IJSPT

ORIGINAL RESEARCH

LOWER EXTREMITY FUNCTIONAL TESTS AND RISK OF INJURY IN DIVISION III COLLEGIATE ATHLETES

Jason Brumitt, PT, PhD, SCS, ATC, CSCS[1]
Bryan C. Heiderscheit, PT, PhD[2]
Robert C. Manske, DPT, MEd, SCS, ATC[3]
Paul E. Niemuth, PT, DSc, SCS, OCS, ATC[4]
Mitchell J. Rauh, PT, PhD, MPH, FACSM[5]

ABSTRACT

Purpose/Background: Functional tests have been used primarily to assess an athlete's fitness or readiness to return to sport. The purpose of this prospective cohort study was to determine the ability of the standing long jump (SLJ) test, the single-leg hop (SLH) for distance test, and the lower extremity functional test (LEFT) as preseason screening tools to identify collegiate athletes who may be at increased risk for a time-loss sports-related low back or lower extremity injury.

Methods: A total of 193 Division III athletes from 15 university teams (110 females, age 19.1 ± 1.1 y; 83 males, age 19.5 ± 1.3 y) were tested prior to their sports seasons. Athletes performed the functional tests in the following sequence: SLJ, SLH, LEFT. The athletes were then prospectively followed during their sports season for occurrence of low back or LE injury.

Results: Female athletes who completed the LEFT in ≥118 s were 6 times more likely (OR = 6.4, 95% CI: 1.3, 31.7) to sustain a thigh or knee injury. Male athletes who completed the LEFT in ≤100 s were more likely to experience a time-loss injury to the low back or LE (OR = 3.2, 95% CI: 1.1, 9.5) or a foot or ankle injury (OR = 6.7, 95% CI: 1.5, 29.7) than male athletes who completed the LEFT in 101 s or more. Female athletes with a greater than 10% side-to-side asymmetry between SLH distances had a 4-fold increase in foot or ankle injury (cut point: > 10%; OR = 4.4, 95% CI: 1.2, 15.4). Male athletes with SLH distances (either leg) at least 75% of their height had at least a 3-fold increase (OR = 3.6, 95% CI: 1.2, 11.2 for the right LE; OR = 3.6, 95% CI: 1.2, 11.2 for left LE) in low back or LE injury.

Conclusions: The LEFT and the SLH tests appear useful in identifying Division III athletes at risk for a low back or lower extremity sports injury. Thus, these tests warrant further consideration as preparticipatory screening examination tools for sport injury in this population.

Clinical Relevance: The single-leg hop for distance and the lower extremity functional test, when administered to Division III athletes during the preseason, may help identify those at risk for a time-loss low back or lower extremity injury.

Key Terms: epidemiology, functional test, single-leg hop, lower extremity functional test

Level of Evidence: 2

[1] Pacific University (Oregon), Hillsboro, OR, USA
[2] University of Wisconsin, Madison, WI, USA
[3] Wichita State University, Wichita, KS, USA
[4] St. Catherine University, Minneapolis, MN, USA
[5] San Diego State University, San Diego, CA, USA

The Institutional Review Boards of Pacific University and Rocky Mountain University of Health Professions approved this study.

Acknowledgements
We would like to acknowledge Linda McIntosh, MS, ATC; Alma Mattocks, MS, ATC; Phil Lentz, MS, ATC; Eric Pitkanen, MS, ATC; and Richard Rutt, PT, PhD, ATC for their contributions to this study.

CORRESPONDING AUTHOR
Jason Brumitt, PT, PhD, SCS, ATC, CSCS
Assistant Professor
School of Physical Therapy
Pacific University (Oregon)
Hillsboro, OR, USA
Email: brum4084@pacificu.edu
phone: 503-352-7265
fax: 503-352-7340

INTRODUCTION

Over 172,000 collegiate student-athletes participated in Division III (D III) sports during the 2009-2010 school year.[1] A musculoskeletal injury to a D III student-athlete may significantly impact the athlete's physical well-being, increase stress, negatively impact school studies, and affect the athlete's team's success.[2-9] Thus, identifying at-risk athletes during the off-season or at the start of the preseason may help coaching staffs and/or sports medicine professionals intervene with training programs that may minimize the athlete's risk of sustaining a sports-related musculoskeletal injury.

A functional test is an assessment tool that is reported to "closely simulate a given sport or activity".[10] The ability of a test to mimic a functional movement may provide information regarding an athlete's readiness level that may not be identified with traditional assessment measures (e.g., manual muscle tests). Recent reports have prospectively assessed the ability of several functional tests to identify athletes at risk for a sports-related injury.[11-14] The Star Excursion Balance Test (SEBT) has been shown to be predictive of lower extremity injury in female high school basketball players.[14] A lower score on the Functional Movement Screen™ (FMS) has been associated with increased risk of time-loss injury in professional football players.[12] The drop vertical jump (DVJ) test has been reported to identify individuals with a greater risk for ACL injury.[11] However, a potential limitation of the SEBT, FMS™, and the DVJ is that these tests may not be able to account for the potentially injurious stresses and forces that are experienced during other dynamic aspects of sports (e.g., landing from a jump for distance or cutting maneuvers) or may require time and/or equipment not readily available to coaches or the sports medicine team.[11,12,14-16]

The standing long jump (SLJ), the single-leg hop (SLH) for distance, and the lower extremity functional test (LEFT) are functional tests that require minimal equipment, are quick to perform, and have been administered to assess athletic fitness as well as an athlete's readiness to return to sport.[17,18] The SLJ (a double-legged jump for distance) and the SLH (a single-legged jump for distance) mimic the functional aspect of jumping and landing and have been reported to assess an athlete's lower extremity strength and neuromuscular control.[10,17-19] The SLH test in particular is frequently utilized to assess lower extremity function in athletes following anterior cruciate ligament reconstruction surgery.[17,18,20-22] The LEFT was initially designed to assess the injured athlete's ability to perform sport-specific movement patterns.[17,18] The LEFT test consists of eight agility drills (forward run, backward run, side shuffle, carioca, figure 8 run, 45° cuts, 90° cuts) performed on a diamond shaped course (Figure 1).[17,18] However, these tests have not been examined for their associations with sports injury risk.

