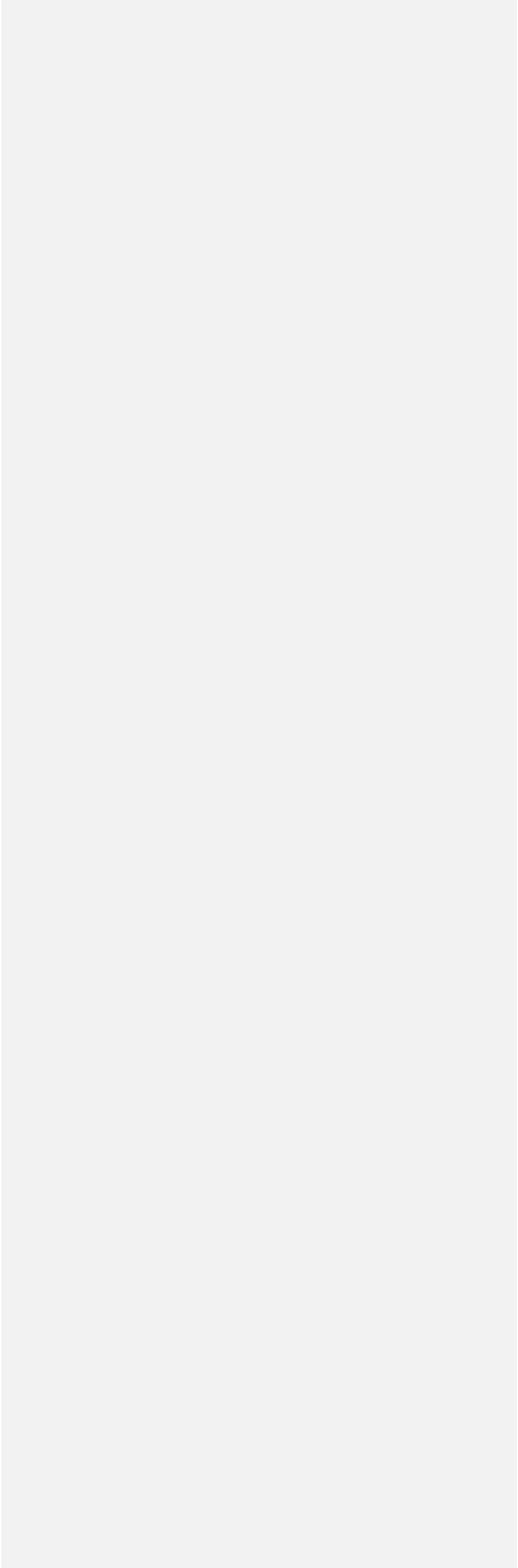


The association of functional screening tests and non-contact injuries in Division I women student-athletes



**Abstract**

To determine the association between functional screening tests and lower body, non-contact injuries in Division I women basketball, soccer, and volleyball student-athletes (SA).

68 injury-free women SA (age:19.1±1.1 yrs, height:171.3±8.7 cm, mass:68.4± 9.5 kg) were tested preseason with single (SH), triple (TH), and crossover (XH) hop for distance, and isometric hip strength (abduction, extension, and external rotation) in randomized order. The first lower body (spine and lower extremity), non-contact injury requiring intervention by the athletic trainer was abstracted from the electronic medical record. Receiver operating characteristic and area under the curve (AUC) were calculated to determine cut-points for each hopping test from the absolute value of between limb difference. Body weight-adjusted strength was categorized into tertiles. Logistic regression determined the odds of injury with each functional screening test using the hopping tests cut-points and strength categories, adjusting for previous injury history. 52 SA were injured during the sport season. The cut-point for SH was 4 cm (sensitivity=0.77, specificity=0.43, AUC=0.53), and TH and XH was 12 cm (sensitivity=0.75 and 0.67, specificity=0.71 and 0.57, AUC=0.59 and 0.41, respectively). A statistically significant association with TH and injuries (adjusted odds ratio=6.50 [95% confidence interval:1.69-25.04]) was found. No significant overall association was found with SH or XH, nor with the strength tests.

