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Preseason Functional Test Scores are Associated with Future Sports Injury in Female Collegiate Athletes

Jason Brumitt
George Fox University, jbrumitt@georgefox.edu

Bryan C. Heiderscheit
University of Wisconsin - Madison

Robert C. Manske
Wichita State University

Paul E. Niemuth
St. Catherine University

Alma Mattocks
Spalding University

See next page for additional authors

Authors
Jason Brumitt, Bryan C. Heiderscheit, Robert C. Manske, Paul E. Niemuth, Alma Mattocks, and Mitchell J. Rauh

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Jason Brumitt,[1] Bryan C. Heiderscheit,[2] Robert C. Manske,[3] Paul E. Niemuth,[4]
Alma Mattocks,[5] and Mitchell J. Rauh[6]

[1]School of Physical Therapy, School of Behavioral and Health Sciences, George Fox University, Newberg, Oregon; [2]Department of Orthopedics and Rehabilitation, University of Wisconsin–Madison, Madison, Wisconsin; [3]Department of Physical Therapy, School of Health Sciences, Wichita State University, Wichita, Kansas; [4]Doctor of Physical Therapy Program, Henrietta Schmoll School of Health, St. Catherine University, Minneapolis, Minnesota; [5]Athletic Training Education Program, Spalding University, Louisville, Kentucky; and [6]Doctor of Physical Therapy Program, School of Exercise and Nutritional Sciences, San Diego State University, San Diego, California

Abstract

Brumitt, J, Heiderscheit, B, Manske, R, Niemuth, PE, Mattocks, A, and Rauh, MJ. Preseason functional test scores are associated with future sports injury in female collegiate athletes. *J Strength Cond Res* 32(6): 1692–1701, 2018—Recent prospective cohort studies have reported preseason functional performance test (FPT) measures and associations with future risk of injury; however, the findings associated with these studies have been equivocal. The purpose of this study was to determine the ability of a battery of FPTs as a preseason screening tool to identify female Division III (D III) collegiate athletes who may be at risk for a noncontact time-loss injury to the lower quadrant (LQ = low back and lower extremities). One hundred six female D III athletes were recruited for this study. Athletes performed 3 FPTs: standing long jump (SLJ), single-leg hop (SLH) for distance, and the lower extremity functional test (LEFT). Time-loss sport-related injuries were tracked during the season. Thirty-two (24 initial and 8 subsequent) time-loss LQ injuries were sustained during the study. Ten of the 24 initial injuries occurred at the thigh and knee. At-risk athletes with suboptimal FPT measures (SLJ ≤79% ht; (B) SLH ≤64% ht; LEFT ≥118 seconds) had significantly greater rates of initial (7.2 per 1,000 athletic exposures [AEs]) and total (7.6 per 1,000 AEs) time-loss thigh or knee injuries than the referent group (0.9 per 1,000 AEs; 1.0 per 1,000 AEs, respectively). At-risk athletes were 9 times more likely to experience a thigh or knee injury (odds ratio [OR] = 9.7, confidence interval [CI]: 2.3–39.9; *p* = 0.002) than athletes in the referent group. At-risk athletes with a history of LQ sports injury and lower off-season training habits had an 18-fold increased risk of a time-loss thigh or knee injury during the season (adjusted OR = 18.7, CI: 3.0–118.1; *p* = 0.002). This battery of FPTs appears useful as a tool for identifying female D III athletes at risk of an LQ injury, especially to the thigh or knee region.

Key Words Division III, epidemiology, field test, lower extremity functional test, single-leg hop

Address correspondence to Jason Brumitt, jbrumitt@georgefox.edu.

Introduction

More than 79,000 female athletes participated in Division III (D III) level collegiate sports during the 2015–2016 academic year in the United States (29). Like other collegiate levels, the risk of injury at the D III level is inherent. Powell and Dompier (32) reported an overall time-loss injury incidence of 4.7 injuries per 1,000 athletic exposures (AEs) in D III female athletes. Female D III soccer players had the highest rate of time-loss injury (10.0 per 1,000 AEs) followed by field hockey (8.2 per 1,000 AEs) and basketball (7.6 per 1,000 AEs) athletes (32).

Practice injury rates for D III athletes were the highest in the preseason at 5.87 per 1,000 AEs (95% confidence interval [CI]: 5.79–5.95), then decreasing to 2.31 per 1,000 AEs (95% CI: 2.27–2.35) during the season, and 1.06 per 1,000 AEs (95% CI: 0.93–1.19) in the postseason (32). Game injury rates for D III athletes were lowest in the preseason at 4.86 per 1,000 AEs (95% CI: 4.45–5.26), then increased to 13.08 per 1,000 AEs (95% CI: 12.91–13.25) during the season, and 7.92 per 1,000 AEs (95% CI: 7.33–8.52) in the postseason (32). The higher injury rates during practices in the preseason and during games in the in-season (and postseason) reflect the challenges associated with preparing athletes for the demands associated with sport participation. For example, a deconditioned athlete may develop an overuse injury as training volume is increased during the preseason or an athlete who is fatigued during a game may be at risk of injury due to altered biomechanics (9,12,13,24,40).

