chronic ankle instability, anterior cruciate ligament (ACL) deficiency, and anterior knee pain.[13–17] In addition, exercise programs focused on balance training have also been associated with reduced injuries,[18,19] and increased neuromuscular power and motor control during vertical jumps and single-legged drop landings.[20–23] Screening balance impairments seems warranted based on its potential to predict and prevent musculoskeletal conditions of the lower extremity. Unfortunately, time-efficient, field-expedient, and reliable measures of balance with exhibited discriminant and predictive validity for lower extremity injury are limited.[10]

The Star Excursion Balance Test (SEBT) requires minimal equipment and can be implemented in "multiple settings and diverse populations (e.g., athletic preseason screening, occupational participation screening, and military physical training sessions)." The SEBT measures the ability to maintain single-leg stance on one leg while the contralateral leg reaches as far as possible in 8 directions. The SEBT has exhibited discriminant validity for identifying individuals with chronic ankle[14,24–26] and ACL instability.[17] In particular, Hubbard et al[24] reported impaired anterior and posteromedial reach in individuals with chronic ankle instability and Herrington et al[17] found significant differences in anterior, posteromedial, medial, and lateral reach in patients with ACL-deficient knees as compared to age-matched controls. Previous research using factor analysis also suggests shared variance and redundancy occur between the eight reach directions of SEBT in healthy controls and individuals with chronic ankle instability.[25]

The Y-balance test (YBT) has built on previous research suggesting redundancy in the 8 directions of the SEBT to develop a more time-efficient test that evaluates dynamic limits of stability and asymmetrical balance in only three directions (anterior, posteromedial, and posterolateral).[27–29] Initial evidence on the YBT for injury prediction is encouraging. Specifically, Plisky et al[10] identified that individuals with anterior left/right asymmetries greater than 4 cm on the

*U.S. Army-Baylor University Doctoral Program in Physical Therapy, ATTN: MCCS-HGP, 3599 Winfield Scott Road, Suite 1301, Fort Sam Houston, TX 78234-6138.

†Telemedicine and Advanced Technology Research Center, U.S. Army Medical Research and Material Command, ATTN: MCMR-TT, Building 1054 Patchel Street, Fort Detrick, MD 21702.

This work was presented as a poster at the 2011 American Physical Therapy Association, Combined Sections Meeting, New Orleans, LA, February 2011.

doi: 10.7205/MILMED-D-13-00222

YBT were 2.5 times more likely to sustain a lower extremity injury. The YBT and SEBT have also exhibited acceptable intrarater reliability among two raters intraclass correlation coefficients (ICC, 0.67–0.96), but a wide range of interrater reliability with point estimate ICC values ranging from 0.35 to 1.[30] In addition, previous reliability assessment specific to the YBT was established with only two raters with a minimum of at least 7 years of clinical experience.[29] Traditionally, mass screenings of athletes or service members require a larger number of examiners and the examiners available for such screenings may vary day to day.

Effective and efficient injury screening requires measurement tools that show reliability in a larger population screening setting using multiple raters with limited experience. Therefore, the primary purpose of this study was to assess the interrater test–retest reliability of the YBT among a group of raters with limited health care or injury screening experience. In addition, previous YBT reliability research has used the maximum reach distance over 3 trials.[29] Considering that maximum performance may significantly vary between raters and ultimately influence reliability, our secondary purpose was to assess both maximal and mean YBT performance. Limited information on YBT performance in service members also exists. Therefore, the final purpose of this study was to describe YBT performance and to determine the proportion of service members with a YBT anterior reach limb asymmetry (>4cm difference) based on its association with increased injury risk.[10]

METHODS

The YBT was one of 15 counterbalanced measures collected as part of a lower extremity injury prevention screening examination conducted at Fort Sam Houston, TX.[9,31] Testing was completed in a group setting with multiple raters and participants were tested on separate days by independent examiners to assess both the influence of different raters and time. Participants were also given 24 to 48 hours between measures to reduce the influence of fatigue from multiple station testing. All testing was performed in the morning between 6:00 a.m. and 10:00 a.m. This time was selected based on traditional physical training hours for military personnel.