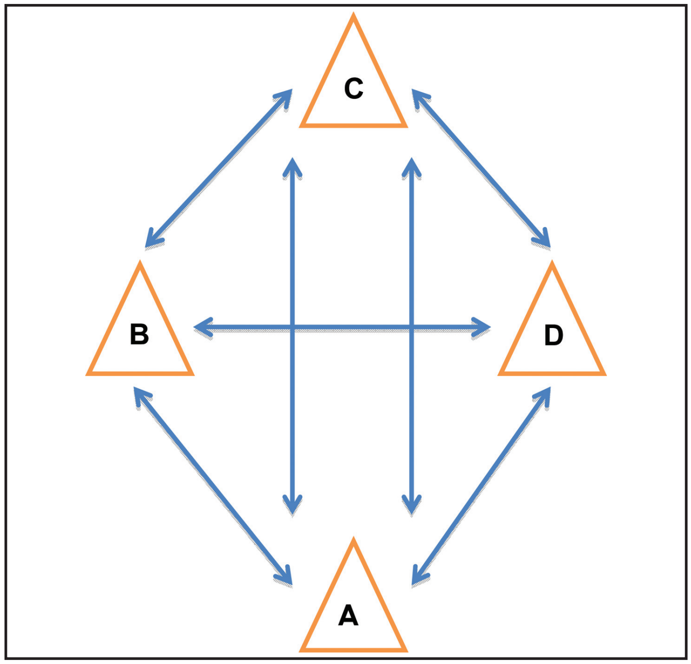

Figure 1. *The LEFT Test. Distance between marker A and marker C is 9.14 meters, and distance between marker B and marker D is 3.05 meters. The athlete completes a series of 16 maneuvers in this course, as described the Appendix.*

The purpose of this prospective cohort study was to determine if the SLJ, the SLH, and the LEFT could be used as preseason screening tools to identify collegiate athletes at risk for a sports-related time-loss low back or lower extremity musculoskeletal injury. The authors hypothesized that athletes with shorter SLJ and SLH distances, and slower times on the LEFT would be at greater risk for injury.

METHODS

Subjects

One-hundred and ninety-three D III collegiate student-athletes (110 females, age 19.1 ± 1.1 yr;

83 males, age 19.5 ± 1.3 yr) from 15 university teams (baseball, lacrosse, softball, volleyball, wrestling; men's and women's basketball, cross-country, soccer, tennis, track & field) volunteered to participate in the study. A student-athlete was excluded from participation if he or she was under the age of 18 or was currently restricted from full sport participation by his or her medical doctor due to injury. The Institutional Review Boards of Rocky Mountain University of Health Professions and Pacific University approved the study. Informed consent was obtained from each subject prior to participation.

Procedures

All testing was performed prior to the start of each sport's competitive season. Each subject completed a questionnaire regarding demographic information including age, years at university, and the age the athlete started playing his/her sport. Subject's height (cloth tape; nearest half inch) and weight (standard medical scale, nearest half pound) were recorded. Immediately before testing, subjects performed a dynamic warm-up consisting of 5-10 minutes of active movements including: forward walking, backward walking, heel walking, tip toe walking, forward lunging, backward lunging, high knee marching. The functional tests were performed in the following order for each athlete: SLJ, SLH bilaterally, and the LEFT.

Standing Long Jump Testing Protocol. The subjects stood with their feet approximately shoulder width apart situated behind, but not on, a line (piece of tape) on the floor. A cloth measuring tape was oriented perpendicular to the start line and fixed to the floor to record distance jumped. The subjects performed 3 submaximal countermovement SLJs with hands behind their back, followed by 3 jumps performed at maximal effort. For a test to be recorded, subjects had to land on both legs under control (maintaining center of mass within their base of support) holding this position for 5 seconds.[17,18] If a subject was unable to land successfully (e.g., lost balance, took an extra step after landing), the SLJ was repeated. The distance jumped was measured from starting line to the rear-most heel.

Single-Leg Hop for Distance Testing Protocol. The subjects stood with their feet approximately shoulder width apart situated behind, but not on, a line (piece of tape) on the floor. The subjects performed 6 SLH for distance (3 for each lower extremity) with hands behind his or her back. A coin-flip determined which leg the subjects hopped off first. For a test to be recorded, subjects would have to hold the landing position for 5 seconds.[17,18] If a subject was unable to land successfully (e.g., land with assistance of the opposite lower extremity, lost balance, or took an extra step after landing), the SLH was repeated. The distance hopped was measured from the starting line to the rear most heel.