Identifying risk factors associated with sport-related injury in collegiate athletes, especially for female athletes, is justified. Previous research has highlighted that collegiate athletes are especially at risk of lower extremity (LE) injuries (1,3,15,21,26,27,30,32,41). More than 50 percent of injuries occur in the LEs (with another 10.0–13.2 percent of injuries occurring in the trunk/back) (21). Female collegiate athletes experience a higher incidence of sports injuries than their male counterparts (32). In addition, female collegiate athletes experience a higher incidence of some sport-related injuries (e.g., noncontact anterior cruciate ligament [ACL] sprains) (2,3,33).

A recent trend in sports medicine research is to determine the risk of injury during sport based on preseason functional performance test (FPT) measures (17,25,36). Functional performance tests such as the Star Excursion Balance Test (SEBT), the Lower Quarter Y Balance Test (YBT-LQ), the Functional Movement Screen (FMS), the drop vertical jump (DVJ), the standing long jump (SLJ), the single-leg hop (SLH) for distance, and the lower extremity functional test (LEFT) have been evaluated in a variety of populations (4–11,16,18–20,22,23,28,31,37,39). Preseason performance on the SEBT (e.g., reach distance asymmetry or lower composite scores) is associated with greater risk of LE injury in high school basketball players, collegiate football players, and Division I athletes (10,19,31,37). Although a preseason score of 14 or below on the FMS was associated with an increased risk of a time-loss injury in professional football players (22), performance on the FMS did not discriminate injury risk in National Basketball Association (NBA) basketball players, D I athletes, junior hockey players, or high school athletes (4,5,16,39). Knee abduction moment measured during the DVJ was associated with ACL rupture in teenage female athletes (n = 205) (20). However, Goetschius et al. (18) reported no relationship between knee abduction moment during the DVJ and the risk of ACL rupture in 1855 female high school and collegiate athletes (age range 15–22). Standing long jump and SLH performances were not associated with a greater risk of lower quadrant (LQ) injury in D III female athletes; however, female athletes with a side-to-side asymmetry of >10% in the SLH had a 4-fold increase in foot and ankle injuries (6). Similarly, a slower performance on the LEFT (>118 seconds) was associated with a 6-fold increase in thigh and knee injuries in D III female athletes (6).

The aforementioned studies represent the LE FPTs that have been prospectively evaluated recently for discriminating risk associations in athletic populations. However, the equivocal findings associated with these studies may leave strength coaches and sports medicine professionals with uncertainty as to which FPT, or combination of FPTs, can best identify athletes who have a greater risk of injury. Thus, additional assessment using more than 1 FPT is warranted. The authors have initiated screening D III athletes using the SLJ, SLH, and LEFT previously (6); however, in that study, each test was individually examined for its ability to dichotomize athletes by injury risk. As previously mentioned, only performance of the LEFT was associated with future LQ injury. The primary purpose of this study was to perform a secondary analysis of preseason FPT measures to determine whether scores on a battery of FPTs were associated with an increased risk of a time-loss LQ (e.g., low back and LEs) sport-related musculoskeletal injury in D III female athletes (6). It was hypothesized that female athletes with suboptimal FPT scores would have a significantly greater risk of time-loss LQ injury. The secondary purpose of this study was to compare injury rates based on a battery of preseason FPT scores in a female D III athlete population. It was hypothesized that female athletes with suboptimal FPT scores would have a significantly greater rate of time-loss LQ injury.

Methods

Experimental Approach to the Problem

The SLJ, the SLH, and the LEFT have been used to (a) assess athletic readiness to return to play after LE injury (14) and (b) to discriminate injury risk in athletic populations. Previous research reported associations between individual tests and future injury risk (6); however, risk profiles based on performance on all tests have not been reported. Thus, analysis of performance on multiple tests is warranted.

Subjects

One hundred six D III female athletes (mean ± SD 19.1 ± 1.1 years; mean height 1.66 m [±0.1]; and mean mass 64.4 kg [±9.0]) from 8 teams (soccer, volleyball, cross-country, basketball, lacrosse, tennis, softball, and track) volunteered to participate in this study. A subject was excluded from study participation if she was younger than 18 years or if she was restricted from full sport participation because of injury. Informed written consent was obtained from subjects before testing. The Institutional Review Board of Rocky Mountain University of Health Professions approved this study. Subjects were informed of the benefits and risks of the investigation before signing the institutionally approved informed consent document to participate in the study. There are no conflicts of interest in this study.