Participants

The convenience sample included participants that were recruited over an 8-week period from service members attending various initial training at Fort Sam Houston, TX. Potential participants were provided an overview of the research study, and specific details of the entrance criteria was discussed before consenting. Every potential participant completed an injury screening form to review inclusion and exclusion criteria. Participants were eligible for inclusion if they were between the ages of 18 and 35 years or emancipated minors, fluent in English, had no current complaint of lower extremity or spine pain, or medical or neuromusculoskeletal disorders that limited participation in work or exercise in the last 6 months. Participants were excluded if they were currently seeking medical care for lower extremity injuries or had previous medical history that included any surgery for lower extremity injuries. Participants were also excluded if they were unable to participate in physical training because of other musculoskeletal injuries, had a history of a pelvic or lower extremity fracture, or were pregnant. All participants who agreed to participate and met inclusion criteria signed an informed consent form approved by Brooke Army Medical Center's Institutional Review Board and returned 48 hours later for data collection.

Raters

The raters in this study consisted of 7 entry-level doctoral physical therapy students. Before testing, all raters underwent training that consisted of approximately 10 hours of hands-on training with the equipment and technique of the 15 tests led by 4 physical therapy faculties and a research assistant. To minimize bias, the participants were randomly assigned to one of 3 raters on day 1 and one of 4 raters on day 2 (24–48 hours later). All participants were assessed by a different randomly assigned rater on day 2 who were blinded to day 1 results. The goal of having random sets of raters blinded to previous results for each assessment was to increase the variability in the study design and to more closely mimic field conditions in the military and athletic mass screening settings. There were no significant difference between raters; therefore, data was aggregated for analysis.

Measurements

The YBT consists of a three-part test that is used to assess lower extremity balance and neuromuscular control to predict lower extremity injury.[30] Each participant viewed a YBT instructional video and performed 6 practice trials to minimize the influence of a learning effect.[32] After the instructional video, participants stood on the center footplate, with the distal aspect of the right foot at the starting line (Fig. 1). While maintaining single leg stance on the right leg, the subject reached with the free limb (left leg) in the anterior (Fig. 2), posteromedial (Fig. 3), and posterolateral (Fig. 4) directions in relation to the stance foot by pushing the indicator box as far as possible. Participants completed 3 consecutive trials for each reach direction and to reduce fatigue subjects altered limbs between each direction. Specifically, testing order was completed as right anterior, left anterior, right posteromedial, left posteromedial, right posterolateral, and left posterolateral. Attempts were discarded and repeated if the subject failed to maintain unilateral stance on the platform, failed to maintain reach foot contact with the reach indicator on the target area while the reach indicator is in motion, used the reach indicator for stance support, or failed to return the reach foot to the starting position under control.

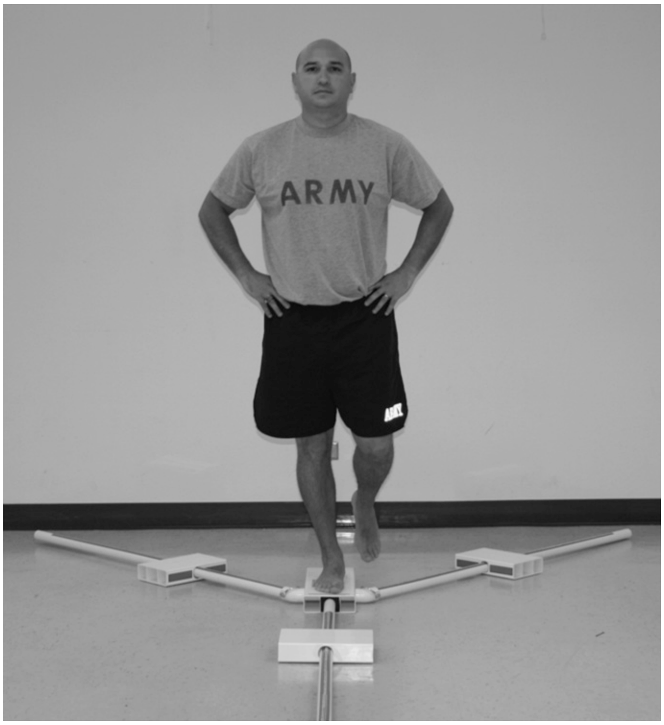

FIGURE 1. Starting position Y-balance test.

