7-25-2018

Functional performance deficits in adolescent athletes with a history of lateral ankle sprain(s)

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ABSTRACT

Objective: To determine if adolescent athletes with a history of lateral ankle sprain(s) (LAS) displayed deficits on functional performance tests (FPTs) and if deficits on FPT were related to the number of previous LAS. **Design:** Cross-sectional study. **Setting:** Biomechanics Laboratory. **Participants:** The injured group (n=24) had a history of ≥1 moderate-severe LAS. The uninjured group (n=34) had no history of LAS. **Main Outcome Measure(s):** The average reach distance of three trials in each direction of the star excursion balance test (SEBT) was normalized to leg length (%). The average of two trials of single-leg-hop test (SLHT) was calculated in seconds. **Results:** The injured group performed significantly worse in 3 directions of SEBT than the uninjured group (P<0.05). SLHT was significantly slower in the injured group compared to the uninjured group (P<0.05). Statistically significant, strong to moderate inverse relationships were found between the numbers of LAS and each of the three directions of the SEBT (P≤0.01). No relationship was revealed between the number of LAS and the SLHT (P > 0.05) **Conclusion(s):** Adolescent athletes with a history of LAS exhibit functional performance deficits on the SEBT and SLHT. Therefore, the SEBT and SLHT may provide clinicians cost- and time-effective objective tools.

Key Words: chronic ankle instability, self-report questionnaire, ankle sprain, clinical postural control test

INTRODUCTION

Ankle sprains are a common and serious problem in young athletes.[1] An estimated 5,373 ankle sprains in 17,172,376 high school athletes were reported in the United States, indicating high school students suffered 3.13 ankle sprains per 10,000 athlete-exposures (15.3% of all injuries) over the academic years 2005-2010.[2] Specifically, lateral ankle sprains are very common in soccer,[3,4] which has high youth participation rates.[5] Up to 70% of individuals with a history of lateral ankle sprain(s) experience re-spraining of the ankle after the initial (index) lateral ankle sprain.[6] Recurrent ankle sprains may lead to long-term issues including time-loss in physical activity[7], a "feeling of instability" ("giving way") of the ankle[8,9], functional performance deficits[10,11], and post-traumatic osteoarthritis (OA) in the ankle[12] in a physically active adult population. Although the majority of the relevant literature has investigated ankle sprain in the adult population, approximately 31% of young athletes (age 15.9±1.2 years) complained of the same symptoms as those reported by the adult population after the index ankle sprain.[13]

Functional performance deficits, including dynamic postural control deficits in a physically active population with a history of lateral ankle sprain(s), have been previously quantified[10,14] because they are a factor that may decrease physical activity[7] and/or even lead to another musculoskeletal injury[15]. Adolescence could be a key time in which the index sprain occurs, [9,16] However, most research to date has focused on recreational college-age athletes and young adults after they have already experienced the index ankle sprain. Current information is limited on the prevalence, severity, onset, or clinical course of ankle sprains in an adolescent population, which is likely the time for preliminary development of instability.[16]

Information regarding functional performance deficits in adolescent athletes with a history of lateral ankle sprain(s) is necessary to assist clinician knowledge of differences in functional performance tests (FPTs) within this age group. FPTs can be used to measure or classify the physical ability of ankle performance in an adult population.[17] One of the most common FPTs is the star excursion balance test (SEBT), which has been widely used in clinical and research settings.[10,18] The SEBT is an established outcome measure of dynamic postural stability that assesses a combination of range of motion, flexibility, neuromuscular control, and strength. The single-leg-hop test (SLHT) has also been widely applied to identify functional performance deficits in an adult population with a history of lateral ankle sprain(s).[10,11,14] However, there is limited application of these tests in an adolescent population. As such, their usefulness, appropriateness, and validity for an adolescent population is unclear. Clinicians may be able to apply these tests to adolescents, to determine if function is lost after an injury, restored after rehabilitation, or as a screening tool to target those in need of interventions.

Therefore, the purpose of this study was 1) to determine if two commonly used FPTs are able to identify functional performance deficits, and 2) to determine if a relationship exists between the number of reported lateral ankle sprain(s) and the FPT scores in adolescent soccer-playing athletes with a history of lateral ankle sprain(s). We hypothesized that adolescent athletes with a history of lateral ankle sprain(s) (an injured group) would demonstrate a shorter reach distance in three reach directions of the SEBT and slower completion time in the SLHT than an uninjured group. We also hypothesized that there would be a significant relationship between the number of reported lateral ankle sprain(s) and the FPTs scores within the injured group.