Procedures

Collection of FPT measures and demographic information occurred at the start of each sport's preseason. Each athlete completed a demographic questionnaire which included age and years at university. Each athlete performed a 5-minute dynamic warm-up, consisting of LE activities, across the width of the basketball court (or across the width of the tennis court for tennis players) before testing. The dynamic warm-up consisted of the following active movements: forward walking, backward walking, heel walking, tip toe walking, forward lunging, backward lunging, and high knee marching. After completing the dynamic warm-up, athletes performed the 3 FPTs starting with the least challenging test, the SLJ, ending with the most challenging and fatiguing test, the LEFT (14,36). One investigator, the primary investigator (PI), collected FPT measures for all athletes.

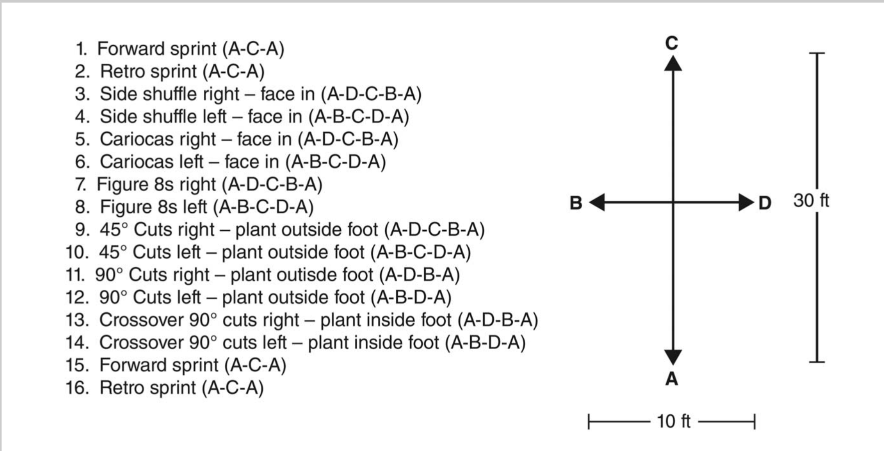

Figure 1. Lower extremity functional test.

Standing Long Jump Testing Protocol. The SLJ was the first test performed by each athlete. Subjects stood with feet approximately shoulder width apart behind a line of tape affixed to the court. Perpendicular to the line of tape was a cloth tape for measuring distance jumped and hopped. Each athlete performed 3 submaximal SLJs with her hands clasped behind her back. Next, each athlete performed 3 maximal effort jumps (with hands clasped behind their back) with distance measured from the starting line to the rearmost heel. For a SLJ to be recorded, the athlete had to land on both legs under control and maintain this position for 5 seconds (14,36). A trial was repeated if the subject unsuccessfully performed the jump. The mean of the 3 jumps was used for data analyses. The PI's test-retest reliability (intraclass correlation coefficient $[ICC]_{3,3}$) for the SLJ (0.96 [95% CI: 0.83–0.97]) has been previously reported (7).

Single-Leg Hop for Distance Testing Protocol. The SLH for distance was the second test performed. Athletes performed 6 SLH tests; 3 for each LE. Athletes were again required to clasp hands behind her back during each hop test. Each athlete stood on 1 foot behind the tape line with a coin flip determining which leg was hopped off first. For an SLH test to be recorded, the athlete had to land on the take-off leg and maintain this position for 5 seconds (14,36). A SLH trial was repeated if the athlete failed to stick the landing. The distance hopped was measured from the starting line to the rear of the heel. The mean ($\pm SD$) of the 3 hops (for each leg) was used for data analyses. The PI's test-retest reliability ($ICC_{3,3}$) for the SLH ([R] SLH 0.95 [95% CI: 0.89–0.98]; [L] SLH 0.96 [95% CI: 0.89–0.98]) has been previously reported (7).

Lower Extremity Functional Test Protocol. The LEFT, a test designed to assess agility and cardiovascular fitness, was the last test performed by each subject (8,14,36,38). The LEFT course is 9.14 meters (m) in the north-south direction and 3.05 m in the west-east direction (Figure 1) (8,14,36,38). Equilateral triangles consisting of 0.305 m (1.0 ft.) strips of tape were placed at the ends of each axis. To start the test, the athlete was positioned behind the southernmost triangle (Figure 1). Before giving the command "go," athletes were told that they were to run in a forward direction from southernmost triangle to the northernmost triangle and back. As

Table 1. Baseline characteristics and functional performance test measures (mean $\pm$ *SD*) of female Division III collegiate athletes.*

