The Influence of Sport Specialization on Landing Error Scoring System Scores in High School Athletes

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ABSTRACT

Purpose: To evaluate the impact of sport specialization on jump-landing performance in high school athletes as measured by the Landing Error Scoring System (LESS).

Methods: Five hundred seventy-four high school athletes participated in a cross-sectional study that evaluated the influence of sport specialization on jump-landing mechanics. The specialization level was assessed via a 3-point classification system (low = 38% of sample, moderate = 31% of sample, and high = 31% of sample). Research site and sex of the athlete were used as covariates in an analysis of covariance for the evaluation of differences in the mean total LESS scores across the three specialization groups, with higher LESS scores indicating poorer jump-landing mechanics.

Results: No differences in total LESS scores were observed between the three sport specialization groups when evaluating research sites independently or together and controlling for research site and sex of the athlete (adjusted mean LESS errors: low = 5.6 ± 2.1, moderate = 5.3 ± 1.9, and high = 5.1 ± 2.0; P > .05).

Conclusions: Jump-landing mechanics do not appear to be influenced by sport specialization status in high school athletes.

N early 8 million high school athletes participate in organized high school sports each year, and that number has increased steadily over the past 10 years.1,2 With this growth in overall participation, a trend that is gaining more attention across America is the practice of sport specialization. Athletes often engage in sport specialization with the hope of successfully competing at higher levels, securing a college scholarship, and playing professionally. However, specializing in a single sport early in life may not accomplish these goals, and the majority of current Division I college athletes were not classified as highly specialized throughout high school.3 Historically, sport specialization was defined by the practice of playing only one sport. Recently, varying levels of sport specialization were evaluated using a three-tier system of low, moderate, and high sport specialization.4-6 In that system, athletes are placed in categories based on the number of months an athlete participates in a single sport per year, the importance of the sport over other sports, and if an athlete quits one sport to focus on another sport.4-6 Differentiating athletes into varying levels of sport specialization will likely prove important in the evaluation of the impact of several negative consequences of sport specialization on athletes, including psychological and physical factors that lead to burnout, social isolation from peers, and increased injury risk.7,8 Several studies reported that individuals who specialized in one sport had increased rates of lower extremity injury.4,6,9,10 This includes overuse injuries such as stress fractures, patellofemoral pain syndrome, and patellar tendinopathy, and acute injuries including knee and ankle ligament sprains. Negative short- and long-term consequences, including time loss from sport participation, the premature development of osteoarthritis, and significant health care costs, are associated with these injuries.11-20 Overall, high school athletes sustain a rate of 22.81 injuries per 10,000 athlete exposures,21 and the relative risk of a higher specialized athlete sustaining a
lower extremity injury is nearly two times greater than a lower specialized athlete. One possible explanation is that specialization may impair neuromuscular control by limiting the development and training of a variety of fundamental motor skills. Because neuromuscular control is a modifiable risk factor for injury, it is an area that clinicians and researchers target to attempt to decrease the risk and burden of injury in athletes.

Neuromuscular control is evaluated through movement control and specifically jump-landing technique, which is crucial to injury prevention efforts. Movement control influences injury risk by minimizing loads on ligaments and other supporting structures. The Landing Error Scoring System (LESS) is one of the most researched and used clinical examinations to assess movement control in active populations. This tool is associated with injuries in several athletic populations and is able to identify possible high-risk movement patterns and deficits in neuromuscular control. The central hypothesis is that highly specialized athletes will perform repetitive sport-specific tasks, resulting in the overdevelopment of certain muscle groups and leading to hazardous lower extremity movement patterns that increase the risk of injury.

Therefore, the primary purpose of this study was to evaluate the impact of sport specialization status on neuromuscular control measured by LESS performance in high school athletes. We hypothesized that highly specialized athletes would exhibit higher (ie, worse) LESS scores than athletes with moderate or low specialization. Because highly specialized athletes are at increased risk for injury, there is a critical need to identify whether a disparity exists in the level of neuromuscular control between specialization groups, and highly specialized athletes may be a population to target with neuromuscular control interventions such as preventive training programs.

