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# Single leg squat test as a clinical tool to predict lower extremity injuries in adolescent athletes

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## Abstract

***Background:*** *The single leg squat test (SLS) is a biomechanical evaluation, simple and easily performed, and has been validated against the gold standard of 3-Dimensional (D) motion analysis [1-3]. A positive SLS test used in frontal plane biomechanical analysis can indicate poor lower extremity mechanics, reduced core strength, or hip abductor weakness indicating a higher risk for lower extremity injury [4-8]. SLS test has been studied primarily with biomechanical outcomes, and there is limited injury data to assess its predictive value in adolescents.*

***Objective:*** *To determine the predictive value of SLS test in predicting lower extremity injuries in adolescent, high school athletes with prospective injury data collected by athletic trainers over a one year period.*

***Design:*** *Longitudinal, non-randomized prospective design.*

***Setting:*** *Clinical and field based.*

***Interventions:*** *258 adolescent athletes from Central Oregon were evaluated while performing a SLS test during initial practices or during pre-participation physicals before the start of the academic year. Injuries sustained while playing sports during the following academic year were reported to each respective high school's certified athletic trainer and recorded on the Sportsware database.*
*Main Outcome Measurements: SLS Test and Injury Reports.*

***Results:*** *The sensitivity, specificity, and negative predictive value (NPV) of the SLS test in predicting lower extremity injuries were 66.67%, 36.59% and 95.74%, respectively. The sensitivity, specificity, and NPV of the SLS test in predicting a lower extremity injury in a high risk group of female soccer players were 50.00%, 30.16%, and 90.48%, respectively.*

***Conclusion:*** *Negative SLS in 36% of athletes was consistent with a low risk of lower extremity injury with 96% NPV. The high NPV is likely related to the low prevalence of LE injury in this study population and wouldn't translate to higher prevalence LE injury populations. Further study is needed to determine clinical utility of the SLS test.*

**Keywords:** Single Leg Squat Test, Biomechanical Analysis, Athletes

## Introduction

Clinicians and researchers are working to reduce the risk of sports related injuries in children and adolescents. One of the goals of pre-participation sports physicals is to identify those students at risk for musculoskeletal injury, but data regarding the predictive value of the assessment is lacking [9-11]. Lower extremity (LE) injury in high school athletes is the most common of all sports injuries 52.8%, with injuries to the knee being the most common of all sports season or career ending injuries [12]. Prevalence of patellofemoral pain was 7.2% for adolescents and 22.7% in adolescent female athletes [13]. Biomechanical assessment and targeted functional training improved symptoms and function in collegiate female athletes with patellofemoral pain [14]. While anterior cruciate ligament (ACL) injury rate/exposure was highest in girls' soccer, both girls and boys demonstrate an incidence rate of 0.062 ACL injuries per 1000 exposures with football, soccer, lacrosse and basketball having the greatest risk [15] compared to other sports. Injury prevention programs have been shown

to reduce ACL injury rates [16,17] and the rates of other lower extremity injuries [18]. Implementation of these injury prevention programs can be challenging and difficult to maintain. An alternative to generalized injury prevention training for all athletes would be to prescreen athletes for individual modifiable risk factors of injury with a biomechanical test with proven predictive value. Identification of poor control of frontal plane knee motion may allow targeted prevention using neuromuscular training and result in reduction of musculoskeletal injury risk [14,17].

Clinical biomechanical tests such as the duck walk and the single leg hop test that are included in the most recent version of the pre-participation physical. The duck walk hasn't been studied for predictive value, but the single leg hop was shown to have only fair predictive value in 12 years or older [19]. Other biomechanical screening tools include the vertical drop-jump test, landing error scoring system, star excursion balance test, functional movement screen, and the Y-balance test that aim to identify at-risk athletes for lower extremity injuries. These biomechanical assessments are costly and/or impractical to implement in a large group pre-participation examinations, or in clinical practice with time limitations.