Characteristic	Total ($n = 106$)	Females in at-risk group ($n = 14$)	Females in referent group ($n = 92$)	p†
Age (y)	19.1 ± 1.1	19.1 ± 1.0	19.1 ± 1.1	0.914
Years in school (y)	2.1 ± 1.0	1.9 ± 0.8	2.1 ± 1.1	0.645
Age starting sport (y)	11.0 ± 3.7	11.1 ± 4.1	11.0 ± 3.6	0.909
Functional performance tests				
Standing long jump (normalized to height)	0.79 ± 0.10	0.69 ± 0.06	0.80 ± 0.10	**≤0.0001**
(R) Single-leg hop (normalized to height)	0.66 ± 0.10	0.55 ± 0.06	0.67 ± 0.09	**≤0.0001**
(L) Single-leg hop (normalized to height)	0.64 ± 0.10	0.55 ± 0.06	0.66 ± 0.10	**≤0.0001**
Lower extremity functional test (s)	117 ± 10	127 ± 11	116 ± 9	**≤0.0001**

*R = right; L = left.
†Independent *t*-tests.
Bold values= statistical significance

TABLE 2. Injury rates and injury severity–female Division III collegiate athletes.*†

Injury category	Total No.	Total AEs	Total Rate	Female athletes in at-risk group No.	Female athletes in at-risk group AEs	Female athletes in at-risk group Rate	Female athletes in referent group No.	Female athletes in referent group AEs	Female athletes in referent group Rate	Rate ratio‡ (95% confidence interval)
All lower quadrant injuries										
Onset										
Initial	24	6,400	3.8	6	695	8.6	18	5,705	3.2	2.7 (1.1–6.9)
Subsequent	8	771	10.4	6	223	26.9	2	548	3.7	7.4 (1.5–36.5)
Total	32	7,171	4.5	12	918	13.1	20	6,253	3.2	4.1 (2.0–8.4)
Severity										
<8 d time loss	23	7,171	3.2	11	918	11.2	12	6,253	1.9	6.2 (2.8–14.2)
≥8 d time loss	9	7,171	1.2	1	918	1.1	8	6,253	1.3	0.9 (0.1–6.8)
Thigh and knee injuries										
Onset										
Initial	10	6,400	1.6	5	695	7.2	5	5,705	0.9	8.2 (2.4–28.4)
Subsequent	3	771	3.9	2	223	9.0	1	548	1.8	4.9 (0.4–54.2)
Total	13	7,171	1.8	7	918	7.6	6	6,253	1.0	8.0 (2.7–23.6)
Severity										
<8 d time loss	10	7,171	1.4	7	918	7.6	3	6,253	0.5	16.0 (4.1–61.5)
≥8 d time loss	3	7,171	0.4	0	918	0.0	3	6,253	0.5	0.0 (NA)

*No. = number of injuries; AEs = athletic exposures; NA= not applicable
†Injury rate per 1,000 AEs.
‡At-risk group (athletes who scored below the cutoff score in all 4 functional performance tests) vs. referent group.

the athlete neared completion of each agility task, the primary investigator provided verbal instruction for the subsequent task and direction of movement (8,14,36,38). The sequence of drills in the LEFT are as follows: forward run, backward run, side shuffles, cariocas, Figure 8s, 45° cuts (plant outside foot), 90° cuts (plant outside foot), crossover 90° cuts (plant inside foot), forward run, and backward run. Each drill, except the forward and backward runs, is performed in a counterclockwise and clockwise direction (8,14,36,38). A stopwatch was used to record (seconds) how fast an athlete completed the course. Tabor et al. (38) reported ICCs of 0.95–0.97.

Injury Surveillance. Daily injury records and AEs were maintained by the university's athletic training staff. The athletic training staff recorded the following characteristics for each injured athlete: body region, side of the body, and number of days missed from sport participation. The operational definition of an injury was any noncontact muscle, joint, or bone problem/injury of the low back or the LE (categorized by region: low back, hip, thigh, knee, leg, ankle, or foot) that occurred either during practice or during competition that required the athlete to be removed from that day's event or to miss a subsequent practice or competition (34,35). The operational definition of an AE was any officially sanctioned team practice or game. The primary investigator reviewed injury records on a weekly basis to ensure accurate data collection.

Statistical Analyses

An a priori sample size estimation of 67 athletes (alpha level of 0.05, power of 0.80) was calculated based on the annual average number of LQ injuries reported by the university's athletic training staff (15). A total of 106 female athletes were recruited over a year and one-half period.

Descriptive statistics (mean ± *SD*) were calculated for athletes' baseline demographics (age, years in school, and age starting sport) and FPT measures. Comparison between at-risk female athletes (e.g., female athletes with each FPT score below previously established cutoff points) and females in the referent group (athletes not in the at-risk group) was calculated by performing independent *t*-tests.