**METHODS**

We used a cross-sectional research design at two different research sites to evaluate whether differences in a clinical measurement of neuromuscular control existed between high school athletes with varying degrees of sport specialization. From the first research site (Wisconsin), a sample of 397 high school athletes (157 male, 240 female) participating in basketball, soccer, volleyball, and tennis from two schools agreed to participate during the 2014 to 2016 school years (Table 1). From the second research site (Connecticut), a total of 177 high school athletes (88 male, 89 female) participating in basketball, football, soccer, and volleyball from five schools volunteered to participate in the study during the 2016-2017 school year (Table 1). All participants and/or their parents or legal guardians signed informed assent and consent forms, respectively, which were approved by both research sites’ institutional review boards before participating. All participants were between the ages of 13 and 18 years. Participants were excluded from testing if they had an injury that prevented them from participating in sports activities on the day of testing.

**Procedures**

Participants attended a single test session. The test session was completed prior to physical activity for the day to assess the participants in a non-fatigued state. Prior to testing, participants completed a questionnaire inquiring about demographic information, sports participation, and specialization history. This questionnaire asked par-

<table>
<thead>
<tr>
<th>Category</th>
<th>Participants</th>
<th>Age (y) (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wisconsin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>157</td>
<td>16 ± 1</td>
</tr>
<tr>
<td>Female</td>
<td>240</td>
<td>15 ± 1</td>
</tr>
<tr>
<td>Boy’s soccer</td>
<td>91</td>
<td>16 ± 1</td>
</tr>
<tr>
<td>Girl’s soccer</td>
<td>78</td>
<td>16 ± 1</td>
</tr>
<tr>
<td>Volleyball</td>
<td>73</td>
<td>15 ± 1</td>
</tr>
<tr>
<td>Boy’s basketball</td>
<td>54</td>
<td>16 ± 1</td>
</tr>
<tr>
<td>Girl’s basketball</td>
<td>53</td>
<td>15 ± 1</td>
</tr>
<tr>
<td>Boy’s tennis</td>
<td>18</td>
<td>16 ± 1</td>
</tr>
<tr>
<td>Girl’s tennis</td>
<td>30</td>
<td>16 ± 1</td>
</tr>
<tr>
<td>Connecticut</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>88</td>
<td>16 ± 1</td>
</tr>
<tr>
<td>Female</td>
<td>89</td>
<td>16 ± 1</td>
</tr>
<tr>
<td>Boy’s soccer</td>
<td>14</td>
<td>16 ± 1</td>
</tr>
<tr>
<td>Girl’s soccer</td>
<td>13</td>
<td>15 ± 1</td>
</tr>
<tr>
<td>Volleyball</td>
<td>25</td>
<td>15 ± 1</td>
</tr>
<tr>
<td>Football</td>
<td>37</td>
<td>16 ± 1</td>
</tr>
<tr>
<td>Boy’s basketball</td>
<td>50</td>
<td>16 ± 1</td>
</tr>
<tr>
<td>Girl’s basketball</td>
<td>52</td>
<td>16 ± 1</td>
</tr>
</tbody>
</table>

SD = standard deviation
participants about their current and past sports participation and was adapted from previous research. Sport specialization categorization was based on three questions related to the definition of “year-round intensive training in a single sport at the exclusion of other sports.” These questions included: “Have you quit other sports to focus on one main sport?”; “Do you train more than 8 months out of the year in one main sport?”; and “Do you consider your main sport more important than other sports?” The answers to these questions were assigned a number value: “1” for yes and “0” for no. A score of 3 was categorized as high, 2 as moderate, and 1 or 0 as low.

**Jump-Landing Task (LESS)**

To clinically evaluate neuromuscular control, all participants were asked to jump forward a distance equal to half of their body height from a 30-cm high box. Immediately on landing, participants rebounded up, jumping for maximum height. Participants were given the opportunity to perform practice trials as needed. A successful jump required participants to: (1) jump forward off of the box (2) with both feet simultaneously, (3) land with both feet in a specified area, approximately half of their body height from the leading edge of the box, and (4) in one fluid motion. Trials that did not meet the prior criteria were excluded and repeated. Each participant completed three successful trials.

