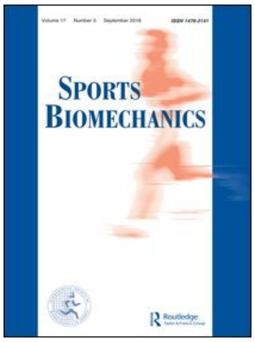

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ARTICLE

The effect of landing surface on landing error scoring system grades

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ABSTRACT

Different landing surfaces may affect lower extremity biomechanical performance during athletic tasks. The magnitude of this effect on clinical screening measures such as jump-landings is unknown. This study determined the effect of court (CS), grass (GS), and tile (TS) surfaces on Landing Error Scoring System (LESS) grades. A repeated-measures design was used. A total of 40 (21F, 19M; mean age = 23.8 ± 2.4 yr) recreational athletes performed a jump-landing task on three different landing surfaces. 2D videography recorded jump-landings in the frontal and sagittal planes. A 2 × 3 (sex by surface) mixed-model repeated-measures analysis of variance was used to examine main and interaction effects associated with surface and sex. No significant sex by landing surface interactions existed for LESS grades. No significant differences were observed on LESS grades for the main effect of surface (CS = 4.83 ± 1.31 points; GS = 5.01 ± 1.40 points; TS = 5.09 ± 1.86 points; all $p > 0.05$). Correlations were found between LESS grades among different conditions (r range = 0.587–0.611; all $p < 0.001$). Commonly used jump-landing surfaces for clinical biomechanical evaluations do not affect LESS grades, suggesting generalisability as a screening tool for anterior cruciate ligament injury risk in different sport environments.

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Anterior cruciate ligament; basketball court; drop jump; grass; drop-jump landing

Introduction

Anterior cruciate ligament (ACL) injuries are common in sports and increase the risk for accelerated development of degenerative joint disease of the knee, knee surgeries, and related physical impairment (Mather et al., 2013; Roos, Adalberth, Dahlberg, & Lohmander, 1995). Female athletes are at a much higher risk for experiencing an ACL injury compared to male athletes across multiple sports and play levels (Dai, Herman, Liu, Garrett, & Yu, 2012). About 70% of these injuries occur through non-contact mechanisms that involve sudden stops, landing, or changes in acceleration, as seen in sports that involve cutting and landing sports (Acevedo, Rivera-Vega, Miranda, & Micheo, 2014; Boden, Sheehan, Torg, & Hewett, 2010; Dai et al., 2012).

Poor jump-landing biomechanics as studied using 3D motion analysis have been shown to be predictive of ACL injury and are likely to be a significant contributing factor to the increased risk for these injuries in female athletes (Dai et al., 2012; Hewett et al., 2005).

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Because of the cost and feasibility limitations of 3D motion analysis, other inexpensive alternatives have been developed. The Landing Error Scoring System (LESS) is a screening test that is both inexpensive and reliable in assessing jump-landing biomechanics on a large-scale (Padua et al., 2009). The system scores jump 'errors' based on 17 criteria previously shown to correlate with the high-risk biomechanics of an ACL injury during a jump-landing task. The LESS is a valid and reliable tool for identifying potentially high-risk movement patterns based on assessments of frontal, sagittal, and transverse plane motion during a jump-landing task. (Padua et al., 2011, 2009). The LESS can identify high-risk biomechanics in athletes in a controlled laboratory setting; however, the applicability of this tool as a large-scale screening method in the field on the actual surfaces of play (i.e., a basketball court or a soccer/football field) needs to be tested.

Prior research has demonstrated an effect of sport playing surface on lower extremity biomechanics in laboratory settings and on ACL strain and injury rates (Balazs et al., 2015; Dowling, Corazza, Chaudhari, & Andriacchi, 2010; Drakos et al., 2010; Thomson, Whiteley, & Bleakley, 2015). Dowling et al. (2010) examined jump-landing mechanics on surfaces with high and low coefficients of friction and found decreased knee-flexion angles and high external knee valgus moments on a high coefficient of friction shoe-surface interfaces during a 30° sidestep cutting task. This finding was attributed to a shift in the participants' task strategy for each surface, which may lead to lower extremity biomechanics that are associated with ACL-injury risk. Differences in the shoe-surface interface have similarly been shown to alter the magnitude of ACL strain in cadaveric models (Drakos et al., 2010). Furthermore, these differences in lower extremity biomechanics and ACL strain may translate into real differences in ACL-injury rates across different playing surfaces, with multiple studies demonstrating greater injury rates during play on surfaces with high coefficients of friction compared to surfaces with low coefficients of friction (Thomson et al., 2015).