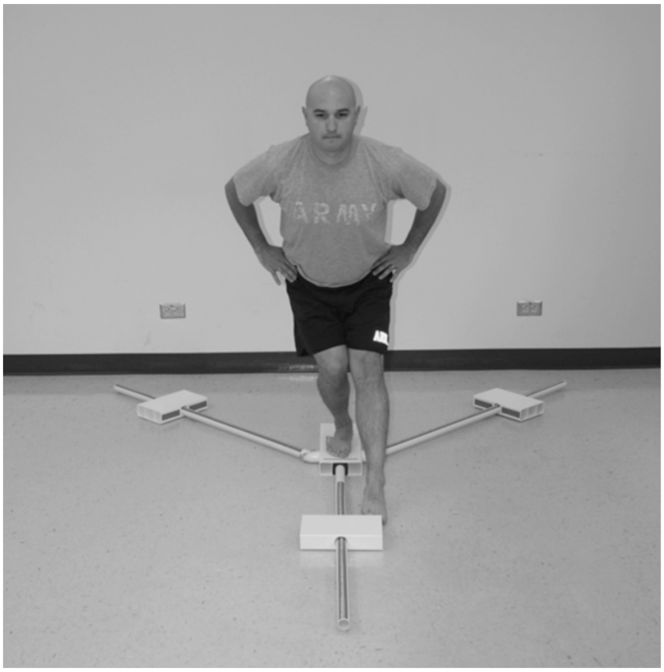

FIGURE 2. Anterior reach Y-balance test.

Participants were allowed a maximum of 6 trials to obtain 3 successful trials for each reach direction.[29,32]

The maximal and average distance reached after 3 successful trials in each direction were recorded at baseline by the rater and approximately 48 hours later by the second randomly

FIGURE 3. Posteromedial reach Y-balance test.

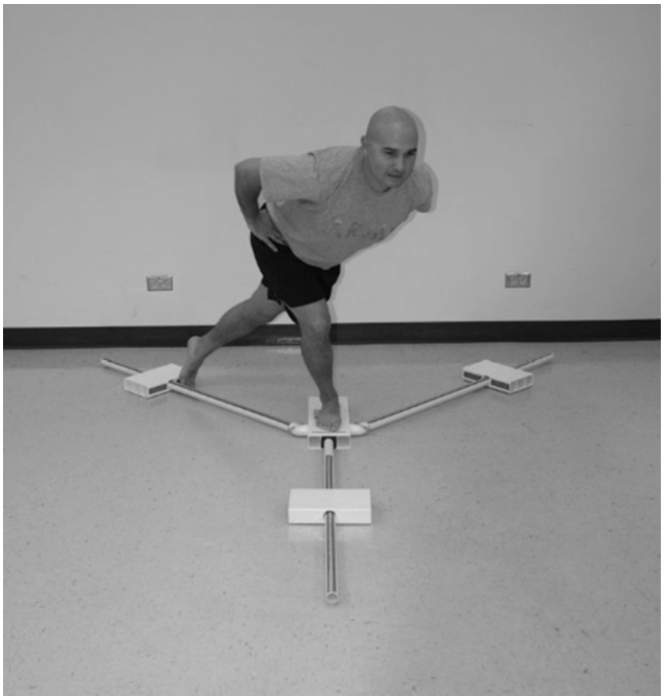

FIGURE 4. Posterolateral reach Y-balance test.

assigned rater. In addition, reach distance was recorded to the nearest 0.5 cm. Subject's lower limb reach was also normalized to leg length, which was measured from the anterior superior iliac spine to the most distal portion of the medial malleolus.

Data Analysis

Maximal and average reach over 3 trials were analyzed for both limbs in the anterior, posteromedial, and posterolateral reach directions. Reach distances were calculated as both absolute reach values and reach values normalized to limb length to allow comparisons across subjects and to previous publications. 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%. Composite reach distance was the sum of the 3 reach directions divided by 3 times limb length, and then multiplied by 100%. Descriptive statistics (means, standard deviations, 95% confidence intervals) were calculated for composite reach distance and each reach distance for both limbs. Paired t tests were used to determine if there was a significant ($p < 0.05$) difference between the performance of the right and left limb. In addition, asymmetry between reach distances and the number of individuals with anterior asymmetry >4cm was calculated.