The LESS was used to evaluate movement errors during the jump-landing task. The LESS is a valid and reliable clinical movement assessment tool to identify high-risk movement during jump-landing tasks, and it accounts for 15 dichotomized items and two global items. Operational definitions for LESS items are described in the appendices of Padua et al. A higher LESS score indicates more landing errors and a poorer jump-landing technique, whereas a lower score indicates fewer errors and a better jump-landing technique.

At the Wisconsin research site, images of the jump-landing trials were captured on two standard video cameras (Panasonic HDC-SD80; Panasonic Consumer Electronics Company, Secaucus, NJ) placed 3.45 meters in front and to the side of the landing zone. The cameras captured a frontal and sagittal plane view. Trained raters reviewed each trial, scoring “1” if an error was present, “0” if no error was present for the 15 dichotomized items, and “0,” “1,” or “2” for two global items totaling an overall score. Raters (n = 3) were required to complete standardized training and achieve clinically acceptable levels of reliability (intraclass correlation coefficient [ICC] > 0.80) prior to evaluating videos. At the Connecticut research site, the jump-landing task was scored using an automated markerless motion capture system (PhysiMax Technologies Ltd, Tel Aviv, Israel) and an Xbox Kinect camera (Microsoft Corporation, Redmond, WA). This automated system is comparable to expert human evaluators for the LESS and produces a score on the same scale as the traditional method of scoring. The average of each participant’s three total LESS scores was used for analysis to assess the group average for each sport specialization group.

**Data Reduction and Statistical Analyses**

The primary dependent variable of interest was the overall LESS score. Previous research was used to power this study. The analysis demonstrated that a total sample size of 159 participants (53 per group) was needed to achieve 80% power (alpha = 0.05; standard deviation = 1.89 errors) to detect a clinically significant difference of one error between the high and low specialization groups. Based on the results of the two ANOVAs, we conducted an analysis of covariance (ANCOVA) to evaluate whether there were differences in total LESS score across specialization groups, while controlling for site and sex. Means and 95% confidence intervals were calculated from the results of the ANCOVA and ANOVA for LESS scores for the specialization groups. Effect sizes were calculated using Hedges’ g statistics (small effect = 0.2, medium effect = 0.5, large effect = 0.8). All data were analyzed using SPSS software (version 24.0; SPSS, Inc., Chicago, IL). Statistical significance was set a priori at a P value of less than .05.

**RESULTS**

A total of 245 males and 329 females participated in this study between the Wisconsin and Connecticut research sites (Table 1). The preliminary one-way ANOVA demonstrated that the Wisconsin research site had lower average total LESS scores compared to the Connecticut research site (P < .01) (Table 2). The pre-
The preliminary ANOVA also demonstrated that females had higher average total LESS scores compared to males ($P < .01$) (Table 3). Therefore, research site and sex of the athlete were used as covariates in the ANCOVA to evaluate differences in total LESS score between sport specialization groups. No significant differences in LESS scores were observed between sport specialization groups (high, moderate, and low) when controlling for site and sex ($P > .05$) (Table 4). Small effect sizes were also observed between the high and moderate ($g = 0.1$) and high and low ($g = 0.2$) groups, indicating these differences have limited clinical importance.

**DISCUSSION**

The most important finding of this study was that sport specialization, when stratified into the 3-point classification system, does not affect LESS scores at a single time point in high school athletes. Several studies have demonstrated that athletes who specialize in one sport are more likely to sustain or report a previous lower extremity injury, but few studies have evaluated the influence that sport specialization has on neuromuscular control, a factor contributing to injury risk.

Neuromuscular control is often evaluated through movement control, particularly during sport-specific movements. The analysis of LESS scores by specialization group and sex revealed no significant differences, suggesting that specialization does not impact neuromuscular control at a single time point.