Lower Extremity Functional Test Protocol. The LEFT test involves eight agility drills performed on a diamond shaped course (Figure 1).[17,18,23] The required testing area for the LEFT was 9.14 meters (m) in a north-south direction and 3.05 m in a west-east direction.[17,18,23] The LEFT consists of eight components (agility tasks) with each task performed twice: forward run, backward run, side shuffle, carioca, figure 8 run, 45º cuts, 90º cuts (Appendix Table 1). The forward run and the backward run are repeated at the end of the sequence (after the 90º cuts).[23] The subjects began each agility task from the same position on the testing area (A). Because of the complexity of the different movements, subjects were not instructed in advance of each of the eight agility tasks. Instead, as subjects neared completion of each agility task, the investigator would provide verbal instructions describing the next task and corresponding direction of movement.[10] As such, subjects were required to respond to the external stimuli (e.g., similar to how a subject would need to change direction during sport), preventing those that could quickly memorize the components from having an advantage. Time was recorded in seconds using a standard stop-watch.

Injury Surveillance. From the start to end of their sports season, daily injury records were maintained for athletes (an athlete is required to be evaluated by a certified athletic trainer after sustaining an injury) including the region of the body injured and how many days were missed from sport participation. The university's athletic training staff was trained in a standardized manner to record the injuries. The operational definition of an injury was any muscle, joint, or bone problem/injury of the low back (lumbar spine) or the lower extremity (categorized by region: hip, thigh, knee, leg, ankle, or foot) that occurred either during practice or competition that required the athlete to be removed from that day's event or to miss a subsequent practice or competition.[24,25] A study investigator reviewed injury records throughout the study to ensure data collection.

Statistical Analyses

An *a priori* sample size estimation was performed based on the average number of low back and lower extremity time-loss injuries experienced annually by the university's athletes as reported by the athletic training staff. Using a prospective cohort design, a power of 0.80, an alpha level of 0.05, and an approximate relative risk of 2.0, a sample of 134 subjects (or 67 per sex) were needed to determine statistically significant associations between a low back or lower extremity injury and the functional tests.

Descriptive statistics (means ± SD) were calculated for the subjects' baseline demographic characteristics and functional test scores. Comparison of means between genders for demographic characteristics and functional test scores were calculated by performing independent *t*-tests. Univariate logistic regression was performed to calculate crude odds ratios (OR) and 95% confidence intervals to identify injury risk associated with test scores.

SLJ. Based on previous clinical recommendations (CR),[17,18] the risk of injury associated with SLJ scores was analyzed using a cutoff score for women (79% of one's height or less/≥80% [referent]) and men (89% of one's height or less/≥90% [referent]).

SLH. Cutoff scores were assessed per gender; one cutoff score based on this study's mean SLH distances as a percentage of one's height (females = 65% and males = 75%) with the other cutoff scores based on previously reported CRs (risk profile: larger % or more [referent]/≥ smaller % or less).[17,18] The second cutoff score (SLH distance/height) used to assess injury risk in female athletes was 69% or less/≥70% [referent] (based on prior CR that hop distance for females should be at least 70% of one's height).[17,18] Two additional cutoff scores (SLH distance/height) were used to assess injury risk in male athletes: 79% or less/≥80% [referent] and 84% or less/≥85% [referent] (based on prior CR that suggest hop distance should be 80-85% of an athlete's height).[17,18] In addition to analysis of SLH distance as a factor of one's height, asymmetry between lower extremities was assessed. The limb symmetry index (LSI) was calculated by dividing SLH distance between lower extremities (shortest SLH distance divided by longest SLH distance). A cutoff score of 10% or less [referent]/≥10% (based on previous CR) was used for analysis of LSI and risk of injury.[17,18]

LEFT. Cutoff scores, based on prior clinical recommendations (CR) and mean scores from this sample, were used to determine injury risk.[17,18] The two sets of cutoff scores used for male athletes were ≤100/101 or more seconds (CR average LEFT time = 100 s)[17,18] and ≤105/106 or more seconds (D-III male athletes' mean time in this sample = 105 s). The two sets of cutoff scores used for female athletes were ≤120/121 or more seconds (CR average LEFT time = 120 s)[17,18] and ≤117/118 or more seconds (D-III female athletes' mean time in this study = 117 s). Data analyses were performed using SPSS Statistics 17 (Chicago, IL) with alpha level set at 0.05.

RESULTS

Forty-six athletes (females = 27; males = 19) experienced a total of 63 time-loss injuries during the study. Thirty-two (16.6%) athletes experienced one injury, 12 (6.2%) experienced two injuries, and two athletes (1.0%) sustained three or more injuries.

SLJ

Mean SLJ distances (normalized by height) for female athletes were 0.79 (± 0.10) and 0.94 (± 0.12) for male athletes. Table 1 presents the univariate odds ratios for normalized SLJ scores for D III student-athletes. No significant risk associations were found for either gender.

