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Original Research

Previous High School Participation in Varsity Sport and Jump-Landing Biomechanics in Adult Recreational Athletes

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Context: Early sports sampling is associated with superior biomechanics in youth athletes; however, the effect of multisport participation on adult biomechanics is unknown.

Objective: To compare jump-landing biomechanics between adult recreational athletes who previously participated in 0, 1, or 2 or more select high school varsity sports (VSs; basketball, lacrosse, soccer, volleyball) that feature landing and cutting tasks.

Design: Descriptive laboratory study.

Setting: University community setting.

Patients or Other Participants: Fifty adult recreational athletes (22 women, 28 men; age = 23.8 ± 2.5 years) with no high school VS experience or with high school VS experience in basketball, lacrosse, soccer, or volleyball. Athletes were grouped into those who participated in 0 (0VS, n = 11), 1 (1VS, n = 21), or 2 or more (2VSs, n = 18) of these sports at the high school level.

Main Outcome Measure(s): The average Landing Error Scoring System (LESS) total score from 3 individual jump landings was determined. A 1-way analysis of covariance using sex as the covariate was calculated to compare groups. The Pearson *R* was used to test for the correlation between the LESS score and number of sports played, and a linear regression analysis was performed using the number of sports played to predict the LESS score. The α level was set a priori at .05.

Results: The 0VS athletes produced similar LESS scores as the 1VS athletes (5.89 ± 1.2 versus 5.38 ± 1.93 points, respectively, $P = .463$), whereas the 2VSs athletes demonstrated lower LESS scores (3.56 ± 1.97 points) than the 0VS ($P = .002$) and 1VS ($P = .004$) athletes. The LESS scores were moderately negatively correlated with the number of high school VSs played ($R^2 = -0.491$, $P < .001$). The linear regression analysis was significant ($F_{1,37} = 9.416$, $P = .004$) with $R^2 = 0.203$. For every additional VS played at the high school level, the LESS score decreased by 1.28 points.

Conclusions: Landing Error Scoring System scores were lower in athletes who had a history of multisport high school varsity participation in basketball, lacrosse, soccer, or volleyball compared with those who had a history of single-sport or no participation in these sports at this level. Multisport high school varsity participation in these sports may result in improved neuromuscular performance and potentially reduced injury risks as adults.

Key Words: sport specialization, neuromuscular performance, injury risk

Key Points

- Multisport involvement in high school varsity basketball, lacrosse, soccer, or volleyball may benefit athletes' neuromuscular control.
- The improvement in neuromuscular control from multisport play appeared to have a dose-dependent relationship.
- Whether similar benefits may be obtained through other combinations of multisport participation is unknown.

Sport specialization, typically defined as participation in a single sport to the exclusion of other sports and activities, is increasingly common among youth athletes despite a lack of evidence that it is required for competitive success.[1,2] Several potential negative consequences have been associated with sport specialization at an early age. These include psychological consequences, such as an elevated risk of discontinuation of sports activities and social isolation, and physical consequences, such as a heightened risk of musculoskeletal injury.[1–4]

Neuromuscular control is an underlying modulator of musculoskeletal injury risk, and neuromuscular-control deficits contribute to injury.[5–9] Different sports feature various physical, neurocognitive-processing, and muscle-activation demands. Thus, each sport may assist with the development of different aspects of neuromuscular control.[10,11] Sport specialization may inadvertently restrict the full development of neuromuscular control, leading to increased risks of certain types of injury. Conversely, multisport participation exposes athletes to different demands and allows for the comprehensive and appropriate development of neuromuscular control. DiStefano et al[10] recently evaluated the neuromuscular control of youth athletes using a jump-landing task (Landing Error Scoring

System [LESS]).[12] Multisport athletes were more likely to demonstrate good biomechanics (LESS <5 points) than single-sport athletes. Medical organizations and sport governing bodies typically suggest the athlete at least reach puberty or the end of primary school (~14 years) before specializing.[13–15]

Physical maturation and the concomitant development of neuromuscular control continue beyond youth participation in high school sports.[16–18] As such, multisport participation in varsity high school programs may continue to positively influence athletes' neuromuscular-control development and injury risk. Rugg et al[19] provided evidence for a translational protective effect of previous multisport participation on injury rates, percentage of games played, and career longevity of first-round National Basketball Association draft picks. Former varsity high school multisport athletes played in a higher percentage of available games during the study follow-up period, were more likely to still be active in the National Basketball Association, and were less likely to sustain a major injury.