Incidence and rate ratios were analyzed based on the frequency of injuries and clustered by anatomical region. Some injuries/injury locations are inherent to certain sports. For example, injuries to the thigh and knee are common in sports, such as soccer, volleyball, basketball, lacrosse, and track (1,3,26,27,30,41). Analyzing injuries by location may illustrate specific associations between injury and preseason FPT scores. These relationships may help clinicians select FPTs as screening tools specific to AE. Three regions were

Table 3. Odds ratios for all LQ musculoskeletal injuries based on baseline demographic measures and FPT categories for female Division III athletes.*

Categories	N	Injury % per category	OR	95% CI	*p*	Sensitivity (95% CI)	Specificity (95% CI)	Likelihood ratios (PLR/NLR)‡
Age (y)								
19 and younger	72	21	1.4	0.5–3.5	0.518	0.63 (0.41–0.81)	0.31 (0.21–0.42)	
20 and older	34	27	1.0	Referent				
Age starting sport (y)								
10 and younger	50	18	1.0	Referent	0.283	0.63 (0.41–0.81)	0.50 (0.39–0.61)	
11 and older	56	27	0.6	0.2–1.5				
History of LQ sports injury								
Yes	73	23	0.9	0.3–2.4	0.813	0.71 (0.49–0.87)	0.22 (0.32–0.43)	
No	33	21	1.0	Referent				
Off-season: weightlifting exercise (h per wk)								
0–<3	66	18	1.9	0.8–4.8	0.162	0.50 (0.29–0.45)	0.34 (0.24–0.45)	
>3	40	30	1.0	Referent				
Off-season: cardiovascular exercise (h per wk)								
0–<3	35	17	1.6	0.6–4.6	0.345	0.25 (0.10–0.47)	0.65 (0.53–0.75)	
>3	71	25	1.0	Referent				
Off-season: plyometric exercise (h per wk)								
0–<3	92	22	1.4	0.4–5.1	0.571	0.83 (0.63–0.95)	0.12 (0.06–0.21)	
>3	14	29	1.0	Referent				
Off-season: scrimmaging (h per wk)								
0–<3	62	21	1.3	0.5–3.1	0.625	0.54 (0.33–74.5)	0.40 (0.30–0.52)	
>3	44	25	1.0	Referent				
SLJ (normalized to height)								
80% or more	49	24	1.0	Referent	0.846	0.58 (0.37–0.78)	0.39 (0.28–0.50)	
79% or less	57	22	1.1	0.4–2.8				
(R) LE SLH (normalized to height)								
65% or more	59	20	1.0	Referent	0.526	0.50 (0.29–0.71)	0.57 (0.46–0.68)	
64% or less	47	25	0.7	0.3–1.9				
(L) LE SLH (normalized to height)								
65% or more	54	24	1.0	Referent	0.745	0.46 (0.26–0.67)	0.50 (0.39–0.61)	
64% or less	52	21	1.2					
Limb symmetry index								
>10%	26	35	2.3	0.9–6.1	0.098	0.38 (0.19–0.59)	0.79 (0.69–0.87)	
≤10%	80	19	1.0	Referent				
Combinations of FPT measures								
SLJ and LEFT† measures below cutoff scores	26	39	**2.9**	**1.1–7.8**	**0.030**	0.42 (0.25–0.59)	0.81 (0.76–0.86)	PLR = 2.1 (1.1–4.1) NLR = 0.7 (0.5–1.0)
Referent	80	18	1.0	Referent				
LEFT† and at least 1 SLH measures below cutoff scores	28	32	2.0	0.8–5.3	0.166	0.38 (0.21–0.56)	0.77 (0.72–0.82)	
Referent	78	19	1.0	Referent				
SLJ, only 1 SLH, and LEFT† measures below cutoff scores	20	35	2.2	0.8–6.3	0.149	0.29 (0.14–0.46)	0.84 (0.80–0.89)	
Referent	86	20	1.0	Referent				

SLJ, (B) SLH, and LEFT† measures below cutoff scores	14	43	3.1	0.95–10.0	0.061	0.25 (0.12–0.40)	0.90 (0.86–0.95)
Referent	92	20	1.0	Referent			
SLJ, (B) SLH, LEFT†, and LSI measures below cutoff scores	3	67	1.0	Referent			
Referent	103	21	7.4	0.6–85.0	0.110	0.08 (0.01–0.27)	0.99 (0.93–0.99)

*FPT = functional performance test; LQ = lower quadrant; SLJ = standing long jump; SLH = single-leg hop; LEFT = lower extremity functional test; CI = confidence interval; LE = lower extremity.
†LEFT = (at-risk group) with score >117 seconds.
‡Likelihood ratios: positive and negative likelihood ratios (PLR and NLR) are reported when an odds ratio (OR) is significant at the $p \leq 0.05$. Bold values= statistical significance

analyzed based on the frequency of injuries: all LQ injuries, injuries to the thigh and knee region, and injuries to the foot and ankle region. Injury rates were calculated per 1,000 AEs for initial and subsequent injuries and by injury severity classification. An initial injury was the first LQ time-loss injury experienced by an athlete during the season. A subsequent injury was an LQ time-loss injury experienced by an athlete after resuming sport participation after the initial injury. Rate ratios (and corresponding 95% CIs) were calculated to compare injury rates between females in the at-risk and referent groups based on onset and severity.