In contrast, the single leg squat test (SLS) is a biomechanical evaluation that is both simple, with good inter and intra rater reliability in children, and has been validated compared to 2D drop jump test and 3D motion analysis for predicting defined abnormal motion patterns [2,5-7,20]. Our prior analysis showed good correlation of SLS result and dynamic knee valgus on vertical drop jump test that has been previously shown to correlate with abnormal frontal plane knee motion [7]. This study indicated the SLS test may be a good screening tool in pre-participation physicals, but limited prospective injury data has been compared to the SLS test to further define its predictive value clinically. The primary purpose of this study is to determine if the SLS test is an adequate clinical screening tool in predicting lower extremity injuries in all sports adolescent high school athletes as well as a high risk group defined as female soccer players with prospective injury data collected by athletic trainers over a 1 year time period. Also, in a higher risk female population, if the SLS is an appropriate diagnostic test for LE injury risk, one would expect the sensitivity, specificity, and the predictive value of the SLS to be of greater predictive value in the high risk population compared to a general athletic population.

## Methods

### *Participants*

Participants consisted of 258 athletes (155 females and 99 males, 4 with incomplete gender data) from high schools in Central Oregon, ages ranging between 14-18 years, mean 15.33 years. These athletes participated in cutting, running, and landing sports including soccer, basketball, football, wrestling, track, cheerleading, softball, and baseball. Only athletes, without prior or current injury were included. Individuals were recruited during the onset of their season during the 2013-15 academic school years and included junior varsity and varsity players. This data was captured to include athletes who participated in more than one sport. A designated high risk group of female soccer athletes was also recruited at the onset of their season. The Institutional Review Board approved this study.

### *Procedures*

The participants were evaluated while performing an SLS test at either their pre-participation physical exam in August before the start of the academic year or the first week of formal team practice at the school. A physician (author), a physical therapist (author), athletic trainers, or exercise physiology students who had undergone training in this testing method performed the testing. The SLS test has shown good inter- and intra-rater reliability in prior studies [5,7].

### *SLS Test*

This test was conducted similarly to the SLS test described [7] (Figure 1). The barefooted athletes were asked to place their hands on their hips and stand on one limb and flex the opposing limb to 90°. They then were instructed to perform an SLS to 30° of knee flexion and then return to a fully extended knee position. Visual inspection was used to estimate whether the participants squatted to 30°. If not, then the rater would give verbal cues to either increase or decrease the amount of knee flexion in subsequent squats. The participants performed the SLS test 3 times in a row on each leg. The athlete was evaluated in the frontal plane only. The investigator noted any abnormal responses, which were defined as arms flailing, the Trendelenburg sign, or collapse of the supporting knee into valgus. We defined a positive SLS test result as >2/3 SLS tests in a single leg with abnormal responses described above. If only one leg met criteria, their ultimate result was a positive test. Thus, a positive SLS test was consistent with postures indicating poor hip and knee biomechanics. Each participant was given either a positive or a negative score on the SLS test. They were then partitioned into two different groups based on these results.

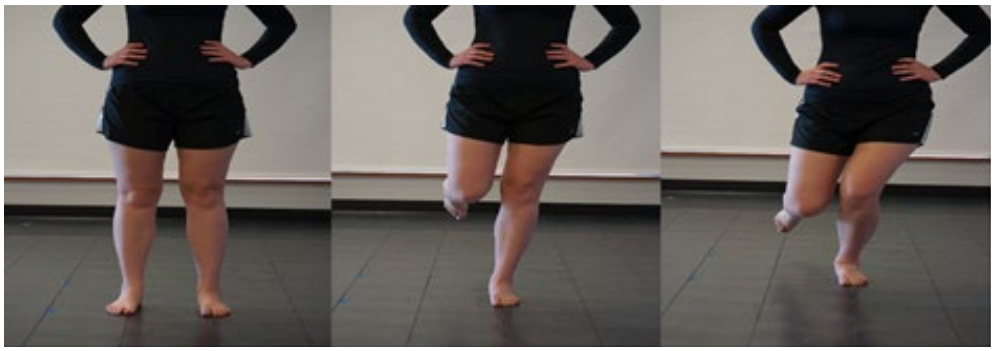

**Figure 1:** Single leg squat with visual assessment of knee alignment during a 30 degree squat [7].

### *Injury Reporting*

Injuries sustained while playing sports during the following academic year were reported to each respective high school's certified athletic trainer. At the time of the injury, data was recorded on Sportsware database. The data was then reviewed and recorded into a separate database for analysis. Lower extremity injuries were defined as anything that brought the athlete in for assessment by the trainer and resulted in a subsequent diagnosis.