SLH

Mean SLH distances (normalized) for female athletes were 0.66 (± 0.10) for the right lower extremity and 0.65 (± 0.10) for the left lower extremity. Mean SLH distances (normalized) for male athletes were 0.75 (± 0.13) for the right lower extremity and 0.75 (± 0.12) for the left lower extremity. Table 2 presents univariate odds ratios for SLH distance based on side-to-side differences (also known as LSI). Female athletes with a side-to-side hop distance dif-

Table 1. *Crude Odds Ratios for Normalized Standing Long Jump Scores for Division III Student-Athletes.*

	N at risk	All Injuries (%)	Odds Ratio	95% CI	Thigh/ Knee Injuries (%)	Odds Ratio	95% CI	Foot/Ankle Injuries (%)	Odds Ratio	95% CI
Standing Long Jump as a % of one's height										
Females (n = 110)										
80% or more†	48	(23)	1.0	Referent	(8)	1.0	Referent	(10)	1.0	Referent
79% or less	62	(26)	1.2	(0.5, 2.8)	(12)	1.4	(0.4, 5.1)	(11)	1.1	(0.3, 3.7)
Males (n = 83)										
90% or more†	51	(28)	1.0	Referent	(12)	1.0	Referent	(12)	1.0	Referent
89% or less	32	(16)	0.5	(0.2, 1.5)	(6)	0.4	(0.1, 1.8)	(9)	0.8	(0.1, 3.3)

CI, Confidence interval

†Cut score based on clinical recommendation[17,18]

Table 2. *Crude Odds Ratios for Single-Leg Hop Scores Side-to-Side Differences between Lower Extremities for Division III Student-Athletes.*

	N at risk	All Injuries (%) Per Category	Odds Ratio	95% CI	Thigh and Knee Injuries (%) Per Category	Odds Ratio	95% CI	Foot and Ankle Injuries (%) Per Category	Odds Ratio	95% CI
Single Leg Hop (Side-to-Side Difference)										
Females										
10% or less†	86	(21)	1.0	Referent	(9)	1.0	Referent	(7)	1.0	Referent
More than 10%	24	(38)	2.3	(0.9, 6.0)	(13)	1.4	(0.3, 5.7)	(25)	**4.4**	**(1.2, 15.4)**
Males										
10% or less†	68	(24)	1.0	Referent	(12)	1.0	Referent	(12)	1.0	Referent
More than 10%	15	(20)	0.8	(0.2, 3.2)	(13)	1.2	(0.2, 6.1)	(7)	0.5	(0.1, 4.6)

CI, Confidence interval

†Cut score based on clinical recommendation[17,18]

ference greater than 10% was associated with a 4-fold increase (OR = 4.4, 95% CI: 1.2, 15.4; p = 0.02) in having a foot or ankle injury.

Table 3 presents univariate odds ratios for the SLH distances as a percentage of an athlete's height. SLH distances as a percentage of height were not associated with time-loss injury in female athletes. Associations between SLH scores and time-loss injury were observed in male athletes with risk of injury increasing with greater SLH distances. Male athletes who hopped less than 75% of their height with their right LE had a significantly lower risk of any injury (OR = 0.3, 95% CI: 0.1, 0.9; p = 0.03, or conversely OR = 3.6, 95% CI: 1.2, 11.2; p = 0.03 if the hop distance was 75% or more of one's height). Male athletes who hopped less than 80% of their height with their right LE also had a significantly lower risk of any injury (OR = 0.2, 95% CI: 0.1, 0.5) and thigh or knee injuries (OR = 0.2, 95% CI: 0.1, 0.9). Conversely, male athletes who hopped 80% of their height or more using their right LE had a 5-fold increase for any injury (OR = 5.5, 95% CI: 1.8, 16.8; p = 0.003) and a 4-fold increase in thigh or knee injuries (OR = 4.8, 95% CI: 1.1, 20.1; p = 0.03). Male athletes who hopped less than 85% of their height[17,18] with their right LE also had a significantly lower risk of any injury (OR = 0.2, 95% CI: 0.1, 0.5; p = 0.002) and thigh or knee injuries

Table 3. *Crude Odds Ratios for Single-Leg Hop Scores as a Percentage of Height for Division III Student-Athletes.*

	N at risk	All Injuries (%) Per Category	Odds Ratio	95% CI	Thigh and Knee Injuries (%) Per Category	Odds Ratio	95% CI	Foot and Ankle Injuries (%) Per Category	Odds Ratio	95% CI
Single Leg Hop (Percentage of Height)										
Females	(n = 110)									
Right Leg										
65% or more†	62	(23)	1.0	Referent	(8)	1.0	Referent	(11)	1.0	Referent
Less than 65%	48	(27)	1.3	(0.5, 3.0)	(13)	1.6	(0.5, 5.7)	(10)	0.9	(0.3, 3.1)
70% or more	37	(26)	1.0	Referent	(11)	1.0	Referent	(11)	1.0	Referent
Less than 70%‡	73	(22)	1.3	(0.5, 3.3)	(8)	1.4	(0.3, 5.6)	(11)	1.0	(0.3, 3.6)
Left Leg										
65% or more†	57	(26)	1.0	Referent	(5)	1.0	Referent	(14)	1.0	Referent
Less than 65%	53	(27)	0.8	(0.3, 2.0)	(15)	3.2	(0.8, 12.8)	(8)	0.5	(0.2, 1.8)
70% or more‡	29	(24)	1.0	Referent	(7)	1.0	Referent	(10)	1.0	Referent
Less than 70%	81	(25)	1.0	(0.4, 2.8)	(11)	1.7	(0.3, 8.3)	(11)	1.1	(0.3, 4.3)
Males	(n = 83)									
Right Leg										
75% or more†	42	(33)	1.0	Referent	(17)	1.0	Referent	(17)	1.0	Referent
Less than 75%	41	(12)	**0.3**	**(0.1, 0.9)**	(7)	0.4	(0.1, 1.6)	(5)	0.3	(0.1, 1.3)
80% or more‡	31	(42)	1.0	Referent	(23)	1.0	Referent	(19)	1.0	Referent
Less than 80%	52	(12)	**0.2**	**(0.1, 0.5)**	(6)	**0.2**	**(0.1, 0.9)**	(6)	0.3	(0.1, 1.1)
85% or more‡	23	(48)	1.0	Referent	(30)	1.0	Referent	(17)	1.0	Referent
Less than 85%	60	(13)	**0.2**	**(0.1, 0.5)**	(5)	**0.1**	**(0.03, 0.5)**	(8)	0.4	(0.1, 1.8)
Left Leg										
75% or more†	42	(33)	1.0	Referent	(17)	1.0	Referent	(17)	1.0	Referent
Less than 75%	41	(12)	**0.3**	**(0.1, 0.9)**	(7)	0.2	(0.0, 1.1)	(5)	0.5	(0.1, 2.0)
80% or more‡	31	(42)	1.0	Referent	(23)	1.0	Referent	(19)	1.0	Referent
Less than 80%	52	(12)	0.2	**(0.1, 0.7)**	(6)	**0.2**	**(0.5, 0.8)**	(6)	0.4	(0.1, 1.7)
85% or more‡	19	(53)	1.0	Referent	(32)	1.0	Referent	(21)	1.0	Referent
Less than 85%	64	(14)	**0.1**	**(0.05, 0.5)**	(6)	**0.1**	**(0.04, 0.6)**	(8)	0.3	(0.08, 1.3)