METHODS

Participants

Participants were recruited from a youth soccer club. The researcher provided an orientation to parents and guardians regarding the test purpose and procedure. An informed consent form, approved by the Institutional Review Board, was also provided during the parent and guardian meeting, with assent from the minor participants. Sixty-five participants (32 male and 33 female) were eligible and recruited based on the inclusion and exclusion criteria. The inclusion criteria were 1) any athletes in the soccer club (age 14 – 18; 90 min physical activity per week); 2) a history of one or more significant unilateral ankle sprains with pain and swelling that caused them to miss at least 1 day of competition or practice; 3) no occurrence of a lateral ankle sprain during the 3 months prior to study enrollment; and 4) an episode of "giving way" in the ankle joint with physical activity; OR no history of ankle sprain and no complaints of the ankle instability or "giving way" with physical activity. The exclusion criteria were a history of lower extremity surgery or fracture, acute signs and symptoms of injury in the lower extremity, a diagnosed vestibular disorder, Charcot-Marie-Tooth disorder, Ehlers-Danlos disorder, or other nerve or connective tissue disorders.[9,19]

A total of 58 participants (30 male and 28 female, Figure 1) were included in the current study while 6 participants withdrew from data collection due to physical inability to complete FPTs and/or pain during the tests, and 1 participant was excluded as a statistical outlier during the data reduction phase. Once all testing sessions were completed, the 58 participants were classified into either the injured (n=24) or uninjured group (n=34) based on self-reported previous injury criteria. The inclusion criteria to classify participants into the injured group included 1) a history of one or more significant unilateral ankle sprains with pain and swelling that caused them to miss at least 1 day of competition or practice, 2) no occurrence of a lateral ankle sprain at least 3 months prior to study enrollment, and 3) an episode of "giving way" in the ankle joint with physical activity. The uninjured group had no history of ankle sprain and no complaints of ankle instability or "giving way" with physical activity.

A series of independent sample t-tests were used to determine whether group differences existed for functional performance test scores for each test. The injured limb was used for the injured group (24 participants). For the uninjured group (34 participants), the side of limb was either matched with the injured group (24 participants) or randomly selected (10 participants).

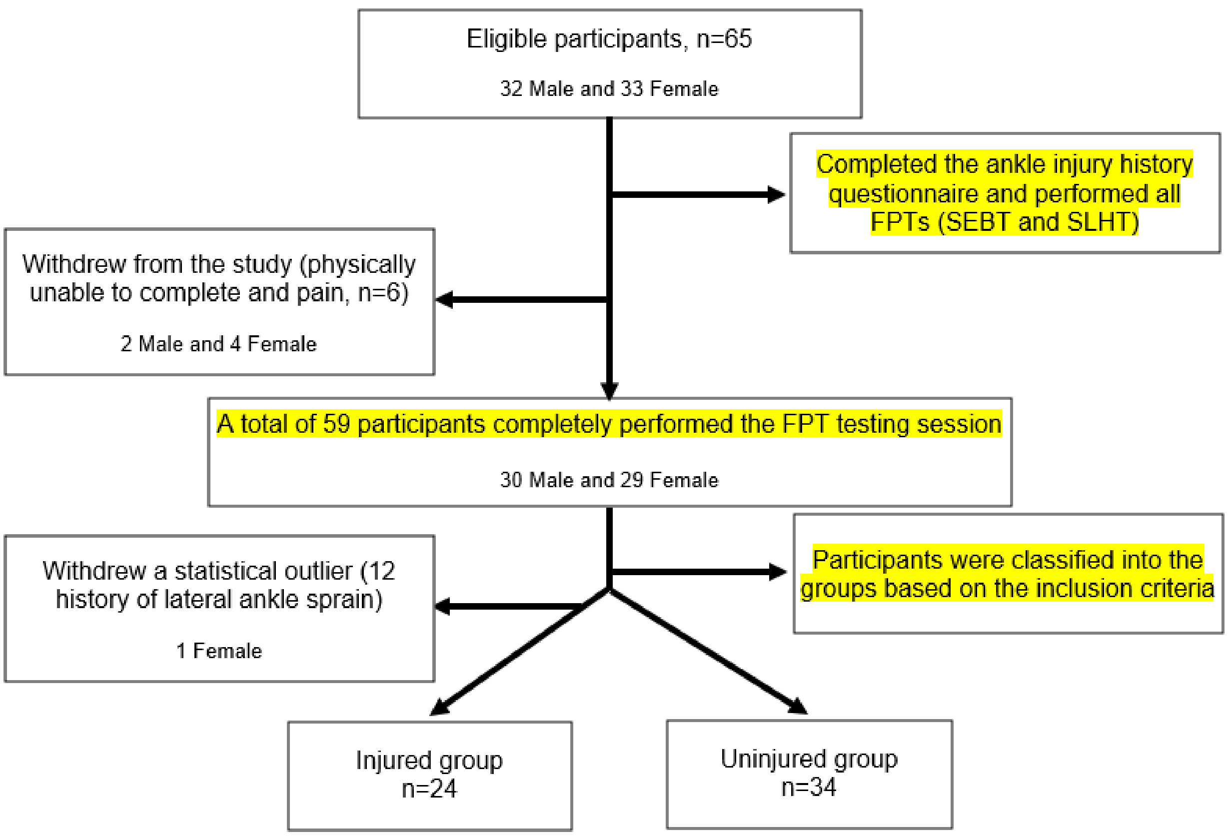

FIGURE 1: Flow chart of eligible participants.