Whether former high school athletes who continue participating in sports at a recreational level as adults can derive long-term neuromuscular benefits is unclear. From societal and health-promotion standpoints, injuries to recreational athletes may reduce overall activity levels and become costly, chronic health care conditions.[20,21] Thus, a strong understanding of the durability of high school sports participation on neuromuscular control and injury risks can help shape sport-specialization recommendations for youth and high school athletes and offer insight regarding injury risks in active adults. The purpose of our study was to examine the effect of different levels of high school varsity participation in the sports of basketball, lacrosse, soccer, and volleyball on neuromuscular control of recreationally active adult athletes during a jump-landing task. We hypothesized that (1) former high schoolers with no varsity sport (VS) experience, single–VS athletes, and multisport athletes would demonstrate progressively better (lower) LESS scores and (2) LESS scores would be inversely proportional to the number of high school VSs played.

METHODS

Design and Participants

This was a cross-sectional descriptive laboratory study. Healthy recreational male and female athletes were sampled from an existing institutional research database. Participants included in the original studies were recruited from the University of Florida community and surrounding areas using flyers and word of mouth. The inclusion criteria were men and women aged 18 to 30 years; current active engagement in basketball, lacrosse, soccer, or volleyball at least 3 times per week without having played any of these sports at the varsity level in high school (0VS group) or current active engagement in basketball, lacrosse, soccer, or volleyball at least once per month with a history of having played 1 (1VS group) or more than 1 (2VSs group) of these sports at the varsity level in high school. Different playing-time inclusion criteria were used for former varsity athletes versus nonvarsity recreational athletes in order to include athletes with a high degree of familiarity with jump landing as an athletic task; these criteria have also been used in previous investigations.[22] Prior VS participation was determined by the participants' self-report at the time of data collection. Only basketball, lacrosse, soccer, or volleyball was used to determine the category of VS participation. These specific sports were included in the study because of the limitations of the database, which was originally created with a focus on these sports.

The exclusion criteria were as follows: (1) presence of an orthopaedic injury at the time of participation (history of fracture, sprain, or strain precluding sport participation in the past 5 months; acute joint or muscle pain of severity >5 points on a 10-point scale); (2) presence of a medical condition limiting full participation in sport-related activity; (3) history of other high school VSs experience (ie, outside of basketball, lacrosse, soccer, or volleyball); or (4) any collegiate- or professional-level sport experience. Participation at the club (eg, American Athletic Union) or junior varsity level during high school was not assessed and was not a criterion for inclusion or exclusion. All participants provided written informed consent. The studies and the procedures by which the participants were originally recruited and tested were approved by the Institutional Review Board at the University of Florida.

Participant Characteristics

Height, mass, and age were obtained at the time of testing. Mass and height were collected using a standard, medical-grade scale. Participants were not given specific instructions on footwear other than to wear comfortable sneakers in which they typically play sports.

Landing Error Scoring System

We used the LESS protocol previously described by Padua et al.[12] The participants jumped from a 0.30-m-high box to a 0.75- × 0.45-m landing target positioned at a distance 50% of their height away from the box. Upon landing, the participant immediately completed a maximal-effort vertical jump. A *successful jump* was characterized by (1) jumping off both feet at the same time; (2) jumping forward, but not vertically, to the landing target; (3) landing with each foot entirely within the target; (4) landing with no more than one-half the length or width of each foot outside of the target during the second landing; and (5) completing the task in a single fluid motion.