CI, Confidence interval

† Study population's mean score

‡ Cut score based on clinical recommendations[17,18]

Note: Bold numbers indicate statistically significant results.

(OR= 0.1, 95% CI: 0.03, 0.5; p=0.005). Conversely, male athletes who hopped 85% of their height or more using their right LE had a 6-fold increase for any injury (OR= 6.0, 95% CI: 2.0, 18.0; p = 0.002) and an 8-fold increase in thigh or knee injuries (OR= 8.3, 95% CI: 1.9, 35.9; p = 0.005).

Similar findings were observed when assessing risk on the left LE. Male athletes who hopped less than 75% of their height with their left LE had a significantly lower risk of "all injuries" (OR= 0.3, 95% CI: 0.1, 0.9; p=0.03 or conversely OR = 3.6, 95% CI: 1.2, 11.2; p = 0.03 if the hop distance was 75% or more of one's height). Male athletes who hopped less than 80% of their height with their left LE also had a significantly lower risk of any injury (OR= 0.2, 95% CI: 0.1, 0.7; p=0.007) and thigh or knee injuries (OR= 0.2, 95% CI: 0.5, 0.8; p=0.03). Conversely, male athletes who hopped 80% of their height on their left LE or more had a 4-fold increase for any injury (OR= 4.4, 95% CI: 1.5, 12.9; p = 0.007) and a 5-fold increase in thigh or knee injuries (OR= 5.1, 95% CI: 1.2, 21.4; p = 0.03). Male athletes who hopped less than 85% of their height (based on CR)[17,18] with their right LE also had a significantly lower risk of any injury (OR= 0.1, 95% CI: 0.05, 0.5; p=0.0001) and thigh or knee injuries (OR= 0.1, 95% CI: 0.04, 0.6; p=0.007). In other words, male athletes who hopped 85% of their height or more using their right LE had a 7-fold increase for any injury (OR= 7.0, 95% CI: 2.2, 21.3; p = 0.001) and an 7-fold increase in thigh or knee injuries (OR= 7.0, 95% CI: 1.7, 28.1; p = 0.007).

LEFT

Mean LEFT scores was 117 (± 10s) for female athletes and 105 (± 9s) for males (Table 4). An increased risk of thigh or knee injury was observed among the slower female athletes. Female athletes who ran slower than either referent group (mean score 117 s; CR 120 s) were at least 6 times more likely to experience a thigh or knee injury (OR=6.0, 95% CI: 1.4, 24.8; p = 0.01 based on the CR and OR=6.4, CI: 1.3, 31.7; p = 0.02, based on the study's mean score). Male athletes who completed the LEFT in 100 sec or less (the CR cutoff score) were more likely to experience a time-loss injury to the low back or lower extremity (OR=3.2, 95% CI: 1.1, 9.5; p = 0.03) or a foot or ankle injury (OR=6.7, 95% CI: 1.5, 29.7; p = 0.01) than male athletes who completed the course in 101 seconds or more.

DISCUSSION

The primary purpose of this study was to determine if performance on the SLJ, the SLH, or the LEFT was associated with low back or lower extremity injury in D III collegiate student-athletes. The results indicated that 1) female athletes with side-to-side asymmetry between SLH distances (>10%) had a 4-fold increase for a foot or ankle injury, 2) male athletes with SLH distances (either leg) at least 75% of their height had at least a 3-fold increase for a low back or lower extremity injury, 3) female athletes who completed the LEFT in 118 seconds or more were 6 times more likely to sustain a thigh or knee injury, and 4) male athletes who completed the LEFT in 100 sec or less were more likely to experience a time-loss injury to the low back or lower extremity than slower male athletes. The SLJ was not associated with increased injury risk for either female or male athletes in this sample.