Using a clinically relevant injury definition, the TH showed the strongest predictive ability for non-contact injuries. This hopping test may be a clinically useful tool to help identify increased risk of injury in women SA participating in high-risk sports.

Keywords: movement asymmetry, musculoskeletal, injury prevention

**Introduction**

Musculoskeletal (MSK) injuries are a common event with National Collegiate Athletic Association (NCAA) student-athletes (SA), specifically in women's basketball(41), soccer(33), and volleyball(36). These 3 sports have some of the highest injury rates for women SA and are surpassed only by gymnastics(16). Injuries with a non-contact mechanism comprise between 25% in basketball(41) to almost 80% in volleyball(36), and the majority of injuries with a non-contact mechanism were non-time-loss injuries(33,36,41). Not only is there a high incidence of injuries(13), there is evidence of long-term declines in health-related quality of life, and high cost in the short and longer term(7,22,34). Therefore, the identification of risk factors for injuries that are amenable to intervention is a priority.

After a MSK injury or surgery, progress with rehabilitation for return to sport is often assessed with strength testing and functional tests, especially following anterior cruciate ligament (ACL) injuries(19,24,31,32). These strength tests may include hip extension, hip abduction, and hip external rotation(29). Recent work suggests that hip external rotation deficits are present in the involved ACL injured limb, even following return to sport-specific training(17). Hopping tests for distance (single, triple, and crossover), specifically asymmetry (i.e., limb differences), are the most commonly utilized functional test in making report to sport decisions after ACL injury(1,27).

Although studies have reported on the association between strength and hopping with incident or second ACL injury(26,28), there remains a paucity of research examining the relationship between these tests and other types of injury.(4) The mechanism of injury for ACL injuries has

been implicated in other types of injuries(26), but the association between these tests and less specific MSK injuries has not been empirically tested. Therefore, the purpose of this study was to determine the association between functional screening tests and lower body (i.e., spine and lower extremity), non-contact (i.e., acute and overuse) injuries in Division I (DI) women basketball, soccer, and volleyball SA. The hypothesis was that greater asymmetry between limbs with the hopping for distance tests would be associated with higher odds of lower body, non-contact injury. A second hypothesis was that SA with weaker proximal hip strength would have higher odds of lower body, non-contact injury.

## **Methods**

### **Experimental Approach to the Problem**

This study was a prospective cohort study of injury-free, women DI collegiate SA. Recruitment of participants and initial data collection of the functional screening tests (independent variables: single, triple, and crossover hop for distance, and maximal isometric hip abduction, extension, and external rotation) occurred during the 2014-7 academic years. Participants were enrolled in the study for one academic year. All participants were enrolled in the study after physician clearance for sport participation from the Department of Sports Medicine's annual pre-participation examination (PPE), and after screening for inclusion. The order of the functional screening tests was randomized, and all personnel involved with the participants during the sport season (e.g., strength and conditioning and sport coaches, athletic trainer [AT]) were blinded to the results of functional screening tests. Participants were then followed during one competitive sport season, and the first lower body, non-contact (i.e., acute or overuse) musculoskeletal injury (hereinafter referred to as injury) was abstracted from documentation in the electronic medical record ([EMR] dependent variable).

**Subjects**

For this study, 75 SA (age:  $19.1 \pm 1.1$  years old, height:  $171.3 \pm 8.7$  cm, and weight:  $68.4 \pm 2.5$  kg) from a DI college athletics program were recruited through the Department of Sports Medicine at the University. The inclusion criterion was clearance to participate in their respective sport as determined by the PPE. Potential participants were excluded with a self-report of a history of concussion within the last 6 months or any current injury from a standard questionnaire (see below) that limited the participant's ability to complete the testing as determined by a licensed physical therapist or AT. Participants were also excluded if not dressed in appropriate attire (self-selected athletic shoes). Participants were recruited from women's basketball ( $n = 16$ ), soccer ( $n = 40$ ), and volleyball ( $n = 19$ ) due to the high injury incidence(2,33,36,41). The University's Institutional Review Board approved the study protocol, and written informed consent was obtained from all participants prior to data collection.