Participants were not provided any feedback or coaching on their technique unless the task was not completed correctly (eg, landing outside of the target area). Before data collection, participants were allowed to practice the jump until they were able to perform it successfully (with a minimum of 3 practice jumps). Three successful jump landings were then recorded for the given surface using standard videography. Two video cameras (model Handycam; Sony Corp, Tokyo, Japan) were placed approximately 3.4 m from the landing target in front of and to the *dominant side* of the participant (determined as the leg the participant would use to kick a ball for maximum distance) to capture frontal- and sagittal-plane views of the jump-landing motion at 30 frames per second (Figure 1).

Investigators trained in the LESS grading technique (D.R., K.J., A.H., C.M.) under the direction of the principal

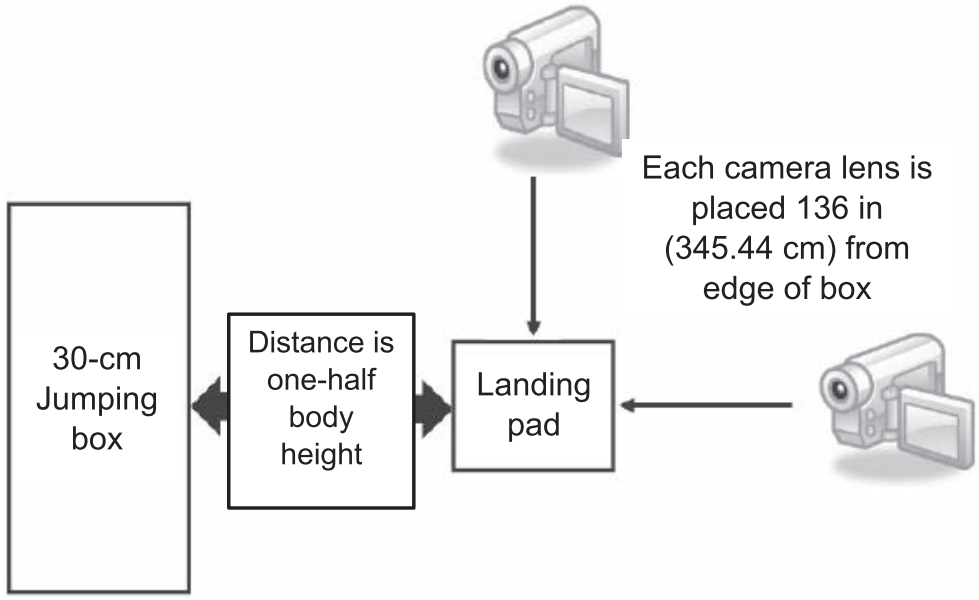

Figure 1. Landing Error Scoring System data-collection setup.[23]

investigator (D.C.H.) completed the LESS grading of the resultant video footage. Two investigators were assigned to independently grade each of the 3 jump landings using the criteria described by Padua et al.[12] The scores from the 2 raters for each jump were then averaged to produce a total score, which was used for analysis. If the grades from the 2 raters differed by more than 1 point, then the principal investigator served as the arbitrator and graded the jump trial to determine the values that were in best agreement.

Statistics

For all analyses, SPSS (version 24; IBM Corp, Armonk, NY) was used. Interrater correlation coefficient values were calculated for each jump-landing trial to assess the interrater reliability of the scoring. We used a 1-way analysis of covariance to assess differences in the LESS scores among the 3 groups. The dependent variable was LESS score, and the independent variable was study group (0VS, 1VS, or 2VSs). Because previous researchers[24] noted an effect of sex on jump-landing biomechanics, we used athlete sex as a covariate. The Tukey honestly significant difference test was calculated as a post hoc analysis to determine where group differences existed. Effect sizes among the 2VSs, 1VS, and 0VS groups were determined using Cohen d tests, where values were classified as *small* ($\geq$0.20), *medium* ($\geq$0.50), or *large* ($\geq$0.80). We also evaluated the relationship between the number of VSs played at the high school level and LESS score using the Pearson *R* test and completed a post hoc linear regression analysis using VSs played at the high school to predict the LESS score. For the correlational and regression analyses, athletes in the 2VSs group were assigned the specific number of VSs played at the high school level (3 athletes had played 3 sports at this level, and 1 athlete had at least 1 season of high school varsity experience in all 4 sports). Significance was established with α set a priori at .05.