Reliability of the maximal reach and average of 3 reach trials was analyzed using ICC. The maximal reach was analyzed using the ICC (2,1) model and the average of 3 trials was analyzed using the ICC (2,3) model. Good reliability was defined as 0.75 or higher, moderate as 0.50 to 0.74, and poor as less than 0.49.[33] Response stability and precision were analyzed by calculating standard error of measurement (SEM) and minimal detectable change (MDC) values at the 95% confidence level. SPSS for Windows, version 16.0 (SPSS, Chicago, IL) statistical software was used to analyze the data.

RESULTS

A total of 64 participants (53 males, 11 females) were enrolled and completed this study (Table I). No participants were excluded from this analysis. There was no significant reach difference between limbs and days ($p > 0.05$); therefore, outside of the descriptive data (Table II), all reach distances unless otherwise stated are in reference to day 1 data of the right lower extremity. On average, service members showed a 57.6 ± 7.1 cm anterior reach, 92.5 ± 9.0 cm posteromedial reach, and 89.1 ± 9.4 cm posterolateral reach. These absolute reach values corresponded to normalized reach values of 63.5%, 102%, and 98.2% of limb length in the anterior, posteromedial, and posterolateral reach directions, respectively. The descriptive statistics of the maximal reach and average reach of 3 trials of both limbs are reported in Table II. Although there was no significant group mean difference in reach distances between limbs ($p > 0.05$), 31.3% (n = 20 of 64) of the subjects had an anterior reach asymmetry of greater than 4 cm suggesting balance asymmetry and potentially increased risk for injury based on a previously published risk index.[10]

TABLE I. Demographics

Type	Mean ± SD	95%CI
Age (years)	25.2 ± 3.8	24.3–26.2
Height (cm)	175.5 ± 9.6	173.1–177.9
Weight (kg)	77.5 ± 12.5	74.4–80.7
Body Mass Index (kg/m^2)	25.1 ± 3.1	24.3–25.9
Limb Length (cm)	92.2 ± 5.9	90.8–93.7

SD, standard deviation; CI, confidence interval.

Interrater test–retest reliability for the maximal reach had good ICC (2,1) values that ranged from 0.80 to 0.85 with an associated SEM ranging from 3.1 to 4.2 cm and MDC values ranging from 8.7 to 11.5 cm for the 3 reach directions. Interrater reliability for the average of 3 reaches in each direction also showed good reliability (ICC (2, 3) values = 0.85–0.93) and measurement error (SEM = 2.0–3.5 cm and MDC values = 5.5–9.7 cm) for the 3 reach directions (Table III).

DISCUSSION

Our results in actively training service members provides initial evidence to suggest that the YBT is reliably obtained in a mass screening setting by multiple raters across a 48-hour period. Findings also build on past literature suggesting that the SEBT and specifically YBT are reliable measures of postural control in active younger adults.[30] Hertel et al[28] showed poor to good day 1 interrater reliability and good day 2 interrater reliability (ICC = 0.81–0.93) when using two experienced raters conducting independent assessments. Authors did not use practice trials and concluded that limited day 1 interrater reliability was likely the result of a significant learning effect seen between the first 6 trials measured. Plisky et al,[29] using 6 practice trials, reported almost perfect (0.97–1.00) interrater reliability; however, the raters in the Plisky study were observing the same trials. Interestingly, our interrater test–retest reliability that was conducted by multiple pairs of independent raters and on separate days closely matched the test–retest (one rater taking repeat measurements 20 minutes apart on the same day) ICC values obtained by Plisky et al.[29] In particular, our ICC values for specific maximal and mean reach distances ranged from 0.80 to 0.93 with SEMs from 2.0 to 4.2 cm. The test–retest reliability for the study of Plisky ranged from 0.85 to 0.88 with SEMs from 2.0 to 3.1 cm. Although direct comparison of results is limited secondary to different testing days, number, and experience of raters, our findings reinforce previous YBT reliability research and provide initial evidence that suggests the YBT has acceptable reliability and measurement stability between multiple raters with limited experience.

The interrater test–retest design we employed using multiple raters mimicked real-world preseason or predeployment screenings. In particular, our examiners were required to each independently instruct and score the YBT performance. An additional potential confounding variable was time as rater's assessments were conducted 48 hours apart. Despite these potential sources of error, reliability between multiple raters and multiple days was maintained in a sample of 64 active duty service members.