**Procedures**

Baseline measurements were completed in the preseason after the PPE. After screening for inclusion and exclusion criteria, all participants performed the functional screening tests in a randomized order wearing standard workout attire; no warm-up was conducted. The functional screening tests were administrated by athletic trainers, physical therapists, and physical therapy students. A standardized training for all functional screening tests was completed by all of the testers.

The hopping for distance tests were designed to assess functional integrity of the knee joint(3,6,27). The tests were found to have good test re-test reliability in women (intra-class

correlation coefficients of 0.80, 0.80, and 0.87 for single, triple, and crossover hop test, respectively)(25) and the combination of these tests were reported to adequately classify people with ACL-deficient knees(27). All hopping tests protocols were performed consistent with published literature(6,27), and started with the participant standing on the right limb with the lead toe behind a clearly marked starting line (Figure 1). For the single hop test, the participant hopped as far as possible and landed on the same limb(6). For the triple hop test, the participant performed 3 consecutive hops, jumping as far as possible, and landing on the same foot(27). Finally, the crossover hop test was performed on a course consisting of a 15 cm wide marking strip. The participant hopped 3 consecutive times on one foot, crossing over (initial hop in the lateral direction) the center strip on each hop. For each hop test, the participants performed 1 practice trial for each limb, followed by 2 measured and recorded trials. To minimize fatigue, up to 30 seconds of rest was offered between individual hop test trials, if needed. No restrictions were placed on arm movement during testing, and no instructions were provided regarding where to look. For a test to be considered successful, the landing had to be maintained for 2 seconds. An unsuccessful hop included any of the following: touching down of the contralateral lower extremity, touching down of either upper extremity, loss of balance, or an additional hop on landing. If the hop was unsuccessful, the participant was reminded of the requirement to maintain the landing, and the hop was repeated. No further instructions were provided to the participants. For each trial, the total distance hopped was measured and recorded to the nearest centimeter from a standard tape measure that was affixed to the floor. After 2 trials with the right limb, the entire procedure was repeated on with the left limb.

Figure 1

Hip strength was assessed with a handheld dynamometer (Microfet, Hoggan Scientific, LLC, Salt Lake City, UT), measured in Newtons, in 3 motions in accordance with previously published literature, including abduction and external rotation(14), and extension(37). The protocols for testing were selected to minimize the effects of the tester's strength(14) as three different testers measured strength. The testing order for limbs and muscle groups was randomized for each participant, and all testing was completed on a standard plinth. Abduction testing was completed in sidelying with a pillow placed between the legs, to abduct the tested leg  $\sim 10^\circ$  [compared with a line between the anterior superior iliac spines] and a strap placed just proximal to the iliac crest and secured firmly around the underside of the table. The dynamometer was placed 5 cm proximal to the lateral knee joint line secured between the tested leg and a second strap wrapped around the leg and the underside of the plinth (Figure 2, panel a). For external rotation, the participant was positioned in sitting with hip and knee flexion ( $90^\circ$ ) and a strap to stabilize the thigh of the tested leg and towel roll between the knees. Resistance was given 5 cm proximal to medial malleolus with a strap around the leg and a stationary object to secure the dynamometer in place (Figure 2, panel b). Finally, for hip extension, the participants were positioned in prone with hip in neutral position and knee in  $70-90^\circ$  of flexion, and holding on to the sides of the table with hands. The dynamometer was placed 5 cm proximal to the knee joint line at the posterior aspect of the thigh (Figure 2, panel c). After 1 submaximal trial to ensure appropriate muscle action, the participant performed three, 5 second maximal isometric contractions; 25-30 seconds of rest were allowed between each trial. An additional 1 minute rest period was given  $\frac{1}{2}$  way through the testing.