### *Statistics*

Lower extremity (LE) injuries were reported for both the positive and negative SLS groups during the 2013-15 academic school years. Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were calculated for the SLS test in relation to lower extremity injuries in the entire group of athletes, a high risk group of female soccer players and for each gender. 95% confidence intervals (CI) were chosen for analysis. Statistical analysis was performed on NCSS 2019 Data Analysis software and MEDCALC.

## Results

### *Overall group analysis*

One hundred and sixty four of the 258 athletes (63.56%) had a positive SLS test result, whereas 94 (36.43%) had a negative SLS test result. There were 12 lower extremity injuries recorded during the 2013-2015 academic years within the study population, 8 occurring to participants with a positive SLS test result. None of the lower extremity injuries were ACL injuries. The main injuries were to the foot and ankle. 3 were hip strains/spasms. Only one knee injury diagnosis, patellofemoral syndrome, was reported in a female soccer player. The sensitivity, specificity, PPV and NPV of the SLS test in predicting lower extremity injuries were 66.67% (CI 34.89-90.08%), 36.59% (30.56- 42.94%), 4.88% (CI 3.29-7.18%) and 95.74% (CI 90.86-98.07%), respectively in Table 1. In addition, the odds ratio for injury risk was 0.946, (CI 0.424-2.11, p=0.892).

| | LE injury | No LE Injury | Sensitivity | Specificity | PPV | NPV |
|---|---|---|---|---|---|---|
| +SLS | 17 | 147 | 66.67% | 36.59% | 4.88% | 95.74% |
| -SLS | 11 | 90 | - | - | - | - |

**Table 1:** Lower Extremity (LE) Injuries. Combined group: sports physicals and high risk group, males and females.

### *High risk group analysis*

The high risk female soccer group was analyzed separately. A total of 67 females were studied. Four lower extremity injuries were recorded. The sensitivity, specificity, PPV and NPV of the SLS test in predicting lower extremity injuries were 50% (6.76-93.24%), 30.16% (19.23-43.02%), 4.35% (CI 1.66-10.93%) and 90.48% (CI 76.88-96.45%), respectively (Table 2). Odds ratio for the all females high risk group was 0.432, (CI 0.057-3.30, p=0.418).

| | LE injury | No LE Injury | Sensitivity | Specificity | PPV | NPV |
|---|---|---|---|---|---|---|
| +SLS | 2 | 44 | 50% | 30.16% | 4.35% | 90.48% |
| -SLS | 2 | 19 | - | - | - | - |

**Table 2:** High risk all female soccer group.

### *Gender analysis*

94/155 females demonstrated a +SLS=60.65% and 68/99 males had a +SLS=68.69%. Four subjects didn't have gender designated in their file and were excluded from the analysis. Eight females and 6 males demonstrated lower extremity injuries. The sensitivity was 50% (CI 11.81-88.19%) in females and 83.33% (CI 35.88-99.58%) in males. Specificity was 38.93% (CI 31.05-47.25%) in females and 32.26% (CI 22.93-42.75%) in males. The PPV was 3.19% (CI 1.44- 6.90%) in females and 7.35% (CI 5.13-10.44%) in males. The NPV was 95.08% (CI 89.44% -97.78%) in females and 96.77% (CI 83.03-99.46%) in males (Table 3). Odds ratio for females was 0.637 (CI=0.124-3.27, p=0.589) and for males the odds ratio was 2.38 (CI=0.266-21.3, p=0.438).

| Female | LE Injury | No LE Injury | Sensitivity | Specificity | PPV | NPV |
|---|---|---|---|---|---|---|
| +SLS | 3 | 91 | 50% | 38.93% | 3.19% | 95.08% |
| -SLS | 3 | 58 | - | - | - | - |
| **Male** | **LE Injury** | **No LE Injury** | **Sensitivity** | **Specificity** | **PPV** | **NPV** |
| +SLS | 5 | 63 | 83.33% | 32.26% | 7.35% | 96.77% |
| -SLS | 1 | 30 | - | - | - | - |