RESULTS

Participant Characteristics

Fifty athletes (22 women, 28 men) met the inclusion criteria for 1 of the 3 groups (0VS = 11, 1VS = 21, and 2VSs = 18). Demographic information on each group can be found in the Table. The 3 groups did not differ based on age, height, mass, or sex proportion ($P > .05$ for all comparisons).

Data Reliability

The interrater correlation coefficient values for LESS grading across each of the individual jump-landing trials between any 2 raters was 0.88, indicating near-excellent interrater reliability. These values are consistent with previously published work.[12,25,26]

The LESS Grades Among Study Groups

The LESS scores for the study groups are shown in Figure 2. The analysis of covariance indicated an effect for group ($F = 4.763$, $df = 3$, $P = .006$). As there was no effect for sex and differences were minimal between the actual and sex-adjusted means, we reported the actual mean

Table. Participant Characteristics

	Varsity Sport(s), No.		
Characteristic	None (n = 11)	1 (n = 21)	≥2 (n = 18)
Age, y, mean ± SD	23.4 ± 3.1	23.8 ± 2.5	24.1 ± 2.2
Height, m, mean ± SD	1.736 ± 0.113	1.746 ± 0.112	1.758 ± 0.102
Mass, kg, mean ± SD	69.2 ± 13.8	67.1 ± 13.2	71.4 ± 12.3
Females/males	5/6	9/12	6/12
Sport played, No.			
Basketball	0	5	14
Volleyball	0	4	5
Soccer	0	9	14
Lacrosse	0	3	8

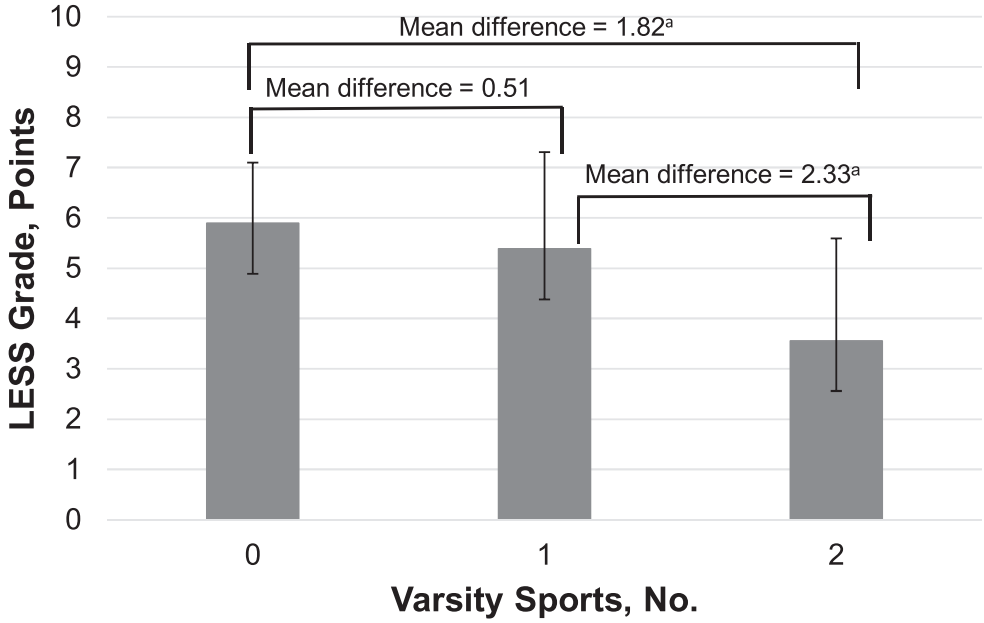

Figure 2. Landing Error Scoring System scores among recreational athletes with no previous high school varsity playing experience, experience with 1 varsity sport, and experience with 2 or more varsity sports. Values are mean ± standard deviation. Mean differences between groups are shown in brackets. [a] Significant pairwise comparisons.