These findings suggest that clinical ACL-injury risk screening may need to be conducted in a manner that replicates the field conditions of the athlete's sport. LESS grades obtained from one setting (e.g., indoor court surface) may not fully translate to a setting with a different landing surface (e.g., grass). These findings may also have research implications; LESS grades obtained in a controlled laboratory setting for use in prospectively determining injury risk may result in a different 'high-risk' threshold value than what would otherwise be obtained if the screening occurred on the surface of the athletes' sport.

Determination of the effect of landing surface on LESS grades will provide key evidence on the applicability of LESS as a screening tool in multiple settings and provide guidance for both future research efforts in this area and for clinical implementation of this screening tool in the field. Therefore, the purposes of this study were as follows: (1) to determine whether differences exist among LESS grades when performed on two common athletic surfaces (court and natural grass) compared to the laboratory tile-floor surface; and (2) to determine whether there are significant sex by landing surface interactions of the LESS grades. We hypothesised that LESS scores would vary across surface conditions, with highest scores on a court surface and lowest scores on a grass surface. Furthermore, we hypothesised that a significant sex by landing surface interaction would exist such that females would demonstrate greater LESS grades than males in the difference environments, with particularly increased grades on the court surface compared to the grass surface.

Methods

Study design

This study used a randomised, repeated-measures design to determine the effect of three different landing surfaces on LESS grades.

Participants

A total of 40 healthy recreational male and female athletes between the ages of 18 and 30 years with experience in performing drop jump-landing tasks were recruited for this study (see Table 1). Participants were recruited from the Gainesville, Florida community and surrounding areas using flyers and word of mouth. The participants were actively engaged in cutting and jump-landing intensive sports such as basketball, volleyball, soccer/football, or lacrosse at least three times a week, or had participated in similar sports on the high-school varsity level and currently participated at least once a month. Potential participants were excluded if any of the following was true: (1) they did not meet the activity-level criteria; (2) they had an orthopedic injury at the time of participation (history of fracture, sprain, or strain within the past five months; acute joint/muscle pain severity of >5/10 points on a 10-point scale); or (3) they had a medical condition limiting them from fully participating in sports-related activity. All participants read and signed an informed consent. This study and its procedures were approved by the Institutional Review Board at the University of Florida.

Participant characteristics

The height, weight, and age of the participants were obtained. Leg dominance was self-reported as the leg with which the participant preferred to kick a ball. Body weight 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 their sport.

LESS testing protocol

The LESS protocol previously described by Padua et al. (2009) was used for this study. The participants jumped from a 0.30 m high box to a 0.75 m by 0.45 m landing target positioned at a distance 50% of their height away from the box. Upon landing, the participant immediately completed a vertical jump at maximal effort. Participants were not provided any feedback or coaching on their technique unless the task was not completed correctly (e.g., landing outside of the target area). Prior to data collection, participants were allowed to practise the jump until they were able to perform it

Table 1. Participant characteristics. Values are means ± standard deviation (SD).

	Men	Women	Combined
Number	20	20	40
Age (yr)	24.4 ± 1.8	23.4 ± 2.8	23.8 ± 2.4
Height (m)	1.84 ± 0.61	1.66 ± 0.62	1.75 ± 0.14
Weight (kg)	79.6 ± 7.8	58.9 ± 6.7	69.8 ± 12.7

successfully (with a minimum of three practice jumps). Three successful jump-landings were then recorded for the given surface using standard videography. Two video cameras (Sony Handycam; Sony Corp.; Tokyo, Japan) were placed 3.4 m from the landing target in front of and to the dominant side of the participant to capture frontal and sagittal plane views of the jump-landing motion at 30 frames per second.

As described by Padua et al. (2009), a successful jump was characterised by (1) jumping off of both feet at the same time; (2) jumping forward, but not vertically, to the landing target; (3) landing with each foot entirely within the landing target; (4) landing with no more than one-half the length or width of each foot outside of the landing target during the second landing; and (5) completing the task in a single fluid motion.

Surface-landing conditions

Surface-landing condition testing order was randomised using a computer-generated random number table and recorded separately in sealed numbered envelopes. Envelopes were assigned to participants in the order of recruitment and the contents of the envelopes were blinded to both participant and research staff until consent was obtained. Two surfaces were selected to represent common athletic landing surfaces: an indoor basketball court and an outdoor grass field. The third condition was an indoor motion-analysis laboratory floor, which was comprised of a stiff tile covering.