#### Figure 2

A health history questionnaire was administered to determine self-reported previous and current

musculoskeletal injuries. Previous injury was defined as a 'yes' response to any of the lower body, location-specific (i.e., anatomic location – knee, ankle) questions. Previous injuries were assessed as a covariate in multivariable models, and current injury was used to determine exclusion for this study. This questionnaire, although not validated, has been used previously in studies involving college SA(35,38). Throughout the competitive season for each sport, sports medicine staff recorded injuries for all participants into an EMR (HealtheAthlete, Cerner Corp, Kansas City, MO). Injury information included injury anatomic location, type of injury (e.g., sprain, contusion), and injury mechanism (i.e., contact or non-contact). For this study, injury was defined as the first lower body (i.e., spine or lower extremity) MSK problem with a non-contact mechanism that caused the athlete to report to the athletic training room and required intervention; contact injuries were excluded and time-loss was not part of the injury definition. In addition, demographic and anthropometric data were recorded by Sports Medicine staff at the PPE. At the conclusion of all sport seasons, the injury, demographic, and anthropometric data were abstracted by 2 of the authors (AJC, MW) for analysis.

### **Statistical Analysis**

Demographic characteristics of the participants injured and uninjured were calculated as means ( $\pm$  standard error [SE]) for continuous variables and differences between the injured and uninjured participants were assessed via Student's *t*-test.

For the hopping for distance tests, asymmetry was calculated as the absolute difference of the distance hopped for each test between the average distance hopped on the right and left leg. A receiver operating characteristic (ROC) curve was created using several cut-points for the

asymmetry between limbs with the hopping tests and area under the curve (AUC) was calculated. For the single hop for distance, 2,4,6,8,10,15, and 20 cm were used as cut-points, whereas for the triple and crossover hop for distance, 4,8,12,16,20,25,30,35, and 40 cm were used. Sensitivity and specificity were calculated for each cut-point. The 3 strength testing trials for each limb and motion were averaged and adjusted for body weight. There were no differences between the right and left limb for any of the motions (data not shown), therefore, right limb was used for analysis. Because the strength measures were not normally distributed, and transformations (i.e., natural log, square) did not correct this, strength was categorized into tertiles.

For all inferential analyses, the dependent variable was binary as injured or uninjured. For the first hypothesis, the cut-points for each hopping for distance test were the independent variables (3 models for single, triple, and crossover hop for distance). For the second hypothesis, the strength categories were the independent variables (3 models for isometric hip abduction, extension, and external rotation). Logistic regression models assessed the association and calculated the odds of injury with hop test cut-points and strength categories. Potential covariates (history of previous injury, and body mass index [BMI] for the hopping tests only) were assessed; previous injury was included in the final models, as BMI did not change the estimate sufficiently to deem a confounder. An alpha of 0.05 signified statistical significance. SAS Version 9.4 (SAS Institute, Inc., Cary, NC) running on a Linux platform was used for analyses.

## **Results**

75 participants were screened for potential participation, and 4 were excluded because of concussion (n = 2), left foot/leg pain (n = 1) and lack of athletic attire (n = 1). An additional 3

people were excluded during the sport season as the mechanism of injury could not be ascertained from the EMR, leaving 68 participants (n = 15 for basketball, n = 38 for soccer, and n = 18 for volleyball). All participants completed the strength testing, and 65/68 (95.6%) completed the hopping tests (n = 3 due to lack of athletic shoes for hopping). 50/68 (73.5%) of the participants had a self-report of a previous injury.

52/68 (76.4%) participants sustained an injury during the sport season. Of the 15 basketball student-athletes, 12 reported an injury, whereas 26/38 in soccer, and 14/18 in volleyball. There were no differences in age, height, and weight between those injured and those not injured (Table 1). Most of the injuries were in the thigh (34.6%) and ankle (23.1%). Although the diagnoses varied, the thigh injuries were primarily quadriceps or hamstring muscle strains, and in the ankle, most of the injuries were ankle sprains.

Table 1

For the hopping tests, the optimal cut-point for single hop was 4 cm (sensitivity=0.77, specificity=0.43, AUC=0.53; Figure 3), and triple and crossover hop was 12 cm (sensitivity=0.75 and 0.67, specificity=0.71 and 0.57, AUC=0.59 and 0.41; Figure 4 and 5, respectively).