values. No difference was evident between the 0VS and 1VS athletes (5.89 ± 1.2 versus 5.38 ± 1.93, respectively; $P = .463$), whereas the 2VSs athletes had lower LESS scores (3.56 ± 1.97) compared with both the 0VS ($P = .002$) and 1VS ($P = .004$) athletes. The effect size of 1-sport participation on LESS score was medium (d = 0.32 for 0VS and 1VS), whereas the effect size of multisport participation on LESS score was large (d = 0.92 for 2VSs and 1VS, and d = 1.39 for 2VSs and 0VS).

Association Between LESS Scores and the Number of VSs Played

The LESS scores were moderately negatively correlated with the number of high school VSs played ($R^2 = -0.491$, $P < .001$). Linear regression analysis performed using the number of VSs to predict the LESS score was significant ($F_{1,37} = 9.416$, $P = .004$) with $R^2 = 0.203$. For every additional VS played at the high school level, the LESS score decreased by 1.28 points.

DISCUSSION

This study provides novel evidence demonstrating differences in neuromuscular control among adults based on high school sports participation. The most important finding was that multisport participation in basketball, lacrosse, soccer, or volleyball at the varsity level in high school was associated with better neuromuscular control during a jump-landing task compared with single-sport or no participation. Our hypotheses were supported by these findings.

The clinical utility of these findings is that poor lower extremity biomechanics during jump landing predict injuries such as stress fractures and anterior cruciate ligament (ACL) ruptures.[23,27] Although the LESS has not yet predicted ACL injuries in athletes of similar ages as those in our study,[23] a 1-point increase in the LESS has been correlated with a 15% greater risk of leg stress fractures in a young adult military population over a 4-year follow-up period.[27] Extrapolation of these results suggests that multisport participation at the varsity level in high school in the 4 sports of interest could reduce the stress fracture risk. Although the physical activity levels between our participants and a military cadet population differed, we believe that these data are potentially generalizable to the public and have widespread relevance to activity transitions and injury risks through adulthood.

Our findings may have been influenced in part by the distribution of athletes who played 2 or more sports. Most athletes in the 2VSs group played 2 VSs, whereas only 4 of the athletes in the 2VSs group played more than 2. The mean LESS score for these 4 athletes was 2.50 points, or approximately 1.35 points lower than for the athletes who participated in 2 VSs. Importantly, the effect size of the sport-participation number was large between the 0VS or 1VS athletes and the multisport athletes but moderate between the 0VS and 1VS athletes. This may indicate that additional athletes at the high end of the number of VSs played could have further strengthened the correlation between the LESS score and the number of sports and provided insight into a potential dose-response relationship.

Limited published data are directly comparable with ours in terms of the participants' ages and sports of interest. However, the concept of single-sport versus multisport effects on jump-landing biomechanics in younger populations was examined in 2 studies. DiStefano et al[10] completed the first cross-sectional study of athletes (N = 355 boys and girls, age range = 8–14 years, average age ~11 years) with different levels of sports participation. Respondents were categorized as *single-sport athletes* if they indicated that basketball or soccer was the only sport in which they had participated in during the prior calendar year and were categorized as *multisport* if they had participated in more than 1 sport during the prior calendar