Abbreviations: SEBT, Star Excursion Balance Test; SLHT, Single Leg Hop Test;

Procedures

Rater reliability for the SEBT and SLHT was established for the single rater prior to data collection. The single rater scored 20 preliminary participants for the SEBT and SLHT and then scored them again one week later on both limbs. Intra-class correlation coefficients ($ICC_{2,1}$) with standard error of measurement (SEM) were calculated. The ICC for the participants for the SEBT and SLHT were excellent ICC (0.89 - 0.97; 0.94), with a SEM of 1.6 cm and 0.06 sec, respectively.

After completing the consent/assent forms, each participant was scheduled for a single test session of 30 minutes either before or after practice on a weekday. All participants completed an ankle injury history questionnaire. Participant demographic information including age, gender, and dominant limb were collected, and leg length from the medial malleolus to anterior superior iliac spine (ASIS) of each limb in a supine position was measured.[20] Participants performed the FPTs including the SEBT and SLHT in a randomized order for both legs. The ankle injury history questionnaire was not reviewed by the rater until the participant completed all testing sessions. Once all the testing sessions were completed, all participants were classified into the groups. Therefore, the rater was blinded to participants' injury status and the self-report questionnaire scores during FPT tests.

Star Excursion Balance Test

The participants performed three trials of the anterior (AN), posteromedial (PM), and posterolateral (PL) reach directions of the SEBT following four practice trials.[18] The participant stood at the center of a grid barefoot and then maintained a single leg stance on the test limb with eyes open and hands on hips while reaching as far as possible in the selected direction.[10,21] The participant lightly tapped a line with the reaching foot and then returned the limb to the starting position. If the participant touched the line heavily with their reaching limb, shifted their weight to the outreaching limb, lifted any part of the testing foot while performing the action, or lifted their hands away from the hip, the trial was counted as incomplete and repeated (Figure 2).[20]

Single Leg Hop Test

Participants also performed two trials of a single leg hop test (SLHT) barefoot on the test limb with no practice trial. Participants were instructed to hop laterally and medially between a tape marker indicating a 30 cm distance for 10 repetitions as fast as possible (Figure 2).[11] If the participant touched the ground with the non-test limb, lost their balance, or could not clearly hop between the 30 cm tape-marker, the trial was counted as incomplete and repeated.[11]

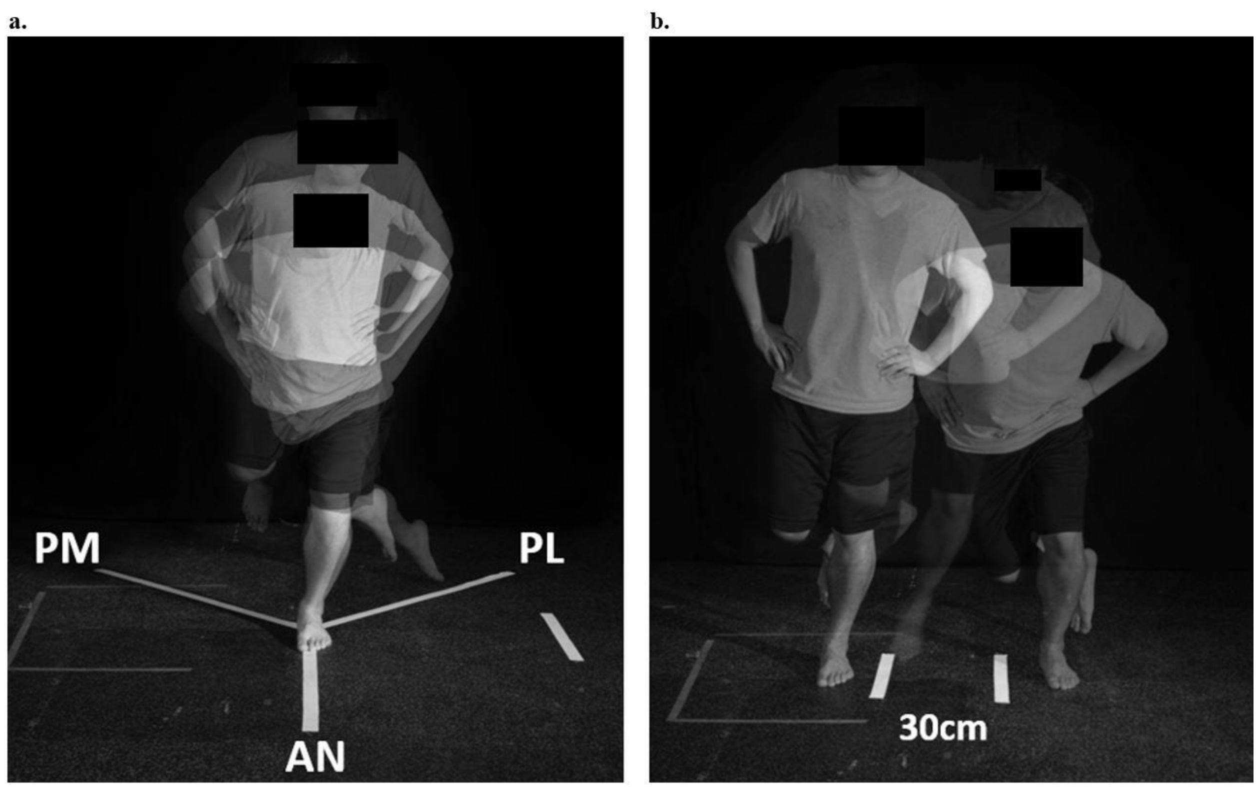

FIGURE 2: Three reach directions of a. Star Excursion Balance Test; b. Single Leg Hop Test (SLHT)