Cutoff Scores. Although a receiver-operator characteristic curve was performed for each test and demographic characteristic to identify cutoff scores for categorizing at-risk and referent groups, analysis of each curve failed to identify a point that maximized sensitivity and specificity. Thus, cutoff scores for FPTs used in this study were based on previously reported scores (6). The cutoff score for the SLJ was 79% of one's height or less (at-risk)/≥80% (referent). The cutoff score for the SLH test was 64% of one's height or less (at-risk)/≥ 65% (referent). The cutoff score for the LEFT was 118 seconds or more (at-risk)/117 seconds or less (referent) (6). Cutoff scores for demographic measures and off-season training habits were based on mean values from this population. Univariate logistic regression was performed to calculate crude odds ratios (ORs) and 95% CIs. Four risk profile categories, based on 2 or more suboptimal FPT scores, were assessed as follows: (a) LEFT score ≥118 seconds and at least 1 SLH measure <65% one's height/referent (e.g., all other athletes not in the "at-risk" group); (b) LEFT score ≥118 seconds and SLJ <80% one's height/referent; (c) LEFT score ≥118 seconds, SLJ <80% one's height, and only 1 SLH measure <65% one's height/referent; (d) LEFT score ≥118 seconds, SLJ <80% one's height, and both SLH measures <65% one's height/referent. Sensitivity and specificity measures were also determined. Positive and negative likelihood ratios (PLR and NLR) were calculated for a risk profile when the OR was $p \leq 0.05$. Adjusted odds ratios (AORs) were calculated using the following potential confounders: age, age starting sport, history of injury, and off-season training habits (weightlifting, cardiovascular exercises, plyometric exercises, and scrimmaging). Data analysis was performed using OpenEpi (for incidence rates and rate ratios) and SPSS Statistics 24 (IBM; Chicago, IL, USA) with the alpha level set at 0.05.

Results

Table 1 presents mean (±*SD*) scores for baseline demographic information and FPT measures. In general, at-risk athletes jumped and hopped significantly shorter distances and were significantly slower to complete the LEFT than athletes in the referent group ($p \leq 0.0001$).

A total of 32 (24 initial and 8 subsequent) time-loss LQ injuries were sustained during the course of the study (Table 2). Of the 24 initial injuries, 10 occurred at the thigh and knee, 12 at the foot and ankle region, and 2 occurred at either the low back or at a leg. The 10 initial time-loss injuries to the thigh/knee region consisted of 4 hamstring strains, 2 quadriceps strains, a groin strain, and 3 knee "strains" not otherwise specified (NOS is often used as an initial diagnosis when initial clinical signs and symptoms do not meet specific diagnostic criteria). Significant internal knee derangement was ruled out for the 3 knee strain NOS cases, and the following minimal time-loss duration (2, 7, and 10 days) occurred. Of the 8 subsequent injuries, 3 occurred at the thigh and knee region, 4 at the leg, and 1 at the foot. The 3 subsequent time-loss injuries to the thigh/knee region consisted of a hamstring strain and 2 knee strains NOS (1 and 5 days of time loss). Females in the at-risk group had, in general, significantly higher rates in the initial, subsequent, and total injury categories.

Female athletes in the LEFT and SLJ risk groups (risk profile 2) were 3 times more likely (OR = 2.9, 95%

TABLE 4. Odds ratios for musculoskeletal injury to the thigh or knee based on baseline demographic measures and FPT categories for female Division III athletes.*†