Figure 3, 4, and 5

A statistically significant association with triple hop ( $p = 0.007$ ) and injury (adjusted odds ratio [AOR] = 6.5, [95% confidence interval [CI]: 1.69 – 25.0]) was found (Table 2). No significant association was found with single ( $p = 0.33$ ) or crossover ( $p = 0.28$ ) hopping tests. Additionally, no statistically significant association was found between hip abduction ( $p = 0.26$ ) or extension

( $p = 0.99$ ) and injury. For hip external rotation strength, there was no overall effect with injury ( $p = 0.12$ ), but those who were in the weakest tertile had significantly higher odds of injury compared with those in the strongest tertile (AOR = 6.5 [1.69 – 25.04]); a significant association was not found for the middle tertile and injury (AOR = 1.47 [0.40 – 5.47]).

Table 2

### Discussion

Because of the high number of MSK injuries in collegiate women SA(13), there is a need to determine a method to identify those at a higher risk of injury to inform prevention interventions. The purpose of the study was to assess the association between common functional tests used in the athletic population - isometric hip strength (abduction, extension, and external rotation) and hopping for distance (single, triple, and crossover) with lower body, non-contact injuries in women SA playing NCAA Division I basketball, soccer, and volleyball. The triple hop showed the strongest predictive ability, and was significantly associated with injuries. None of the strength tests, nor the single or crossover hop had an overall association with injury in this group of Division I women SA.

Injuries among NCAA women collegiate SA are common in basketball(41), soccer(33), and volleyball(36). Data from the NCAA Injury Surveillance System revealed an injury rate in women's basketball of 6.54/1,000 athletic exposures (AE; 1 SA participating in 1 NCAA-sanctioned practice or competition(8)) (95% CI: 6.22 – 6.85/1,000 AE)(41) and in women's soccer 8.44/1,000 AE (95% CI: 8.09 – 8.79/1,000 AE)(33). Approximately ½ of these injuries were non-time-loss injuries (52.3% and 47.5% for women's basketball(41) and soccer(33),

respectively). High injury rates were also reported in a four-year study of 20 SA on a DI women's volleyball team (8.4/1,000 hours of practice or competition) with the large majority of these injuries categorized with a non-contact mechanism(36). The injury rates for these 3 women's sports are the highest for all women's NCAA championship sports other than gymnastics (10.4/1,000 AE)(16), making identification of injury risk factors amenable to intervention a priority.

Hopping for distance tests are frequently used to assess progress in rehabilitation and determine when an athlete is ready to return to play after lower extremity injuries(21,31). The single hop has also been shown to predict patient-reported knee function after ACL reconstruction(20). Despite the popularity of these tests during rehabilitation, very little is known about the ability of the hopping for distance tests to identify someone at increased risk for injury. Brumitt, et al.(5) measured the single hop in 193 Division III SA from 15 university teams and assessed the association of this test with 1 day time-loss injuries. A significant association was found with asymmetry (calculated as shorter distance/longer distance) in the single hop with foot and ankle injuries (OR = 4.4 [95% CI: 1.2 – 15.4]) among the women SA, but for the male SA, shorter hop distances had a protective effect with all injuries, as well as thigh and knee injuries specifically. Conversely, Frisch, et al.(10) found no significant association with single and 1 day time-loss injury in 67 male youth football (soccer) players.

The triple hop has been assessed in only one study in 359 NCAA DI men and women SA(12). A factor analysis determined the left and right triple hop along with a vertical jump loaded on a 'power' factor, which was not associated with injury. The triple hop alone and the crossover hop

have not been assessed in these previous studies and to our knowledge, the current study is the first to assess the association of the triple and crossover hop with injury. The current study found a significant increased odds of injury with lower triple hop distance, and a moderately good prediction of injury using a cut-point of 12 cm for the difference hopped between limbs and injury. The differences in findings for the single hop between the current study and Brumitt, et al.(5) may be explained by difference in methods. Brumitt, et al.(5) included women SA in sports not included in the current study (lacrosse, softball, cross-country, tennis, and track and field), and the injury definition was any injury (no limitation on mechanism) restricted to 1 day time-loss injuries, and then categorized into all, thigh and knee, and foot and ankle. The current study had 76.4% of the SA who sustained an injury compared with 25% in Brumitt, et al.(5) These differences may be attributable to differences in level of competition (DI vs. DIII), sports included, and/or injury definition. The injury definition may be a particularly salient difference as non-time-loss injuries can be a significant contributor to the overall injury burden for collegiate SA(15). Additionally, the statistical analysis did not assess or adjust for any confounding(5), and the lack of independence in the sample may have biased the results. Despite the differences in study, the seemingly positive findings in women SA for the single hop, as well as the addition of the current study's positive findings for the triple hop merit further study of these tests to better understand injury risk in collegiate SA.