year. Compared with multisport athletes, a higher frequency of single-sport athletes demonstrated poor (LESS score >5 points) versus good (LESS score <5 points) neuromuscular control. Children who participated in more than 1 sport over a period of years and continued to the time of the study were 5.8 times more likely to have good LESS scores than early specializers. The authors did find group differences in average LESS scores when accounting for the level of participation (recreational versus elite) and the degree of prior specialization. The group differences based on the degree of prior specialization within either participation level category were small compared with those in our study, ranging from 0.65 points (elite athletes) to 1.08 points (recreational athletes). In a separate investigation of adolescent female soccer athletes (N = 40, average age ~15 years), Beese et al[28] administered jump-landing tasks and the LESS. They were unable to detect any differences in LESS scores between soccer specializers and soccer players with other sport experience; however, this was a smaller study and the mean differences between the single-sport and multisport groups trended in the same direction and were of similar magnitude as DiStefano et al[10] found (LESS scores: single sport = 6.84 ± 1.81 versus multisport = 6.07 ± 1.93, $P = .15$). Collectively, these findings may indicate that continuing multisport participation through high school has significant benefits to neuromuscular control that are additive to any benefits of multisport participation gained before high school. As previously noted, current recommendations discourage sport specialization before approximately age 14 or life and maturation events that are comparable with this age. Our results suggest a significant added benefit to neuromuscular control beyond this point from multisport participation. Additional investigations of the relative benefits of multisport participation through different stages of athlete development and maturation (including high school) may help inform future recommendations regarding sport specialization.

A key finding from our work is that the influence of multisport participation in basketball, lacrosse, soccer, or volleyball on neuromuscular control may endure into adulthood. Neuromuscular control–based injury-prevention programs are effective in reducing the risk of lower extremity musculoskeletal injuries; yet these interventions typically require preseason training to be effective and postseason training to retain the benefits of the intervention.[9] Without postseason maintenance, the program benefits can degrade over a period of months. This pattern stands in contrast to the evidence from our study, which indicates that multisport participation during high school in basketball, lacrosse, soccer, or volleyball may provide neuromuscular-control benefits that endure over a much longer period, given our participants' average age of ~24 years.

This study was not without limitations. The inclusion criteria for the previous studies targeted participation in jumping or cutting sports. Although this similarity made our participants comparable with those of DiStefano et al[10] and Beese et al,[28] it also prevented us from demonstrating any potential benefits to neuromuscular control from participation in sports that feature very different athletic demands, such as cross-country and track, football, golf, swimming, or wrestling. Including more participants with different multisport histories would have strengthened the ability to predict the LESS score based on the number of sports played and revealed a potential sport-number threshold at which performance errors can be minimized. Future investigators should consider a more comprehensive range of sports participation or intentional contrasts among athletes with different types of multisport experience, such as primarily jumping or cutting sports, primarily endurance sports, individual or team sports, and mixed sports.

We classified athletes by the number of VSs played at the high school level but did not quantify the athletes' history of participation in sports at the junior varsity level or outside of high school. Although VS typically represents the most intensive level of sport participation in the high school age range, participation in other sports at other levels may also benefit neuromuscular control during growth and maturation. The inclusion criteria for the participants' level of current recreational involvement were minimal and potentially subject to a range of activity volumes; however, the common level of current sport participation consisted of intramural sports play and occasional pickup games, as might be typical for students in a university setting.

We also lacked access to the participants' history of sport activities before high school. The relationships noted in this study based on a high school sports classification may represent a continuation of behaviors from earlier in life. Nevertheless, the magnitude of the differences among the groups in our study compared with those in prior investigations of younger populations implies the presence of an additional effect from diverse high school sport participation. Finally, we assessed neuromuscular control and did not directly address injury history or prospectively measure injury risk. Although the LESS has been shown to have predictive value for ACL injuries in youth soccer athletes and lower extremity stress fractures in military cadets,[25,27] its specific utility for the recreationally active adult athlete is unknown.

Finally, it is important to note that a cause-and-effect relationship was not established by our findings. Although participating in more than 1 of the sports of interest at the varsity level was associated with a better LESS score, the 2VSs participants may have been better athletes and, thus, had more opportunity or ability to participate in multiple sports at this level.

CONCLUSIONS

Previous participation in multiple high school VSs (basketball, lacrosse, soccer, or volleyball) that feature significant landing and cutting athletic demands was associated with lower LESS scores in adult recreational athletes compared with participation in no or 1 VS. Continued multisport participation in basketball, lacrosse, soccer, or volleyball throughout maturation may provide long-lasting benefits to neuromuscular control and potential injury risk into early adulthood.

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