TABLE II. Y-Balance Test Descriptive Statistics

Type	Direction	Lower Extremity	Absolute Reach (cm) Mean ± SD[a] (95% CI)	Normalized Reach (%) Mean ± SD[a,b] (95% CI)
Maximal Reach	Anterior	Left	60.0 ± 7.4 (58.2,61.8)	66.0 ± 7.8 (64.2,68.0)
		Right	59.8 ± 7.1 (58.1,61.5)	65.8 ± 7.6 (64.0,67.7)
	Posteromedial	Left	95.7 ± 8.3 (93.7,97.7)	105.3 ± 8.3 (103.4,107.3)
		Right	95.0 ± 8.7 (92.9,97.1)	104.6 ± 8.9 (102.5,106.7)
	Posterolateral	Left	91.3 ± 8.5 (89.2,93.3)	100.5 ± 9.1 (98.4,102.7)
		Right	92.1 ± 9.4 (89.8,94.3)	101.4 ± 9.6 (99.1,103.7)
	Composite	Left	246.9 ± 21.8 (241.7,252.2)	90.6 ± 7.5 (88.8,92.4)
		Right	246.8 ± 23.0 (241.3,252.4)	90.6 ± 7.9 (88.7,92.5)
Average Reach of 3 Trials	Anterior	Left	57.8 ± 6.8 (56.1,59.4)	63.6 ± 7.2 (61.9,65.3)
		Right	57.6 ± 7.1 (55.9,59.3)	63.5 ± 7.7 (61.6,65.3)
	Posteromedial	Left	93.2 ± 8.5 (91.2,95.3)	102.7 ± 8.6 (100.6,104.8)
		Right	92.5 ± 9.0 (90.4,94.8)	102.0 ± 9.4 (99.7,104.2)
	Posterolateral	Left	88.3 ± 8.5 (86.2,90.3)	97.2 ± 9.4 (95.0,99.5)
		Right	89.1 ± 9.4 (86.9,91.4)	98.2 ± 10.0 (95.8,100.6)
	Composite	Left	239.3 ± 21.5 (234.1,244.4)	87.8 ± 7.6 (86.0,89.7)
		Right	239.4 ± 23.5 (233.7,245.0)	87.9 ± 8.3 (85.9,89.9)

CI, confidence interval; SD, standard deviation. [a]Values represent mean ± standard deviation (95% confidence interval). [b]Normalized reach was calculated as reach distance/limb length(anterior superior iliac spine to medial malleolus) × 100.

In contrast to previous YBT literature,[10,29] our study investigated both maximal and mean performance and its influence on reliability. Interrater test–retest reliability was good for both maximal and mean YBT reach distance, with the average of 3 reaches having superior ICC, SEM, and MDC values. In particular, the use of mean versus maximum values resulted in approximately a 1 cm decrease in individual SEM reach differences and a 2 cm decrease in composite reach distance. The use of 3 trials to obtain a mean reach distance value has also been reported by other studies.[25,32,34] In addition to both maximal and mean YBT scores in our study showing good reliability, measurement stability was improved when averaging 3 trials. Considering that 6 practice trials and 3 test trials are recommended to reduce a learning effect on the YBT,[30,35] practitioners and researchers should continue to evaluate the potential utilization and validity of both maximal and mean YBT performance.

YBT-normalized anterior reach performance for military members in our sample was less than those identified in a sample of college-age students (mean ± SD = 80 + 11%) and high school athletes (mean + SD = 83 ± 7.1%).[10,25] Potential explanation for these findings includes the fact that our subjects were slightly older (mean age = 25.2 years), and although actively running and performing push-ups and sit-ups, our subjects were not required to take part in sporting or recreational activities.

The final purpose of our study was to identify the percentage of U.S. service members with anterior reach limb asymmetries. Similar to Plisky et al[10] who examined 245 individuals and found 31.9% with anterior limb asymmetries, our study revealed 31.3% of military service members with greater than a 4-cm difference in anterior limb reach distance. Although specific injury-predictive cut scores have not been identified in a military population, these findings do reinforce that almost one-third of our sample had asymmetric dynamic balance in the anterior sagittal plane. Whether these balance asymmetries in actively training service members lead to injuries has yet to be determined.