Data reduction and analysis

Means and standard deviations were calculated as descriptive data for the participants' demographics, ankle injury history questionnaire and performance on each FPT (Table 1). The body mass index percentiles (BMI%), recommended by Center for Disease Control and Prevention (CDC) and American Academy of Pediatrics (AAP) for use in adolescents, were also calculated because BMI% is more appropriate for this age group than BMI score based on participant height and weight.[22]

The average of three trials in the SEBT in each direction was normalized to % leg length. A greater % indicates better dynamic stability.[23] SLHT finish time was recorded to the nearest 0.01 second by a handheld stopwatch (60-Memory Stopwatch; Traceable™, Friendswood, TX). The fastest completed time from two trials of the SLHT was used for analysis.[11] The tester was blinded to the status of ankle injury during administration of the tests.

Statistical Analysis

A-priori sample size calculations were performed (G*Power, Version 3.1.5, Kiel, Germany) with statistical power=0.80, $P \leq 0.05$ from tabled data in similar studies utilizing FPTs in individuals with CAI, as this was the only comparison available. The necessary sample size for comparison of the performance on the SLHT between a CAI and control group ranged from 3 to 23 participants, depending on the study.[11,24] Another similar study[14] using SEBT, indicated that a necessary sample size would be 33 to 1,437 per group for a power level of 0.81 with an effect size of 0.1 to 0.7 and an $\alpha \leq 0.05$. However, these studies only included recreationally active college students or young adults. To our knowledge, no studies have assessed injured and uninjured adolescent sport populations using these tests. Our feasible, preliminary, targeted sample size of 30 in each group was set within the established limits of a meaningful sample size for comparisons of interest.

Exploratory data analyses were performed to identify outliers in the data (Figure 1). A participant with a history of 12 lateral ankle sprains was considered an outlier in the number of lateral ankle sprains due to the number being nearly 4 times larger than the mean and standard deviations (3.08±1.84) of the overall number of lateral ankle sprain(s). All the authors agreed to classify the participant as an outliner before removing the individual's data.

A series of independent samples t-tests were used to determine whether group differences existed for functional performance test scores for each test between the involved limb in the injured group and the matched limb (24 matched; 10 randomly selected) in the uninjured group. Additionally, effect sizes were calculated using a bias-corrected *Hedges' g*. The strength of effect sizes was interpreted as weak (≤ 0.4), moderate (0.41 to 0.7), and strong (≥ 0.7).[25] Due to the violation of an assumption based the results of a Shapiro-Wilk test of normality, Spearman's rank correlation coefficients (*rho*) were performed between the number of reported previous ankle sprains and the FPT scores within the injured group. The correlation coefficients were interpreted as a weak relationship if between 0.01 – 0.40, moderate relationship if between 0.41 – 0.69, and strong relationships if between 0.70 – 1.00.[26] An alpha level of $P < 0.05$ was set for all analyses. All statistical analyses were performed using Statistical Package for the Social Sciences™ 22.0 (SPSS, Inc., Chicago, IL).

RESULTS

There were no significant differences in age, height, mass, and BMI% between groups (Table 1). The injured group had significantly lower CAIT scores and higher IdFAI scores than the uninjured group (Table 1). Means and standard deviations, mean differences, and effect sizes (*Hedges' g*) for the SEBT and SLHT are shown in Table 2. The injured group performed significantly shorter reaches in all three reach directions of SEBT than the uninjured group, indicating decreased performance. The effect sizes for the difference between group means were moderate (SEBT-PM and SEBT-PL) to strong (SEBT-AN). Also, the injured group demonstrated a significantly slower time to complete the SLHT than the uninjured group, indicating decreased performance with a strong effect size (0.86).