Data processing and LESS grading

Once the video data were collected, the videos were spliced and randomised. Two investigators trained in the LESS grading technique (K.J. and D.R.) under the direction of the principal investigator (D.H.) independently assigned a LESS grade to each jump-landing, and the average score from the two raters was used for analysis. Each jump recording was graded using the criteria described by Padua et al. (2009). Seventeen scored items in the checklist represented errors in landing technique, graded as a '0' or '1' with the former signifying that correct form was observed in the jump-landing task. If the grade scores differed by more than one point, then the principal investigator served as the arbitrator and graded the jump trial to determine the values that were in best agreement. Tester blinding to the participant's identity or surface condition for a given jump-landing during video scoring was not possible.

Statistical analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (version 23.0; IBM Corp.; Chicago, IL, USA). Descriptive statistics were obtained to characterise the study groups. Pearson's correlations were assessed, with a Bonferroni correction for multiple tests. Intra-class correlation coefficients (ICC) were used to determine the reliability of the average score for participants across each surface type. ICC values were also calculated for each jump landing trial across all surfaces to assess the inter-rater reliability of the scoring. To determine whether differences existed in the LESS grades between men and women among the three landing-surface conditions, a 2 × 3 (sex by landing surface) mixed-model repeated-measures analysis of variance was used. Significance was established *á priori* at 0.05 for all statistical tests.

Results

Correlations among the surface conditions

Significant correlations existed among the LESS grades of the different conditions ($r = 0.587$ for tile surface vs grass surface, $r = 0.608$ for court surface vs grass surface, and $r = 0.611$ for court surface vs tile surface; $p < 0.001$ for all comparisons). The reliability of scoring across surface types was good for each pairwise analysis (ICC = 0.781 for tile surface vs grass surface, ICC = 0.755 for court surface vs grass surface, and ICC = 0.805 for court surface vs tile surface; p < 0.001 for all comparisons). The ICC values for LESS grading across all trials between the two raters was 0.93, indicating excellent inter-rater reliability.

Sex-based differences among landing surfaces

The LESS grades for the drop jump-landings for male and female participants are shown in Table 2. We found no significant interaction of sex by landing-surface condition ($p = 0.943$). Moreover, there were no significant main effects of sex ($p = 0.624$) or landing surface ($p = 0.758$).

Discussion and implications

The purposes of this study were to determine whether differences existed among LESS grades when performed on two common athletic surfaces and a laboratory tile-floor surface, and to determine whether significant sex by landing-surface interaction existed for LESS grading. The main findings were as follows: (1) the mean LESS scores were not different among basketball court, field grass, or laboratory concrete surfaces; and (2) no significant sex by landing-surface interactions existed for the LESS scores. Thus, our study hypotheses were not supported by these findings.

These results indicate that the LESS may be relatively insensitive to a range of different landing conditions. We found that significant moderate to moderately high correlations existed in LESS grades between the different surface conditions. This implies a relatively high degree of consistency of LESS grades for a given athlete among different jump-landing surfaces, and thus provides support for potential use of the LESS for ACL-injury risk screening in landing-surface conditions that may be different from the athletes' actual sporting environment. This increases the robustness of the LESS as an ACL-injury risk screening tool as practical implementation of screening efforts may occur in a large variety of settings, ranging from the athletes' playing surface (e.g., grass or court) to non-playing environments such as a physician's office for a pre-participation examination.

Table 2. LESS grades for men and women for drop jump-landings on different landing surfaces. Values are means ± SD and are expressed in points. The *p* values are provided for the main effects of sex and surface and the interaction of the two variables.

	Laboratory concrete	Basketball court	Grass	Sex *p* (sig)	Surface *p* (sig)	Sex by surface interaction *p* (sig)
Men	5.06 ± 2.19	4.70 ± 1.35	4.97 ± 1.53			
Women	5.11 ± 1.47	4.97 ± 1.28	5.06 ± 1.27			
Combined	5.09 ± 1.86	4.83 ± 1.31	5.01 ± 1.40	0.624	0.758	0.943