To the authors' knowledge this is the first study to examine these functional tests as preseason measures to predict the likelihood of sports injury at any level of competition. Coaching staffs and strength coaches at the D III level are limited in available resources to assess fitness and injury risk during the preseason. In some cases, coaches may only have two weeks of formal practice prior to the first competition. The three tests assessed in this study are quick to administer, require minimal equipment, and can be administered by one individual. Other strengths associated with our study include its prospective design and its overall subject size. During the preseason, we were able to create a risk profile for each athlete prior to the onset of injuries reducing the likelihood of measurement and recall bias.[24, 25]

SLJ

Contrary to the authors' hypothesis, no association was found between SLJ distance and risk of a time-loss low back or lower extremity injury in this sample. Several possible explanations exist. First, the cutoff score that was used was based on data from previous clinical commentary. Davies et al incorporated the SLJ test (performed with arms behind one's back) into their "functional testing algorithm;" a rehabilitation progression developed to guide rehabilitation management for patients recovering from a lower extremity injury.[17,18] In their return to sport testing protocol, to advance from one stage of the functional testing algorithm to the next, men were required to jump (SLJ) at least 90% of their height and women were required to jump at least 80% of their eight.[17,18] These suggested minimum SLJ scores are based on clinical recommendations with regard to return to sport after injury rather than as descriptive preseason scores for healthy D III athletes. In the current study 60% of female athletes and 39.7% of male athletes were unable to meet the prior CR. Analysis using a ROC curve was not possible with the current sample size and the range of values observed; hence the reliance on previous CR was used for analysis. Second, the standing long jump may not be a sensitive test for some athletes based on sport-specific pathomechanics. For example, while a standing long jump may be a sensitive test for female volleyball and basketball players it may not be as sensitive a test for female softball players. Ultimately, a homogenous sample (e.g., basketball or volleyball players versus baseball and softball players) may reveal cut scores for the SLJ appropriate for specific populations. Third, it may be that athletes with greater SLJ scores (e.g., the male athletes in this population) possess the athletic ability that allow them to jump distances that may create forces when landing from a jump that may increase risk of injury.[19,26] Marquez et al[26] reported greater peak vertical and horizontal forces in male volleyball players when landing from the longer of two jumping positions. Increased ground reaction forces have been reported as a potential contributing factor in athletes who sustained an ACL injury.[27] Male athletes in this study who jumped 90% of their height or more experienced a greater percentage of injury than their male counterparts that jumped 89% of their height or less (Table 1). Although this association between SLJ distance and injury risk was not significant, future research assessing SLJ distance in males who participate in jumping sports (e.g., basketball, jumping events in track) appears warranted.

SLH

The increased risk of injury in female athletes with side-to-side asymmetry during the SLH test was consistent with the authors' hypothesis. However, this association was only found for foot or ankle injuries. Davies et al[17,18] suggested that a female's single limb functional hop test for distance should be within 15% of opposite leg, or alternately that the LSI should be greater than 85% when functionally testing the rehabilitating athlete. The current results suggest that some D III female athletes may be at risk for injury if the asymmetry between limbs is greater than 10%. The data did not allow for analysis of other cutoff scores (e.g., >15%, >20%, etc.) due to a lack of subjects with test scores at these levels. No significant associations were found between time-loss injury and asymmetry between SLH for male athletes.

Contrary to what was expected, male athletes had an increased risk of injury if their SLH distance was 75% of their height or greater. Davies et al[17,18] suggested that males should be able to hop at least 80% of their height prior to returning to sport after a knee injury. In this population of D III athletes, the mean SLH distance was 75% (both legs) of their height. Cutoff scores were based on the male athlete's mean SLH distances and prior CRs.[17,18] The authors are unable to explain why this injury relationship was observed but suggest that male athletes who achieve high SLH scores may have been at greater risk for injury as some of them may have had greater playing time during games, although this variable was not recorded in the current study. Thus, the authors recommend that future studies should account for total sport participation time (e.g., starters play more minutes than other teammates during games) and assess the athletes for lower extremity biomechanical differences. The authors of the current study do not suggest that male athletes should be trained (or undertrained) to decrease their SLH distances. As stated previously, there are likely multiple factors in addition to SLH distance that increase injury risk.

LEFT

Using either the CR referent cutoff score and the mean time referent cutoff score determined in the current study, female athletes with slower LEFT times were found to have a 6-fold increase in thigh or knee injury (female athletes sustained time-loss injuries to the knee (n = 5) and thigh (n = 6)) as compared to female athletes with faster times. A possible reason the slower female athletes in this sample were at a greater risk for injury was because they may have been in a less-conditioned state (e.g., muscular weakness, less coordinated, etc.) at the start of the season. Whether or not slower female athletes present with dysfunctional kinetics and kinematics is unknown. Further research is necessary to assess kinetic or kinematic differences between slower and faster female athletes.

Contrary to the findings among female athletes, faster male athletes had a higher risk of low back or lower extremity injury, when compared to slower male counterparts, especially for ankle or foot injuries (Table 4). The difference in risk association between females (greater risk with slower LEFT scores) and

Table 4. *Crude Odds Ratios for Lower Extremity Functional Test Scores for Division III Student-Athletes.*

Lower Extremity Functional Test (sec)	N at risk	All Injuries (%) Per Category	Odds Ratio	95% CI	Thigh and Knee Injuries (%) Per Category	Odds Ratio	95% CI	Foot and Ankle Injuries (%) Per Category	Odds Ratio	95% CI
Males	(n = 83)									
100 (s) or less‡	23	(39)	1.0	Referent	(17)	1.0	Referent	(26)	1.0	Referent
101 (s) or more	60	(17)	**0.3**	**(0.1, 0.9)**	(10)	0.5	(0.1, 2.1)	(5)	**0.1**	**(0.0, 0.7)**
105 (s) or less†	47	(26)	1.0	Referent	(13)	1.0	Referent	(8)	1.0	Referent
106 (s) or more	36	(19)	0.7	(0.2, 2.0)	(11)	0.9	(0.2, 3.3)	(13)	0.6	(0.1, 2.7)
Females	(n = 106)									
117 (s) or less†	61	(18)	1.0	Referent	(3)	1.0	Referent	(7)	1.0	Referent
118 (s) or more	45	(29)	1.8	(0.7, 4.6)	(18)	**6.4**	**(1.3, 31.7)**	(12)	0.5	(0.1, 2.2)
120 (s) or less‡	72	(19)	1.0	Referent	(4)	1.0	Referent	(13)	1.0	Referent
121 (s) or more	34	(29)	1.7	(0.7, 4.4)	(21)	**6.0**	**(1.4, 24.8)**	(3)	0.2	(0.3, 1.7)

CI, confidence interval.