TABLE 1. Participant Demographic Mean ± Standard Deviation

	Injured	**Uninjured**	***P*-value**
Number of Subjects (%)	24 (41.4%)	34 (58.6%)	N/A
Age (yrs.)	15.5 ± 1.3	15.6 ± 1.4	0.73
Gender (Male / Female)	11(45.8%)/13(54.2%)	19(55.9%)/15(44.1%)	N/A
Height (cm)	162.2 ± 8.5	162.7 ± 7.1	0.82
Mass (kg)	59.1 ± 9.2	57.2 ± 8.5	0.43
BMI (%)	66.7 ± 22.3	56.2 ± 27.0	0.12
Number of Ankle Sprains	3.1 ± 1.8	N/A	N/A
Range of Ankle Sprains	1 – 8	N/A	N/A

BMI – body mass index percentile

TABLE 2. Injured Group versus Uninjured Group Comparisons

	Injured	**Uninjured**	**Mean Difference**	**95% CI**		**Hedges' g**
				Injured	**Uninjured**	
SEBT-AN*	60.3 ± 15.2	71.6 ± 11.0	11.3%	53.9 to 66.7	66.6 to 74.9	0.86

SEBT-PM*	75.8 ± 16.5	85.2 ± 17.0	9.4%	68.8 to 82.7	79.3 to 91.2	0.55
SEBT-PL*	65.7 ± 8.8	72.7 ± 12.3	7.0%	62.0 to 69.4	67.7 to 76.3	0.63
SLHT*	15.1 ± 5.9	11.3 ± 2.8	3.7sec	12.7 to 17.4	10.6 to 12.5	0.86

SEBT – star excursion balance test; AN – anterior reach direction; PM – posteromedial reach direction; PL – posterolateral reach direction; SLHT – single leg hop test; *Statistically significant difference between the groups ($P < 0.05$)

The results of the Spearman's rank correlation coefficients (*rho*) indicated that there was a strong inverse relationship between the PL direction (*rho* = -0.71, $P = 0.001$) and the number of reported lateral ankle sprains, and moderate inverse relationships between the AN (*rho* = -0.50, $P = 0.012$) and PM (*rho* = -0.62, $P = 0.001$) directions and the number of reported lateral ankle sprains. There was also a weak, statistically non-significant positive relationship between the SLHT and number of reported lateral ankle sprains (*rho* = 0.40, $P = 0.053$). Scatter plots in Figure 3 and 4 show the patterns of relationships between each FPT and number of reported lateral ankle sprains.

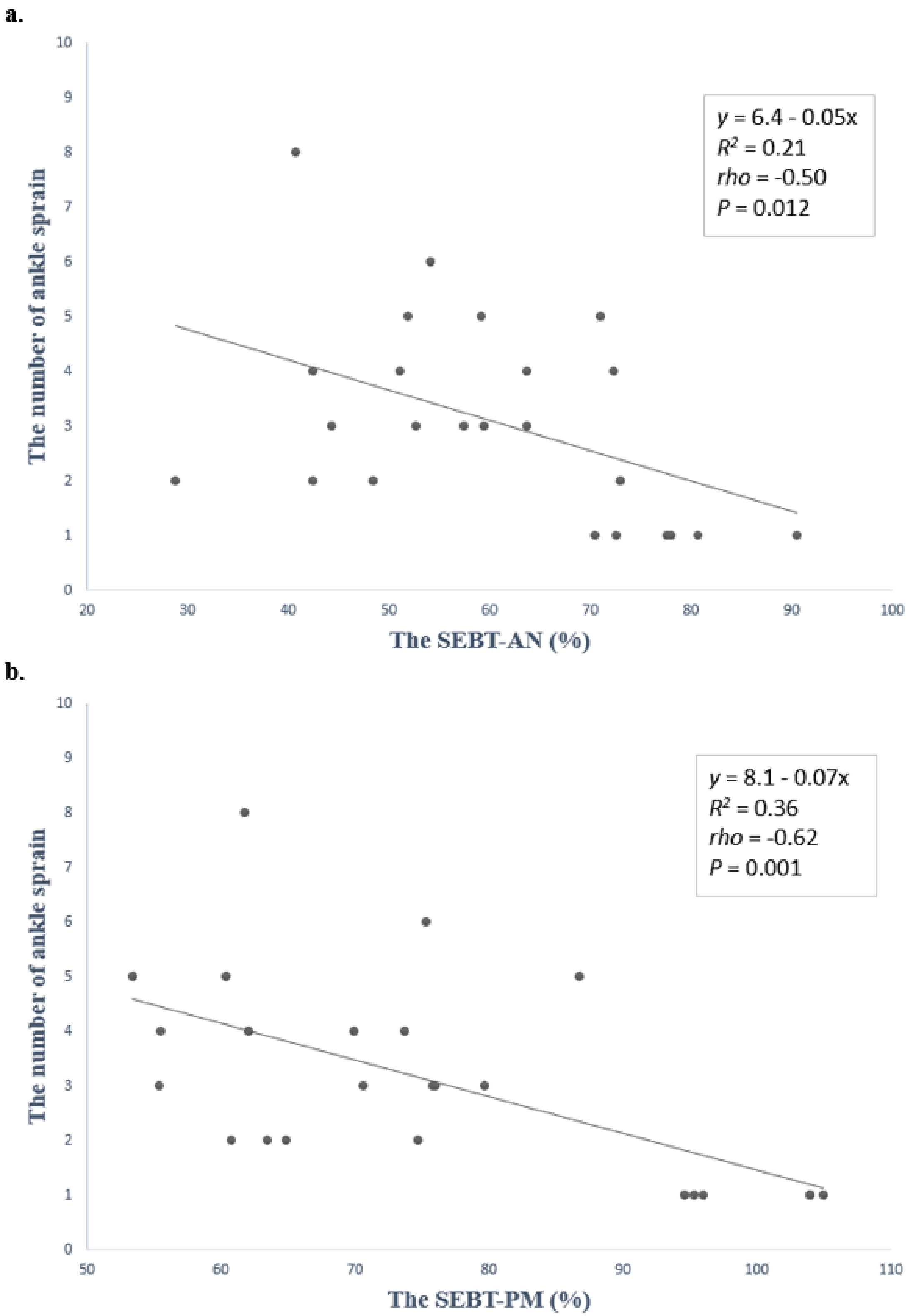

FIGURE 3. Relationship between a. the SEBT-AN and b. PM, and the number of reported lateral ankle sprains in the injured group (n=24)