Categories	N	Injury % per category	OR	95% CI	*p*	Sensitivity (95% CI)	Specificity (95% CI)	Likelihood ratios (PLR/NLR)§
Age (y)								
19 and younger	72	11	2.0	0.4–10.0	0.398	0.80 (0.44–0.97)	0.33 (0.24–0.44)	
20 and older	34	6	1.0	Referent				
Age starting sport (y)								
10 and younger	50	8	1.0	Referent	0.634	0.60 (0.26–0.88)	0.48 (0.38–0.58)	
11 and older	56	11	1.4	0.4–5.2				
History of LQ sports injury								
Yes	73	11	1.9	0.4–9.5	0.431	0.80 (0.44–0.97)	0.32 (0.23–0.43)	
No	33	6	1.0	Referent				
Off-season: weightlifting exercise (h per wk)								
0–<3	66	11	1.5	0.4–6.0	0.598	0.70 (0.35–0.93)	0.39 (0.29–0.49)	
>3	40	8	1.0	Referent				
Off-season: cardiovascular exercise (h per wk)								
0–<3	35	9	0.9	0.2–3.5	0.831	0.30 (0.07–0.65)	0.67 (0.56–0.76)	
>3	71	10	1.0	Referent				
Off-season: plyometric exercise (h per wk)								
0–<3	92	9	0.6	0.1–3.0	0.510	0.80 (0.44–0.97)	0.13 (0.06–0.21)	
>3	14	14	1.0	Referent				
Off-season: scrimmaging (h per wk)								
0–<3	62	11	1.7	0.4–7.1	0.442	0.70 (0.35–0.93)	0.43 (0.33–0.53)	
>3	44	7	1.0	Referent				
SLJ (normalized to height)								
80% or more	49	10	1.0	Referent	0.820	0.60 (0.26–0.88)	0.40 (0.30–0.50)	
79% or less	57	9	1.2	0.3–4.4				
(R) LE SLH (normalized to height)								
65% or more	59	7	1.0	Referent	0.302	0.60 (0.26–0.88)	0.57 (0.47–0.68)	
64% or less	47	13	2.0	0.5–7.6				
(L) LE SLH (normalized to height)								
65% or more	54	4	1.0	Referent	0.057	0.80 (0.44–0.97)	0.54 (0.44–0.64)	
64% or less	52	15	4.7	0.9–23.4				
Limb symmetry index								
>10%	26	12	1.4	0.3–5.7	0.674	0.30 (0.07–0.65)	0.76 (0.66–0.84)	
≤10%	80	9	1.0	Referent				
Combination of FPT measures								
SLJ and LEFT‡ measures below cutoff scores	26	19	3.6	0.9–13.5	0.061	0.50 (0.19–0.81)	0.78 (0.69–0.86)	
Referent	80	6	1.0	Referent				
LEFT‡ and at least 1 SLH measures below cutoff scores	28	25	**8.3**	**2.0–35.0**	**0.004**	0.70 (0.35–0.93)	0.78 (0.69–0.86)	PLR = 3.2 (1.8–5.6) NLR = 0.4 (0.2–1.0)
Referent	78	4	1.0	Referent				

SLJ, only 1 SLH, and LEFT‡ measures below cutoff scores	20	25	**5.4**	**1.4–21.0**	**0.015**	0.50 (0.19–0.81)	0.84 (0.76–0.91)	PLR = 3.2 (1.5–6.9) NLR = 0.6 (0.3–1.1)
Referent	86	6	1.0	Referent				
SLJ, (B) SLH, and LEFT‡ measures below cutoff scores	14	36	**9.7**	**2.3–39.9**	**0.002**	0.50 (0.19–0.81)	0.91 (0.83–0.96)	PLR = 11.8 (4.6–30.2) NLR = 0.4 (0.2–0.8)
Referent	92	5	1.0	Referent				
SLJ, (B) SLH, LEFT‡, and LSI measures below cutoff scores	3	33	5.2	0.4–63.4	0.194	0.10 (0.0–45.0)	0.98 (0.93–0.99)	
Referent	103	9	1.0	Referent				

*FPT = functional performance test; LQ = lower quadrant; SLJ = standing long jump; SLH = single-leg hop; LEFT = lower extremity functional test; CI = confidence interval; LE = lower extremity.
†Only 1 SLH below mean score.
‡LEFT = (at-risk group) with score >117 seconds.
§Likelihood ratios: positive and negative likelihood ratios (PLR and NLR) are reported when an odds ratio (OR) is significant at the $p \leq 0.05$. Bold values= statistical significance

CI: 1.1–7.8; $p = 0.030$) to experience an LQ injury (Table 3). The sensitivity, specificity, and likelihood ratios (LRs) associated with this risk profile were 0.42 (95% CI: 0.25–0.59), 0.81 (95% CI: 0.76–0.86), PLR = 2.1 (1.1, 4.1), and NLR = 0.7 (0.5, 1.0).

There were associations between preseason FPT measures and thigh or knee injury in 3 of the 4 test battery categorizations (Table 4). Female athletes (n = 28) with slower LEFT scores and at least 1 SLH measure below the cutoff score were 8 times more likely to experience a time-loss thigh or knee injury (OR = 8.3, CI: 2.0–35.1; $p = 0.004$). Athletes with a slower LEFT score, a shorter SLJ, and only 1 SLH score below the mean were 5 times more likely to have a thigh or knee time-loss injury (OR = 5.4, CI: 1.4–21.0; $p = 0.015$). Athletes with suboptimal scores on each of the 4 FPTs were 9 times more likely to experience a thigh or knee time-loss injury (OR = 9.7, CI: 2.3–39.9; $p = 0.002$). The sensitivity, specificity, and LR associated with this risk profile were 0.50 (95% CI: 0.21–0.77), 0.91 (95% CI: 0.88–0.94), PLR = 11.8 (4.6, 30.2), and NLR = 0.4 (0.2, 0.8).