In the current study, there was no association between isometric hip abduction or extension and injury in the sample of women collegiate basketball, soccer, and volleyball. In contrast to these findings, Hegedus, et al.(12) did report a significant association with a factor labeled 'hip stability,' which included right and left side plank tests for hip abduction and adduction, and

injury (OR = 0.44 [95% CI: 0.20 – 0.95]). More recently, isometric hip abduction strength was significantly able to predict ankle sprains in male competitive soccer players(30). The seemingly contradictory findings for hip abduction may be related to Type II error (see below), as well as differences in methods to assess hip strength(12) or samples studied(12,30). Decreased hip strength (abduction and external rotation) was associated with patellofemoral pain in women(14), but not known if this decreased hip strength preceded or was a consequence of knee pain. The current study did find a significant association in one of the comparisons with hip external rotation, but there was no consistent effect. Therefore, the relative contribution of hip strength to non-contact injury in women remains an important area of study.

It is important to consider the results of this study as the focus was on the ability of functional screening tests to identify student-athletes in women's basketball, soccer, and volleyball at risk for MSK injury during the sports season. Injuries in sports are multi-factorial,(23) and there are several intrinsic and extrinsic factors to examine. This study adds to the literature by identifying the triple hop as a field-expedient test that is associated with and has predictive ability for injury. Recently, Brumitt, et al.(4) reported on a significant association of a test cluster identified 'at risk' women collegiate students-athletes and lower quarter (OR = 2.9 [95% CI: 1.1 – 7.8]) and thigh or knee (OR = 9.7 [95% CI: 2.3 – 39.9]) injuries. 'At-risk' was defined as below a cut-point for standing long jump (SLJ) and lower extremity functional test (LEFT) for lower quarter injuries and below a cut-point for SLJ, LEFT, and single hop for thigh and knee injuries. Future research should consider including the triple hop in test clusters to define 'at-risk' student-athletes combined with training factors known to be associated with injury including training load,(9,11) fitness,(39,40) for early identification for delivery and evaluation of injury prevention

interventions.

There are several limitations worth considering for the interpretation of these results. Type II error cannot be ruled out for some of the findings. Despite recruiting participants for 3 years, and capturing almost all eligible (18+ years old, injury-free, and cleared for practice from PPE) SA, some comparisons were underpowered. Interestingly, the single and crossover hop tests had post-hoc power of 0.41 and 0.47, respectively, but Type II error was not a concern for the triple hop tests. The sample size is also evident in the wide confidence intervals, especially for the hopping tests. Multi-university or data collection over 5 years may help further elucidate the association of these tests with non-contact injuries; this may be particularly useful in the tests with higher parameter estimates (i.e., hip external rotation strength and crossover hop for distance). The testers were not the same for each academic year of participant recruitment. Some measures, especially the proximal hip strength may have error with different tester's strength.(18) However, we attempted to address this with a standardized training for the testers, following precise standard protocols, and selecting protocols that minimize between-tester differences.(14) Previous injury was a self-reported measure and there were lack of available details to allow a more precise categorization of previous injury, and we did not collect information on playing experience. An additional limitation was the inability to discern the injury mechanism (i.e., contact, non-contact) for 3 SA from the EMR data. A sensitivity analysis with all 3 categorized as non-contact injuries and also as not non-contact injury did not appreciably change the results. Finally, this study included only women's basketball, soccer, and volleyball. Care should be exercised in generalizing beyond these sports.

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In conclusion, the triple hop showed the strongest predictive ability for lower body, non-contact injury in NCAA DI women SA. This hopping test may be a clinically useful tool to help identify increased risk of injury in women collegiate SA playing high-risk sports.