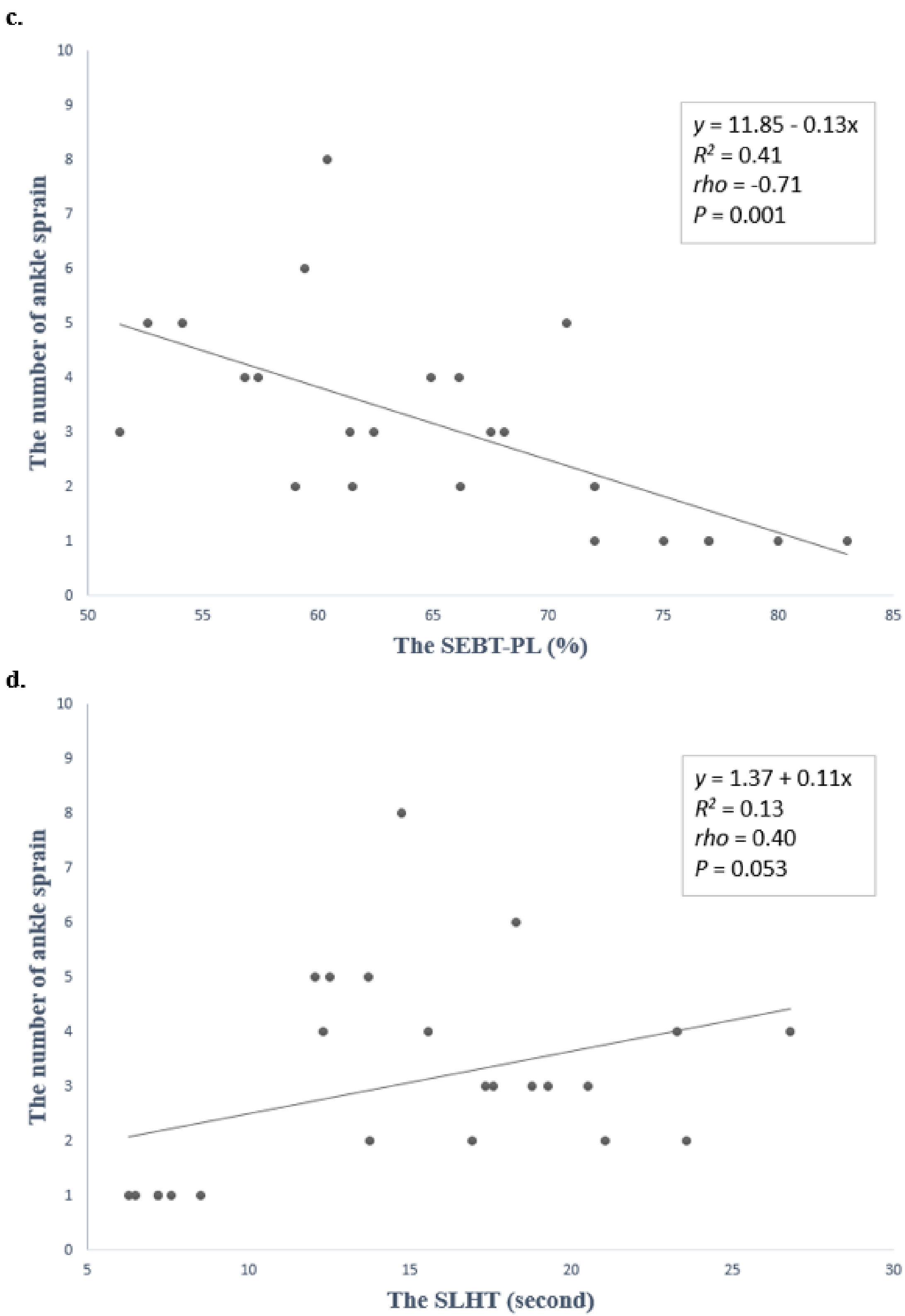

FIGURE 4. Relationship between c. the SEBT-PL and d. SLHT, and the number of reported lateral ankle sprains in the injured group (n=24)

DISCUSSION

The purpose of this study was to determine if there were differences in functional performance ability between injured (a history of lateral ankle sprain[s]) and uninjured groups in an adolescent soccer-playing population. Our most important finding was that the injured group demonstrated functional performance deficits in the SLHT and all three reach directions (AN, PM, and PL) of the SEBT, supporting our hypothesis. Similar to an adult population, an adolescent population who reported history of ankle injury demonstrated deficits in dynamic postural stability and functional deficits on the SEBT and SLHT than those with no ankle injury history.[10] Therefore, it appears clinicians may utilize the SEBT and the SLHT to differentiate functional performance ability in adolescents with and without a history of lateral ankle sprain(s).