Finally, multivariate logistic regression models were performed for 2 FPT categories found to be significant during univariate regression analysis: (a) suboptimal SLJ and LEFT scores and "all injuries" and (b) all 4 FPTs with suboptimal scores and "thigh/knee injuries." After adjusting for a history of previous injury, subjects with suboptimal SLJ and LEFT scores were 3 times more likely to experience an LQ injury (AOR = 3.6 [95% CI: 1.3–10.3] $p = 0.02$). After adjusting for history of injury, off-season weightlifting, and off-season cardiovascular training, female athletes with suboptimal scores on all 4 FPTs had an 18-fold increased risk of time-loss thigh or knee injury during the season (AOR = 18.7 [95% CI: 3.0–118.1] $p = 0.002$).

Discussion

Suboptimal performance on each test (the SLJ, both SLH tests, and the LEFT) in a battery of FPTs was associated with an increased risk of a time-loss LQ injury, especially to the thigh and knee region. Risk of injury increased when one's FPT scores were combined with age, age starting sport, injury history, and/or off-season training habits.

The overall LQ time-loss injury rate of 4.5 per 1,000 AEs in this study was similar to the overall rate reported by Powell and Dompier (32) At-risk individuals had significantly higher rates of LQ injuries than their counterparts. These findings highlight the importance of accurately identifying at-risk female athletes. A strength coach and/or a sports medicine professional may be able to intervene with exercise programs once at-risk individuals are identified. Individual sport injury incidence rates were not calculated for this study because of the relatively small size per specific sport. However, most injuries were experienced by athletes in sports with known higher rates: volleyball, soccer, lacrosse, and basketball players (1,3,26,27).

Preseason assessment of characteristics of athletic performance to identify athletes at risk of injury is an emerging area of sports medicine research (4–10,16,19,22–24,31,37,39). Preliminary studies have reported associations between preseason measures on the YBT-LQ and subsequent sport-related LE injury; however, the magnitude of risk differs by sex, the operational definition of an injury, and the direction of reach during the test (10,19,22,37). Differences in cutoff scores between studies may reflect the need to establish performance profiles for all athletic populations instead of relying on 1 cutoff score for universal risk assessment. A limitation of the aforementioned studies is that they did not link specific injuries or regions to YBT-LQ scores.

Some researchers have prospectively assessed athletes with the FMS, a battery of static and dynamic tests (4,5,16,22,39). A preliminary report (22) established a relationship between the preseason score and subsequent time-loss injury in professional (National Football League [NFL]) football players; however, additional studies have reported no significant association between the FMS score and future injury in sports (4,5,16,39).

The results of this study demonstrated that suboptimal performance on each of the study's FPTs was associated with a 9-fold increase in a time-loss thigh or knee injury in a general population of female D III collegiate athletes. This finding is also clinically relevant when comparing the findings in this study with previously published results (6). Risk associations based on preseason performance of the SLJ, SLH, and LEFT and future risk of time-loss LQ injury have been previously reported; however, risk analysis was only assessed per individual test performance. Brumitt et al. (6) reported a 6-fold increased risk of thigh or knee injury in a global population of female collegiate D III athletes who completed the LEFT in 118 seconds or more. However, preseason performance of the SLJ or the SLH for distance was not associated with a greater risk of a time-loss LQ, thigh/knee, or foot/ankle injury (note: asymmetry between LEs with the SLH was associated with a 4-fold increase in foot/ankle injury) (6). The results from this secondary analysis demonstrate that categorizing athletes into at-risk and "referent" groups based on performance on 2 or more tests may improve a clinician's ability to identify individuals who are at a greater risk of a time-loss injury during the season.

Some limitations of this study should be noted. Despite the sample tested, the risk profiles might only be specific to a general, female D III athlete population. The utility of these tests as a preseason screening tool may have limited generalizability to some sports teams (e.g., teams with lower rates of LQ injury) or to Division I or II athletes. Future research is warranted to determine risk profiles for other athletic populations and for specific sports. A second limitation of this study was the reliance on the athletes to report the mechanism of injury to the athletic trainer. University athletic trainers are not always present at each practice because of their multiple job responsibilities. Although we believe that the injuries that occurred during this study were noncontact in nature, we cannot exclude the possibility of a contact-related injury.

Practical Applications

Preseason scores on a battery of FPTs, consisting of the SLJ, SLH, and the LEFT, were associated with an increased risk of a time-loss LQ injury in female D III athletes. These inexpensive tests are easy to administer and do not require special equipment. This battery of tests could be administered by a strength coach and/or sports medicine professional to identify female collegiate athletes who may be at a higher risk of injury, especially to the thigh or knee region. If an athlete presents as at-risk (e.g., lower SLJ and SLH measures and a slower LEFT), the strength coach could individualize an athlete's training program to address deficits. Increasing one's strength and agility may have a protective effect reducing the risk of a noncontact time-loss injury during the season.

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