Some limitations to our study do exist. First, our study was limited to actively training service members involved in initial entry training, thus potentially limiting the external validity and generalization of our findings to all military

TABLE III. Y-Balance Test Interrater Reliability

Type	Direction	ICC (95%CI)	SEM (cm)	MDC (cm)
Maximal Reach ICC (2,1)	Anterior	0.82 (0.72,0.89)	3.1	8.7
	Posteromedial	0.81 (0.71,0.88)	3.7	10.3
	Posterolateral	0.80 (0.68,0.87)	4.2	11.5
	Composite	0.85 (0.76,0.91)	9.0	24.8
Average Reach of 3 Trials ICC (2,3)	Anterior	0.93 (0.88,0.96)	2.0	5.5
	Posteromedial	0.91 (0.85,0.94)	2.7	7.5
	Posterolateral	0.85 (0.75,0.91)	3.5	9.7
	Composite	0.91 (0.85,0.95)	7.0	19.5

CI, confidence interval; ICC, intraclass correlation coefficient; SEM, standard error of the measurement; MDC, minimal detectable difference (95%).

populations (e.g., Rangers, Seals, Special Forces). Second, subjects in our sample were screened with medical questionnaires and all participants had to fully squat and hop on one limb without pain before inclusion. Conducting the YBT in populations that have not undergone additional medical screening may ultimately result in increased abnormal YBT asymmetries.

Future research examining the YBT in the general population when used in mass screenings, as well as in different military and athletic populations, may enhance the external validity of the YBT. Additional study involving the predictive validity of the YBT to determine future injuries is also needed. Finally, research that establishes the responsiveness and influence of treatment techniques on YBT performance in military-specific populations appears warranted.

CONCLUSIONS

Among multiple raters with limited health care experience, the YBT showed good interrater test–retest reliability and minimal levels of measurement error. The YBT had good interrater test–retest reliability for both the maximal and average of 3 reaches. The measurement error was minimized and interrater test–retest reliability improved when the mean of 3 reach trials was used. Although, our participants underwent screening before participation, 31.3% of military members exhibited greater than a 4-cm asymmetry on the anterior reach YBT. Additional research in various military and athletic populations examining the predictive validity, responsiveness, and the influence that training has on YBT scores is needed.

ACKNOWLEDGMENTS

This study was done in collaboration with research assistants from the University of Texas Health Science Center and U.S. Army-Baylor University, Departments of Physical Therapy. The authors also want to thank Jennifer Prye for her assistance with manuscript preparation.