**Table 3:** Comparison of female and male for Lower Extremity Injuries.

## Discussion

Pre-participation sports evaluation and risk stratification has become an increasingly popular practice with the intended goal of decreasing the injury rates to athletes. The population within our study included a general group of adolescent athletes participating in cutting, landing and running sports, and female soccer players representing a high-risk group for sustaining lower extremity injuries. Prospective studies involving this population that correlates SLS results correlated with lower extremity injury rates are limited. Our findings indicate that the SLS test has its greatest clinical utility in the negative predictive value for this population of high school athletes. Thus, a negative SLS in both genders indicated a low risk of lower extremity injury. We found that this exam is easily performed and realistically reproducible for pre-participation physical exams with large groups of patients. We didn't find any better diagnostic value in a high risk group of female athletes compared to the general athletic adolescent population. While a positive test is not predictive or lower extremity injury, a negative SLS may define a group that would potentially not need targeted injury prevention exercises.

Other studies have analyzed a variety of biomechanical tests and their relationship to predicting lower extremity injuries in adolescents [21-25] and collegiate athletes [26-30]. Consistent with our data, Räisänen, et al reported the SLS test in 14-21 year olds demonstrated poor sensitivity for future injury risk based on ROC AUC analysis [25]. While their study population was of similar age, it was limited to athletes participating in only two sports (floorball and basketball). They found the odds ratio of an abnormal SLS test demonstrated a 2.7 times increased risk for LE injury (particularly the ankle). In our group there wasn't an associated increased risk of LE injury by odds ratio with a positive SLS test. In a group of female collegiate athletes' single leg squat testing was associated with patellofemoral pain and test results improved with neuromuscular training [14]. In National Collegiate Athletic Association (NCAA) Division I athletes, single leg squat and double leg squat testing demonstrating poor movement quality results correlated with higher LE injury risk. Sensitivity and specificity were similar to our findings [31]. Nakagawa, et al found in military recruits that SLS testing demonstrating abnormal frontal plane knee angles was a predictor of patellofemoral pain [32]. Meta analysis of SLS testing of all types demonstrated moderate reliability and feasibility in a clinical setting [33].

From our previous work we determined that the SLS correlated with 2D motion analysis with drop jump test consistent with abnormal knee biomechanics. To further our understanding of the SLS test and its association with injury, our presented research includes analysis of 2 cohorts: the general adolescent population risk and a predetermined high risk population of female soccer players as recommended by Dr. Bahr [34]. The negative predictive value of the test allows a clinician to determine a negative SLS test in adolescent athletes would be associated with a reduced risk of lower extremity injury. This adds to the body of knowledge regarding the sensitivity and specificity of biomechanical and musculoskeletal examination. However, this analysis is consistent with the studies noted above demonstrating the SLS test has low sensitivity making it a poor overall screening test. Two thirds of the athletes in our cohort would need further testing to determine their risk. Other limitations of our study include the following. Despite the large overall number of athletes studied, there was a small number of injuries that likely impacted the methodology. The low prevalence of LE injury in this study population 4.7% statistically would be associated with a high negative predictive value. Translation into other athletic populations would depend on the prevalence of lower extremity injury in that population. Raisanen's study of elite handball and floorball athletes had a much higher prevalence of lower extremity injuries 49%, illustrating that assessment of the population studied is important in translating results [25]. Also, time loss from each injury was not reported and determination of significance of injury therefore couldn't be analyzed.

## Conclusion

Lower extremity injury in sports is common in high school athletes, ranging from 21-57% of all injuries sustained in 1 year [12]. Within this general population of high school athletes participating in cutting, running and landing sports there is an increased risk of sustaining lower extremity injuries. Our data suggests that the SLS test is not an adequate screening tool for risk assessment. Future studies should look prospectively for biomechanical factors with a stronger relationship with injury risk and be performed with larger numbers of athletes.


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