### Table 2
**Unadjusted Mean LESS Score by Specialization Groups and Research Site**

<table>
<thead>
<tr>
<th>Research Site</th>
<th>Specialization Group</th>
<th>Participants</th>
<th>Mean</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wisconsin</td>
<td>Low</td>
<td>132</td>
<td>5.1</td>
<td>4.9 to 5.4</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>114</td>
<td>5.1</td>
<td>4.8 to 5.5</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>147</td>
<td>5.0</td>
<td>4.7 to 5.3</td>
</tr>
<tr>
<td>Connecticut</td>
<td>Low</td>
<td>87</td>
<td>6.4</td>
<td>6.0 to 6.8</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>60</td>
<td>5.9</td>
<td>5.3 to 6.4</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>30</td>
<td>6.1</td>
<td>5.3 to 6.8</td>
</tr>
</tbody>
</table>

LESS = Landing Error Scoring System; CI = confidence interval

### Table 3
**Unadjusted Mean LESS Score by Specialization Groups and Sex of the Athlete**

<table>
<thead>
<tr>
<th>Sex</th>
<th>Specialization Group</th>
<th>Participants</th>
<th>Mean</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Low</td>
<td>102</td>
<td>5.4</td>
<td>5.0 to 5.8</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>71</td>
<td>5.1</td>
<td>4.7 to 5.5</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>72</td>
<td>4.8</td>
<td>4.4 to 5.2</td>
</tr>
<tr>
<td>Female</td>
<td>Low</td>
<td>117</td>
<td>5.8</td>
<td>5.4 to 6.2</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>103</td>
<td>5.6</td>
<td>5.2 to 6.0</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>109</td>
<td>5.3</td>
<td>4.9 to 5.7</td>
</tr>
</tbody>
</table>

LESS = Landing Error Scoring System; CI = confidence interval

### Table 4
**Adjusted Mean LESS Score by Sport Specialization Classification**

<table>
<thead>
<tr>
<th>Specialization Classification</th>
<th>Participants</th>
<th>Mean ± SD$^a$</th>
<th>Effect Size$^b$</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>219</td>
<td>5.6 ± 2.1</td>
<td>0.2</td>
<td>5.4 to 5.9</td>
</tr>
<tr>
<td>Moderate</td>
<td>174</td>
<td>5.3 ± 1.9</td>
<td>0.1</td>
<td>5.0 to 5.6</td>
</tr>
<tr>
<td>High</td>
<td>177</td>
<td>5.1 ± 2.0</td>
<td>0.0</td>
<td>4.8 to 5.4</td>
</tr>
</tbody>
</table>

LESS = Landing Error Scoring System; SD = standard deviation; CI = confidence interval

$^a$Adjusted means controlling for site and sex.

$^b$Effect size compared to high specialization.
tasks. The LESS was developed to be a clinical movement screening tool to identify movement errors during a jump-landing task that were associated with abnormal joint loading and injury risk. It has been used to screen for acute injury in youth soccer athletes and has been able to identify athletes with low risk of anterior cruciate ligament injury in this population. Elements of the LESS have also been used to screen for overuse injury. For example, individual items such as asymmetric foot contact and decreased plantar flexion angle at initial contact are associated with lower extremity stress fractures in U.S. Military Academy cadets.

Theoretically, neuromuscular control deficits are thought to develop due to a lack of diversification in sport and physical activity. Highly specialized athletes perform repeated movement patterns, resulting in an overdevelopment or underdevelopment of certain muscle groups. Ultimately, this leads to poor movement patterns and the increased potential for injuries. In contrast, low specialization athletes are exposed to a variety of movement patterns resulting in improved movement control. However, contrary to our hypothesis, no differences were observed between specialization groups, which suggests that specialization level is not associated with movement control as measured by the LESS.

To our knowledge, only one other study evaluated the LESS within the context of sport specialization in high school athletes. In that study, the LESS scores did not differ between single-sport and multi-sport female high school soccer athletes. Our study expanded on these findings by increasing the sample size, adding male athletes, and using a different sport specialization classification method, and we reached similar conclusions.