† Mean LEFT score for athletes in this study

‡ Cut score based on clinical recommendations[17,18]

males (greater risk with faster LEFT scores) may be related to gender differences in lower extremity biomechanics during cutting maneuvers and the forces associated with sprinting.[28-31]

Several limitations in the current study are noted. First, although more athletes were recruited than the necessary number of subjects based on the power analysis, the authors were limited in the ability to appropriately conduct several specific analyses based on sport or type of injury due to smaller sample sizes in these several sports. However, as previously mentioned, a function of the study was to assess the three tests for potential application among the global student-athlete body. Second, because we included D III university athletes from 15 teams, some athletes may have had a lower risk of injury by virtue of the sport they play. For example, in our study we found that athletes in some sports (e.g., women's soccer) experienced more time-loss injuries than those in other sports (e.g., women's tennis). Future investigations should assess injury risk based on functional test scores per sport. Third, we were unable to test all athletes in all sports. Characteristics of those who did not volunteer for the study may have changed our overall jump scores in the "at risk" and "not at risk" groups, thus affecting our overall risk estimates. Fourth, although we standardized injury severity based on time loss from sport, we were unable to categorize injuries based on mechanism (traumatic or gradual onset).

CONCLUSION

Preseason scores on the LEFT and the SLH for distance were associated with an increased risk of low back and lower extremity injury in D III collegiate athletes. These tests are quick to administer, require minimal personnel, and do not require special equipment. These tests warrant further consideration as preparticipatory screening examination tools for sport injury in more specific athlete populations.

REFERENCES

1. National Collegiate Athletic Association. Differences among the three divisions: division III. 2011. Available at: http://www.ncaa.org/wps/wcm/connect/public/NCAA/About+the+NCAA/Who+We+Are/Differences+Among+the+Divisions/Division++III/About+Division+III. Accessed July 16th, 2012.
2. Cowley HR, Ford KR, Myer GD, et al. Differences in neuromuscular strategies between landing and cutting tasks in female basketball and soccer athletes. *J Athl Train.* 2006; 41: 67-73.
3. Franklin A, Panchik D. Injuries and the quality of life of collegiate athletes: a pilot study. *Internet J Allied Health Sci Pract.* 2010; 8(4): 1-9.
4. Freedman KB, Glasgow MT, Glasgow SG, et al. Anterior cruciate ligament injury and reconstruction among university students. *Clin Orthop Relat Res.* 1998; 208-212.