### **Practical Applications**

Preseason scores on the triple hop for distances were predictive for lower body (i.e., spine and lower extremity), non-contact injuries, and were also associated with an increased risk of injury in student-athletes who are members of Division 1 women's basketball, soccer, and volleyball. The triple hop is a quick, field-expedient test that could be included efficiently by strength and conditioning and sports medicine professionals to identify women collegiate student-athletes who may be at a higher risk of injury. Once identified, a strength coach could work on injury prevention interventions focused on strength, power, proprioception to reduce the risk of lower body, non-contact injuries during the season.

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Table 1. Demographic and injury characteristics in women basketball, soccer, and volleyball student-athletes

Variable	Injured (n = 52) Mean (SE)	Not injured (n = 16) Mean (SE)	p-value
Age (years)	19.2 (1.1)	18.9 (1.1)	0.27
Height (cm)	172.3 (8.8)	168.5 (9.0)	0.14
Weight (kg)	69.5(10.1)	65.1 (8.9)	0.11
Injury location n (%) <sup>*</sup>		N/A	
Spine	6 (11.5%)		
Hip	4 (7.7%)		
Thigh	18 (34.6%)		
Knee	10 (19.2%)		
Ankle	12 (23.1%)		
Foot	1 (1.9%)		

\* 1 student-athlete had a diagnosis of 'general lower extremity tightness and pain' so location was not able to be ascertained

Table 2. Association of strength and hopping tests with non-contact lower body injuries in women basketball, soccer, and volleyball student-athletes

Test	Unadjusted	Adjusted for previous injury (yes/no)
Isometric strength tests (n = 68)		
Hip extension		
1 <sup>st</sup> tertile (Weakest)	1.28 (0.32 – 5.01)	1.10 (0.27 – 4.5)
2 <sup>nd</sup> tertile	1.43 (0.37 – 5.56)	1.03 (0.24 – 4.39)
3 <sup>rd</sup> tertile (Strongest)	1.0 (referent)	1.0 (referent)
Hip abduction		
1 <sup>st</sup> tertile (Weakest)	1.75 (0.37 – 8.37)	1.51 (0.31 – 7.43)
2 <sup>nd</sup> tertile	0.43 (0.11 – 1.60)	0.45 (0.12 – 1.73)
3 <sup>rd</sup> tertile (Strongest)	1.0 (referent)	1.0 (referent)
Hip external rotation		
1 <sup>st</sup> tertile (Weakest)	6.00 (1.11 – 32.54)	6.09 (1.09 – 34.19)
2 <sup>nd</sup> tertile	1.62 (0.45 – 5.78)	1.47 (0.40 – 5.47)
3 <sup>rd</sup> tertile (Strongest)	1.0 (referent)	1.0 (referent)
Hopping for distance tests (n = 65)		
Single hop		
> 4 cm	2.44 (0.71 – 8.43)	1.91 (0.52 – 7.02)
≤ 4 cm	1.0 (referent)	1.0 (referent)
Triple hop		
> 12 cm	7.31 (1.95 – 27.34)	6.50 (1.69 – 25.04)
≤ 12 cm	1.0 (referent)	1.0 (referent)
Crossover hop		
>12 cm	2.67 (0.80 – 8.93)	2.02 (0.56 – 7.24)
≤ 12 cm	1.0 (referent)	1.0 (referent)