Dynamic postural stability testing and/or functional performance tests are well established in the adult age groups.[10,11,14,24] Few prior studies[27,28] have investigated postural stability using dynamic postural stability test and/or functional performance test in adolescent populations. However, this is a relevant age to study because it is likely the time of index ankle sprain and may initiate the clinical path to Chronic Ankle Instability (CAI). To our knowledge, no previous studies have assessed the SEBT and SLHT between injured and uninjured groups in the adolescent population. Previous works[27,28] have indicated that decreased postural stability in non-instrumented and instrumented dynamic postural stability tests may result in ankle and/or lower extremity injury in pediatric and adolescent populations. Based on the primary purpose and results, adolescent soccer players with a history of lateral ankle sprain(s) showed functional performance deficits. Therefore, the SLHT and SEBT can be utilized as a functional performance test in adolescent individuals with a history of lateral ankle sprain(s). These quick, inexpensive, and easily applied tests appear to effectively demonstrate deficits in an injured group.

Additionally, a Spearman's rank correlation coefficient (*rho*) was performed to investigate if a relationship existed between the number of reported lateral ankle sprains and the FPT scores within the injured group. The findings indicate there were strong to moderate inverse relationships between all three reach directions of the SEBT (AN, PM, and PL) and the number of reported lateral ankle sprains. As the number of reported lateral ankle sprains increased, the reach distances in the AN, PM, and PL directions on the SEBT decreased, supporting the hypothesis. The three reach directions of the SEBT are region specific FPTs which have been shown to identify dynamic stability deficits following a lateral ankle sprain.[18,28] However, there was no statistically significant relationship between the SLHT and the number of reported lateral ankle sprains in adolescent soccer-playing athletes with a history of lateral ankle sprain, only a trend. This finding may indicate that the number of reported lateral ankle sprains may not necessarily relate to functional performance ability on the SLHT, in contrast with the three directions of the SEBT, due to the nature and different demands of the tests.[10] Clinicians can recognize that as the number of previous ankle sprains increases, performance on the SEBT is likely to decrease in adolescent soccer players.

There is currently limited research regarding CAI and its development in adolescent populations. A previous systematic review indicated that the prevalence of CAI was comparable and often higher in children and adolescent populations than that of an adult population.[16] Repeated ankle sprain after an initial ankle sprain was high across most groups of children and adolescents.[16] Medical records and patient-report outcomes (PRO) indicated that most of the participants (close to 100%) who had a history of ankle injury still experienced a re-injury in their ankle joint.[29] Therefore, our findings support that an adolescent population is the key age group that clinicians and researchers should focus on developing prevention, evaluation, and rehabilitation for CAI.[9,16,30] Additionally, there is currently no accepted high-quality clinical tool to assess the prevalence of CAI in children and an adolescent population.[16] Thus, the results from our study may provide evidence that the SEBT and SLHT tests can be successfully applied to, and discriminate between, adolescents with and without a history of lateral ankle sprain(s).

Although our results indicated that normalized reach distances in the three reach directions of the SEBT were decreased in the injured group similar to the results of previous studies[14,18] with an adult population, overall performance on the SEBT tended to be lower for adolescents than that for the adult population. This could potentially be due to their physical (musculoskeletal) immaturity, based on our observation.

Limitations

Our study has limitations on generalization because it was only a single sport and season with a relatively small sample size. Also, the severity, number, and type of ankle sprains were not considered in this study. A prospective longitudinal study is necessary to determine if recurrent ankle sprain and symptoms of CAI after index sprain are associated with dynamic postural stability deficits in an adolescent population. Also, there is a potential for a fatigue effect on the participants who completed FPTs after a daily practice. However, there were no significant differences in any FPTs measures between participants who completed FPTs before (48 participants; AN 66.7±13.6%; PM 80.9±16.5%; PL 69.6±11.4%; SLHT 13.01±4.5s) or after (10 participants; AN 66.0±16.3%; PM 81.5±21.1; PL 68.7±11.6%; SLHT 12.9±5.7s) practice

($P<0.05$). In addition, several other FPTs have been shown to be useful in adults; however, their clinical utility in children has not been assessed.[11,14] Therefore, more research is necessary to determine their clinical usefulness.

Conclusions

Our results indicate that adolescent participants with a history of lateral ankle sprain(s) demonstrated dynamic postural stability deficits in all 3 directions (AN, PM, and PL) on the SEBT and on the SLHT. Therefore, the SEBT and SLHT may provide clinicians cost- and time-effective objective tools for screening to determine dynamic functional deficits due to a previous lateral ankle sprain. Future research may develop clinical cut-off scores to indicate those who are at risk for further injury and would benefit from rehabilitation interventions.