Sport specialization and sport sampling relating to neuromuscular control was also evaluated by DiStefano et al. in a youth athlete population (ages 8 to 14 years). Sport sampling is participation in a variety of different sports, whereas sport specialization is participation in one sport and exclusion of other sports. In this investigation, participants were dichotomized into “good” (LESS < 5) and “poor” (LESS ≥ 5) jump-landing mechanics groups. Participants were then compared based on sport sampling status (high, moderate, and low) and single-sport and multi-sport specialization, while using the three-tier classification method to validate their specialization definition. Athletes with a high sport sampling were more likely to be classified as having “good” jump-landing mechanics than moderate and low sport sampling athletes. Multi-sport athletes were more likely to demonstrate “good” jump-landing mechanics compared to single-sport athletes in this population, but no differences were demonstrated between single-sport and multi-sport athletes when mean LESS score was evaluated as a continuous variable. This study suggests that sport sampling has neuromuscular control benefits in the youth population.

In contrast, our study investigated if there were differences in the average total LESS score between any of the three categories without dichotomizing by “good” or “poor” in a high school athlete population (ages 13 to 18 years). Neither study demonstrated a difference in average total LESS score by specialization classification when the LESS was evaluated as a continuous variable. In combination with the results of Beese et al., this suggests that a single time point measure of the LESS may not be sensitive enough to detect differences in movement control in high school athletes as it relates to sport specialization or in youth athletes when using the three-tier classification system. Another potential interpretation is that sport specialization may not affect movement control in this population, and a high level of sport sampling at a young age may have a greater influence on movement control than the presence of sport specialization in youth and high school athletics. Nonetheless, it is likely that factors not controlled for in the study, such as volume of training, age of sport specialization, and sport sampling, may be responsible for the increase in injury risk observed in highly specialized high school athletes.

Previous literature suggested that exceeding recommended volumes of training, in combination with sport specialization, can contribute to injury risk in adolescent and youth athletes. Athlete exposure and training volume becomes particularly important when considering overuse and chronic injury, because overtraining is a primary mechanism for the development of overuse injury in athletes. Jayanthi et al. observed that highly specialized athletes were at an increased risk for overuse but not acute injury, and injured athletes spent more time in organized sports per week compared to uninjured athletes. The results of Post et al. expanded on this work. They found that highly specialized youth athletes had a 45% to 91% higher probability of reporting a previous injury, and athletes who exceeded months per year and hours per week sport volume recommendations had a 26% to 85% greater probability of reporting a previous injury. These investigations suggest that the
volume of training and the athletes’ exposure to injury risks may be more important factors than varying levels of neuromuscular control in specialized athletes.

We controlled for differences in the research site and the athlete’s sex in average LESS score between the two research sites. Females have been shown to demonstrate poorer jump-landing mechanics overall in comparison to males, which was consistent with our study. Although we demonstrated small effect sizes between specialization groups, we elected to include sex as a covariate in the ANCOVA to remain consistent with previous literature. Additionally, different scoring methods were used at each site (conventional vs automated scoring). The automated system has shown good agreement with the conventional method. We believe the differences in data collection methodology between the two research sites are a strength. Both research sites had large, independent sample sizes with similar conclusions.

Limitations

One of the main limitations of this study was that athlete exposure and training volume data were not collected. Additionally, sport sampling data and age of specialization were not captured in the current investigation. These elements may have a greater influence on neuromuscular control than the presence of sport specialization, and it is possible that our sample was not highly specialized long enough to have observable neuromuscular control differences yet.

IMPLICATIONS FOR CLINICAL PRACTICE

This study demonstrated that LESS scores for a single time point were not different across the sport specialization classification groups (high, moderate, and low). These results remained consistent even after controlling for the research site and sex of the athlete. This is the first study to evaluate the LESS in high school athletes based on the three-group sport specialization criteria. The results of this study suggest that differences in neuromuscular control relating to jump-landing strategy may not be responsible for the increased risk of injury observed in highly specialized athletes. Additionally, it is also possible that the LESS may not be sensitive enough to detect neuromuscular control differences between specialization levels. Alternative risk factors may be more critical to mitigate injury risks such as sport exposure, training volume, age of specialization, and sport sampling history. Clinicians and coaches should focus their efforts on changing specialization patterns and focusing on safe sport recommendations related to volume and athlete exposure. These factors are easily modified and may prove more effective in mitigating risk injury. Future research should continue to prospectively measure injury incidence across age groups and geographical locations as it relates to sport specialization in an effort to further validate this classification system, while taking into consideration several measures of neuromuscular control longitudinally.

REFERENCES