**Figure titles**

Figure 1. Diagram of single, triple, and crossover hop

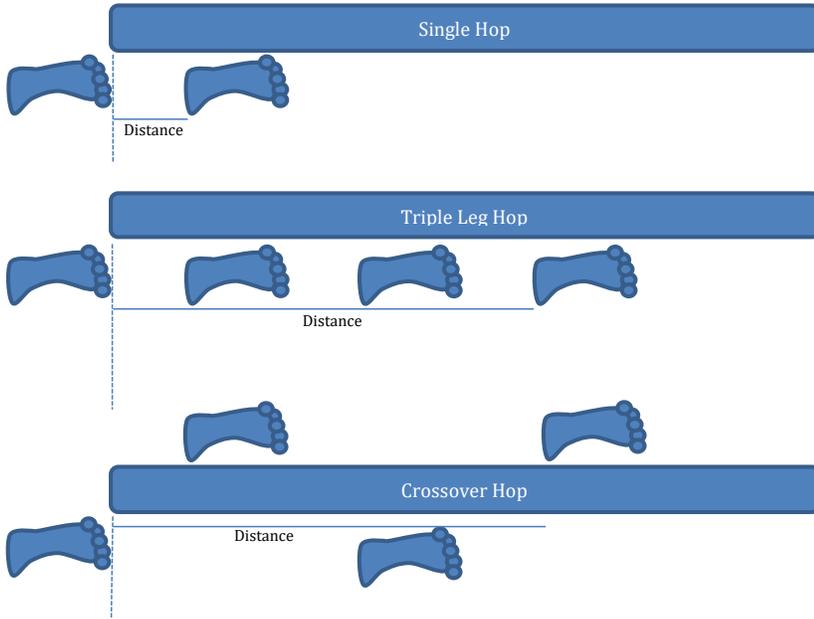


Figure 2. Starting position for the proximal hip strength testing for abduction (panel a), external rotation (panel b), and extension (panel c)



Figure 3. Receiver operator characteristic (ROC) curve for different cut-points of single hop for distance and lower body, non-contact injuries in women basketball, soccer, and volleyball student-athletes (n = 65). Cut-points assessed included 2,4,6,8,10,15, and 20 cm.

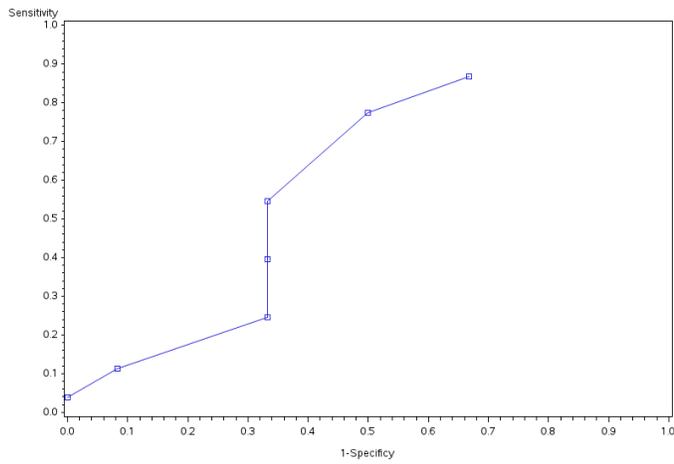


Figure 4. Receiver operator characteristic (ROC) curve for different cut-points of triple hop for distance and lower body, non-contact injuries in women basketball, soccer, and volleyball student-athletes (n = 65). Cut-points assessed included 4,8,12,16,20,25,30,35, and 40 cm.

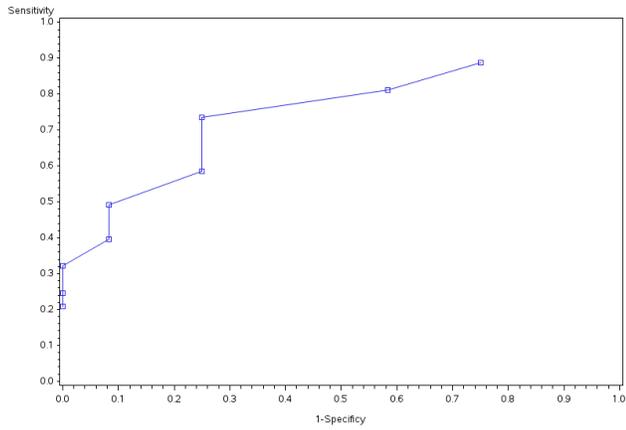


Figure 5. Receiver operator characteristic (ROC) curve for different cut-points of crossover hop for distance and lower body, non-contact injuries in women basketball, soccer, and volleyball student-athletes (n = 65). Cut-points assessed included 4,8,12,16,20,25,30,35, and 40 cm.