REFERENCES

1. Adirim TA, Cheng TL. Overview of injuries in the young athlete. *Sports Med Open.* 2003;33(1):75-81.
2. Swenson DM, Collins CL, Fields SK, Comstock RD. Epidemiology of US high school sports-related ligamentous ankle injuries, 2005/06-2010/11. *Clin J Sport Med.* 2013;23(3):190-196.
3. Swenson DM, Yard EE, Collins CL, Fields SK, Comstock RD. Epidemiology of US high school sports-related fractures, 2005-2009. *Clin J Sport Med.* 2010;20(4):293-299.
4. Nelson AJ, Collins CL, Yard EE, Fields SK, Comstock RD. Ankle injuries among united states high school sports athletes, 2005-2006. *J Athl Train.* 2007;42(3):381-387.

5. Associations NFoSHS. 2014-15 High School Athletics Participation Survey. 2016; http://www.nfhs.org/ParticipationStatistics/PDF/2014-15_Participation_Survey_Results.pdf. Accessed Sep 27, 2016.

6. McKay GD, Goldie PA, Payne WR, Oakes BW. Ankle injuries in basketball: injury rate and risk factors. *Br J Sports Med.* 2001;35(2):103-108.

7. Hubbard-Turner T, Turner MJ. Physical Activity Levels in College Students With Chronic Ankle Instability. *J Athl Train.* 2015;50(7):742-747.

8. Hiller CE, Kilbreath SL, Refshauge KM. Chronic ankle instability: evolution of the model. *J Athl Train.* 2011;46(2):133-141.

9. Gribble PA, Delahunt E, Bleakley C, et al. Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the international ankle consortium. *J Orthop Sports Phys Ther.* 2013;43(8):585-591.

10. Ko J, 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.

11. Docherty CL, Arnold BL, Gansneder BM, Hurwitz S, Gieck J. Functional-performance deficits in volunteers with functional ankle instability. *J Athl Train.* 2005;40(1):30-34.

12. Hintermann B, Boss A, Schafer D. Arthroscopic findings in patients with chronic ankle instability. *Am J Sports Med.* 2002;30(3):402-409.

13. Tanen L, Docherty CL, Van Der Pol B, Simon J, Schrader J. Prevalence of chronic ankle instability in high school and division I athletes. *Foot Ankle Spec.* 2014;7(1):37-44.

14. Linens SW, Ross SE, Arnold BL, Gayle R, Pidcoe P. Postural-stability tests that identify individuals with chronic ankle instability. *J Athl Train.* 2014;49(1):15-23.

15. Plisky P, Rauh M, Kaminski T, Underwood F. 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.

16. Mandarakas M, Pourkazemi F, Sman A, Burns J, Hiller CE. Systematic review of chronic ankle instability in children. *J Foot Ankle Res.* 2014;7(1):21-31.

17. Rosen AB, Needle AR, Ko J. Ability of Functional Performance Tests to Identify Individuals With Chronic Ankle Instability: A Systematic Review With Meta-Analysis. *Clin Sport Med.* 2018;Publish Ahead of Print.

18. 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.

19. Wikstrom EA, Brown CN. Minimum reporting standards for copers in chronic ankle instability research. *Sports Med Open.* 2014;44(2):251-268.

20. Gribble PA. Considerations for normalizing measures of the star excursion balance test. *Meas Phys Educ Exerc Sci.* 2003;7(2):89-100.

21. Herrington L, Hatcher J, Hatcher A, McNicholas M. A comparison of Star Excursion Balance Test reach distances between ACL deficient patients and asymptomatic controls. *The Knee.* 2009;16(2):149-152.

22. Kuczmarski RJ, Ogden CL, Guo SS, et al. 2000 CDC Growth Charts for the United States: methods and development. In. *Vital Health Stat 11*2002:1-190.

23. Hertel J, Miller SJ, Denegar CR. Intratester and intertester reliability during the star excursion balance tests. *J Sport Rehabil.* 2000;9(2):104-116.

24. Caffrey E, Docherty CL, Schrader J, Klossner J. The ability of 4 single-limb hopping tests to detect functional performance deficits in individuals with functional ankle instability. *J Orthop Sports Phys Ther.* 2009;39(11):799-806.

25. Hedges LV. Distribution theory for glass's estimator of effect size and related estimators. *J Educ Behav Stat.* 1981;6(2):107-128.

26. Cohen J. *Statistical power analysis for the behavioral sciences.* 2nd ed. Hillsdale, N.J.: L. Erlbaum Associates; 1988.

27. McGuine TA, Greene JJ, Best T, Leverson G. Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med.* 2000;10(4):239-244.

28. 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.

29. Weir MA, Watson AW. A twelve month study of sports injuries in one Irish school. *Ir J Med Sci.* 1996;165(3):165-169.

30. Konradsen L, Bech L, Ehrenbjerg M, Nickelsen T. Seven years follow-up after ankle inversion trauma. *Scand J Med Sci Sports.* 2002;12(3):129-135.