REFERENCES

1. Almeida SA, Williams KM, Shaffer RA, Brodine SK: Epidemiological patterns of musculoskeletal injuries and physical training. Med Sci Sports Exerc 1999; 31: 1176–82.
2. Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD: A retrospective case-control analysis of 2002 running injuries. Br J Sports Med 2002; 36: 95–101.
3. Knapik JJ, Bullock SH, Canada S, et al: Influence of an injury reduction program on injury and fitness outcomes among soldiers. Inj Prev 2004; 10: 37–42.
4. Knapik JJ, Sharp MA, Canham-Chervak M, Hauret K, Patton JF, Jones BH: Risk factors for training-related injuries among men and women in basic combat training. Med Sci Sports Exerc 2001; 33: 946–54.
5. Jones BH, Cowan DN, Tomlinson JP, Robinson JR, Polly DW, Frykman PN: Epidemiology of injuries associated with physical training among young men in the army. Med Sci Sports Exerc 1993; 25: 197–203.
6. National Center for Injury Prevention and Control, Centers for Disease Control and Prevention. CDC Injury Research Agenda. Atlanta, GA, U.S. Department of Health and Human Services, 2002.
7. van Mechelen W: Running injuries. A review of the epidemiological literature. Sports Med 1992; 14: 320–35.
8. Ruscio BA, Jones BH, Bullock SH, et al: A process to identify military injury prevention priorities based on injury type and limited duty days. Am J Prev Med 2010; 38: S19–S33.
9. Teyhen DS, Shaffer SW, Lorenson CL, et al: The Functional Movement Screen: a reliability study. J Orthop Sports Phys Ther 2012; 42: 530–40.
10. 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: 911–9.
11. Vrbanic TS, Ravlic-Gulan J, Gulan G, Matovinovic D: Balance index score as a predictive factor for lower sports results or anterior cruciate ligament knee injuries in Croatian female athletes: preliminary study. Coll Antropol 2007; 31: 253–8.
12. Trojian TH, McKeag DB: Single leg balance test to identify risk of ankle sprains. Br J Sports Med 2006; 40: 610–13.
13. Aminaka N, Gribble PA: Patellar taping, patellofemoral pain syndrome, lower extremity kinematics, and dynamic postural control. J Athl Train 2008; 43: 21–8.
14. Akabari M, Karimi H, Farahini H, Faghihzadeh S: Balance problems after unilateral lateral ankle sprains. J Rehabil Res Dev 2006; 43: 819–24.
15. Gribble PA, Hertel J, Denegar CR, Buckley WE: The effects of fatigue and chronic ankle instability on dynamic postural control. J Athl Train 2004; 39: 321–9.
16. Gribble PA, Hertel J, Denegar CR: Chronic ankle instability and fatigue create proximal joint alterations during performance of the Star Excursion Balance Test. Int J Sports Med 2007; 28: 236–42.
17. Herrington L, Hatcher J, Hatcher A, McNicholas M: A comparison of Star Excursion Balance Test reach distances between ACL deficient patients and asymptomatic controls. Knee 2009; 16: 149–52.
18. Emery CA, Rose MS, McAllister JR, Meeuwisse WH: A prevention strategy to reduce the incidence of injury in high school basketball: a cluster randomized controlled trial. Clin J Sport Med 2007; 17: 17–24.
19. McGuine TA, Keene JS: The effect of a balance training program on the risk of ankle sprains in high school athletes. Am J Sports Med 2006; 34: 1103–11.
20. Benjaminse A, Habu A, Sell TC, et al: Fatigue alters lower extremity kinematics during a single-leg stop-jump task. Knee Surg Sports Traumatol Arthrosc 2008; 16: 400–7.
21. Myer GD, Ford KR, McLean SG, Hewett TE: The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. Am J Sports Med 2006; 34: 445–55.
22. Myer GD, Ford KR, Brent JL, Hewett TE: The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes. J Strength Cond Res 2006; 20: 345–53.
23. Myer GD, Ford KR, Palumbo JP, Hewett TE: Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. J Strength Cond Res 2005; 19: 51–60.
24. Hubbard TJ, Kramer LC, Denegar CR, Hertel J: Correlations among multiple measures of functional and mechanical instability in subjects with chronic ankle instability. J Athl Train 2007; 42: 361–6.
25. Hertel J, Braham RA, Hale SA, Olmsted-Kramer LC: Simplifying the star excursion balance test: analyses of subjects with and without chronic ankle instability. J Orthop Sports Phys Ther 2006; 36: 131–7.
26. Hale SA, Hertel J, Olmsted-Kramer LC: The effect of a 4-week comprehensive rehabilitation program on postural control and lower extremity function in individuals with chronic ankle instability. J Orthop Sports Phys Ther 2007; 37: 303–11.
27. Kinzey SJ, Armstrong CW: The reliability of the star-excursion test in assessing dynamic balance. J Orthop Sports Phys Ther 1998; 27: 356–60.
28. Hertel J, Miller S, Denegar CR: Intratester and intertester reliability during the Star Excursion Balance Tests. J Sport Rehabil 2000; 9: 104–16.

29. Plisky P, Gorman P, Kiesel K, Butler R, Underwood F, Elkins B: The reliability of an instrumented device for measuring components of the Star Excursion Balance Test. N Am J Sports Phys Ther 2009; 4: 92–9.
30. 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: 339–57.
31. Teyhen D, Shaffer S, Lorenson C, et al: Reliability of lower quarter physical performance measues in healthy service members. US Army Med Dep J 2011; July–September: 37–49.
32. Robinson RH, Gribble PA: Support for a reduction in the number of trials needed for the star excursion balance test. Arch Phys Med Rehabil 2008; 89: 364–70.
33. Portney LG, Watkins MP: Foundations of Clinical Research: Applications to Practice. Upper Saddle River, NJ, Prentice Hall, 2009.
34. 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: 501–6.
35. Gribble PA, Tucker WS, White PA: Time-of-day influences on static and dynamic postural control. J Athl Train 2007; 42: 35–41.