5. Harris LL. Integrating and analyzing psychological and stage theories to challenge the development of the injured collegiate athlete. *J Athl Train.* 2003; 38(1): 75-82.
6. Johnston LH, Carroll D. The psychological impact of injury: effects of prior sport and exercise involvement. *Br J Sports Med.* 2000; 34: 436-439.
7. Kilpatrick M, Hebert E, Bartholomew J. College students' motivation for physical activity: differentiating men's and women's motives for sport participation and exercise. *J Am Coll Health.* 2005; 54(2): 87-94.
8. Perna FM, Antoni MH, Baum A, et al. Cognitive behavioral stress management effects on injury and illness among competitive athletes: a randomized clinical trial. *Ann Behav Med.* 2003; 25(1): 66-73.
9. Selby R, Weinstein HM, Bird TS. The health of university athletes: attitudes, behaviors, and stressors. *J Am Coll Health.* 1990; 39(1): 11-18.
10. Reiman MP, Manske RC. *Functional Testing in Human Performance.* Champaign, IL: Human Kinetics; 2009.
11. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* 2005; 33(4): 492-501.
12. Kiesel K, Plisky PJ, Voight ML. Can serious injury in professional football be predicted by a preseason functional movement screen? *N Am J Sports Phys Ther.* 2007; 2(3): 147-158.
13. Olmsted LC, Carcia CR, Hertel J, et al. Efficacy of the star excursion balance tests in detecting reach deficits in subjects with chronic ankle instability. *J Athl Train.* 2002; 37(4): 501-506.
14. Plisky PJ, Rauh MJ, Kaminski TW, et al. 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.
15. Cook G, Burton L, Hoogenboom B. Pre-participation screening: the use of fundamental movements as an assessment of function – part 1. *N Am J Sports Phys Ther.* 2006; 1(2): 62-72.
16. Cook G, Burton L, Hoogenboom B. Pre-participation screening: the use of fundamental movements as an assessment of function – part 2. *N Am J Sports Phys Ther.* 2006; 1(3): 132-139.
17. Davies GJ, Zillmer DA. Functional progression of a patient through a rehabilitation program. *Orthop Phys Ther Clin N Am.* 2000; 9(2): 103-117.
18. Davies GJ, Heiderscheit BC, Clark M. The scientific and clinical rationale for the use of open and closed kinetic chain rehabilitation. In: Ellenbecker TS, ed. *Knee Ligament Rehabilitation*. Philadelphia, PA: Churchill Livingstone; 2000: 291-300.
19. Elvin NG, Elvin AA, Arnoczky SP, et al. The correlation of segment acceleration and impact forces with knee angle in jump landing. *J Appl Biomechanics.* 2007; 23:203-212.
20. Ardern CL, Webster KE, Taylor NF, et al. Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery: two-thirds of patients have not returned by 12 months after surgery. *Am J Sports Med.* 2011; 39: 538-543.
21. Grindem H, Logerstedt D, Eitzen I, et al. Single-legged hop tests as predictors of self-reported knee function in nonoperatively treated individuals with anterior cruciate ligament injury. *Am J Sports Med.* 2011; 39: 2347-2354.
22. Logerstedt D, Grindem H, Lynch A, et al. Single-legged hop tests as predictors of self-reported knee function after anterior cruciate ligament reconstruction: the Delaware-Oslo ACL cohort study. *Am J Sports Med.* 2012; 40: 2348-2356.
23. Tabor MA, Davies GJ, Kernozek TW, et al. A multicenter study of the test-retest reliability of the lower extremity functional test. *J Sport Rehabil.* 2002; 11: 190-201.
24. Rauh MJ, Koepsell TD, Rivara FP, et al. Epidemiology of musculoskeletal injuries among high school cross-country runners. *Am J Epidemiol.* 2005; 163(2):151-159.
25. Rauh MJ, Macera CA, Trone DW, et al. Epidemiology of stress fracture and lower-extremity overuse injury in female recruits. *Med Sci Sports Exerc.* 2006; 38(9): 1571-1577.
26. Marquez WQ, Masumura M, Ae M. The effects of jumping distance on the landing mechanics after a volleyball spike. *Sports Biomech.* 2009; 8(2): 154-166.
27. Chappell JD, Yu B, Kirkendall DT, et al. A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *Am J Sports Med.* 2002; 30: 261-266.
28. James CR, Sizer PS, Starch DW, Lockhart TE, Slauterbeck J. Gender differences among sagittal plane knee kinematic and ground reaction force characteristics during a rapid sprint and cut maneuver. *Res Q Exerc Sport.* 2004; 75: 31-38.
29. Pollard CD, Heiderscheit BC, van Emmerik REA, Hamill J. Gender differences in lower extremity coupling variability during an unanticipated cutting maneuver. *J Appl Biomech.* 2005; 21: 143-152.
30. Pollard CD, Sigward SM, Powers CM. Gender differences in hip joint kinematics and kinetics during side-step cutting maneuver. *Clin J Sports Med.* 2007; 17: 38-42.
31. Sigward SM, Powers CM. The influence of gender on knee kinematics, kinetics and muscle activation patterns during side-step cutting. *Clin Biomech.*

Appendix Table 1. *The 16-Step Sequence of Multidirectional Skills Involved in the Lower Extremity Functional Test.*

Step	Skill	Direction	Skill description	Target Sequence
1	Forward run	Forward	Subject forward runs between targets, turning at C.	A, C, A
2	Retro run	Backward	Subject backpedals between targets, turning at C.	A, C, A
3	Side shuffle	Right	Subject performs a side-shuffle maneuver to the right, facing the center, around the outside of the entire course	A, D, C, B, A
4	Side shuffle	Left	Subject performs a side-shuffle maneuver to the left, facing the center, around the outside of the entire course	A, B, C, D, A
5	Carioca	Right	Subject performs a carioca maneuver to the right, facing the center, around the outside of the entire course.	A, D, C, B, A
6	Carioca	Left	Subject performs a carioca maneuver to the left, facing the center, around the outside of the entire course.	A, B, C, D, A
7	Figure-8 run	Right	Subject forward runs around targets D and B and circles targets A and C from inside out	A, D, C, B, A
8	Figure-8 run	Left	Subject forward runs around targets D and B and circles targets A and C from inside out	A, B, C, D, A
9	45° cuts	Right	Subject forward runs to the right, plants the outside foot, and cuts 45° toward the next target.	A, D, C, B, A
10	45° cuts	Left	Subject forward runs to the left, plants the outside foot, and cuts 45° toward the next target.	A, B, C, D, A
11	90° cuts	Right	Subject forward runs to the right, plants the outside foot, and cuts 90° toward the next target.	A, D, B, A
12	90° cuts	Left	Subject forward runs to the left, plants the outside foot, and cuts 90° toward the next target.	A, B, D, A

Appendix Table 1. *The 16-Step Sequence of Multidirectional Skills Involved in the Lower Extremity Functional Test.*

Step	Skill	Direction	Skill description	Target Sequence
13	90° Cross-over cuts	Right	Subject forward runs to the right, plants the inside foot, crosses the outside foot over 90°, and runs toward the next target.	A, D, B, A
14	90° Cross-over cuts	Left	Subject forward run to the left, plants the inside foot, crosses the outside foot over 90°, and runs toward the next target.	A, B, D, A
15	Forward run	Forward	Subject forward runs between targets.	A, C, A
16	Retro run	Backward	Subject backpedals between targets.	A, C, A

Reprinted, with permission, from M.A. Tabor, G.J. Davies, T.W. Kernozek, et al., 2002, "A multicenter study of the test–retest reliability of the Lower Extremity Functional Test," Journal of Sport Rehabilitation 11(3): 190-201.