The finding of LESS being relatively insensitive to different surface landing conditions is in contrast to findings from a prior study examining the effect of surface on lower extremity biomechanics during a cutting task (Dowling et al., 2010). It is possible that the two surface conditions in this study utilised surfaces with coefficients of friction that had a greater magnitude of difference (0.38 vs. 0.87) compared to the surfaces utilised in the current study. Furthermore, the current study utilised a drop-landing task rather than a cutting task, and it is possible that the cutting task in the prior study required greater athletic demands which allowed differences in biomechanics between the surface types to be more apparent. Indeed, the study by Dowling, Corazza, Chaudhari, and Andriacchi required that the participants utilise their maximum comfortable approach speed for the low friction surface condition. Despite this, the main kinematic finding in that study was a reduced knee flexion at initial contact in the high friction surface condition with a mean difference of less than three degrees relative to the low friction surface condition. It is doubtful that a mean difference of this magnitude would be relevant to the methods of the LESS, which relies on visual judgement by a human observer.

The LESS grades obtained in our study are relatively consistent with the prior literature. Padua et al. (2009) and Theiss et al. (2014) collected data on incoming military cadets and reported mean LESS grades of 4.92 points and 5.28 points, respectively, which are very similar to our reported values (see Table 2). Although the average age of the participants in these studies was slightly younger (mean age 19.3 yr in Theiss et al., 2014), it is likely that these incoming cadets were of the same maturational status as the participants in the present investigation. Similarly, our strong inter-rater reliability (ICC = 0.93) was found to be similar to both Padua et al.'s (2009; ICC = 0.84) and Onate, Cortes, Welch, and Van Lunen's (2010; ICC = 0.84). On the other hand, prior studies have noted sex-based differences in LESS grades, with females demonstrating a higher number of errors (Padua et al., 2009; Theiss et al., 2014). In contrast to these studies, we did not observe any main effects for LESS grades based on sex. Females demonstrated mean LESS grades that were slightly higher than for males, particularly for the court-surface condition, but this was not significant. It is possible that our sample size, which was far smaller than Padua et al.'s (2009) and Theiss et al.'s (2014), was insufficient to reliably detect such differences. It is also possible that the footwear used by the female participants was sufficiently different compared to that used by the male participants to blunt any sex-based differences in LESS grades. If these findings are repeated with larger samples and among additional landing surfaces, the collective evidence may indicate that the LESS could successfully be used in the actual environment in which the athlete plays.

Although our study used video cameras to review jumps at a later date, previous research has been done to look at the use of a modified scoring criteria, the LESS real-time (LESS-RT), which does not require the use of video-camera recording, assessing jump-landing tasks in the field. The LESS-RT was shown to be reliable and compared well with the original LESS study (Padua et al., 2011). Further research into the validity of LESS-RT on the surfaces tested here and others would further strengthen its practical use.

Limitations, strengths, and future directions

Limitations are present within this study. We elected against the use of particular standard athletic footwear as the primary hypothesis was to determine within-participant differences across landing surfaces. As previously noted, however, this may have affected participant comparisons, such as those based on sex. Additionally, this study evaluated the LESS grades after jump-landings on two surfaces, a basketball court and natural grass, that are commonly associated with specific footwear. The specific use of basketball shoes or soccer/football cleats on their respective surfaces could have resulted in a change in the shoe-surface interface sufficient to produce biomechanical alterations detectable by the LESS. This may be particularly true of the grass-cleat interface, and additional testing in this area is warranted. A strength of the study lies, however, in the repeated-measures design where the only variable to change between participants was the landing surface. As such, the footwear effect on LESS scores was likely low in this study. This study was limited to laboratory tile, court, and natural grass surfaces, but several other possible playing surfaces may be considered in future studies, such as synthetic outdoor turf. Furthermore, this study population consisted of college-aged recreational athletes, which does not represent the full diversity of athletic populations that participate in sports considered to be at elevated risk for ACL injury. It is possible that different magnitudes of effect of landing surface may be observed in populations of particular sports or maturational categories. Strengths of this study include rigorous LESS grading training for the raters that resulted in very high ICC values. The relative homogeneity of the participants included in the study may also have reduced variation in the scoring. Finally, the frame rates of the cameras used in this study could have introduced insensitivity to the LESS grading process. While 30 frames per second is consistent with previous studies by Padua et al. (2009) and Onate et al. (2010), it is possible the some differences could be distinguished with the use of cameras with higher frame rates by virtue of a more accurately assessment of the moment of initial contact during landing.

Conclusion

There were no significant differences in the LESS grades between court, grass, and laboratory-tile surfaces. This study suggests that the LESS may be useful for injury-risk screening when performed on landing surfaces outside the laboratory such as a basketball court or a soccer/football field.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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