Clinical Implications of Landing Distance on Landing Error Scoring System Scores

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Context: The Landing Error Scoring System (LESS) screens for risk of noncontact anterior cruciate ligament injury. The LESS requires individuals to jump forward from a 30-cm box to a distance of 50% of their body height. However, different landing distances have been cited in the scientific literature.

Objective: To examine whether landing distance influences LESS outcomes.

Design: Cross-sectional study.

Setting: Laboratory.

Participants or Other Participants: Seventy young active individuals (34 males, 36 females).

Intervention(s): Participants performed 3 × 30-cm jump-landing tasks under 2 landing conditions in randomized order: (1) 50% of body height (da50%), (2) self-selected distance (das).

Main Outcome Measure(s): Mean LESS scores, proportions of individuals categorized at high (LESS: ≥5 errors) and low (LESS: <5 errors) injury risk, and landing distances were compared between conditions using generalized estimating equations. Consistency of risk categorization was examined using odds ratios (ORs) and McNemar tests. McNemar and Wilcoxon signed rank tests were used to compare the occurrence of specific LESS errors.

Results: Participants landed closer to the box under the das condition (difference = −23.28 [95% CI = −20.73, −25.81]%, P < .001). Group mean LESS scores (difference = −0.01 [95% CI = −0.59, 0.57] error, P = .969) and risk categorization (OR = 0.94 [95% CI = 0.47, 1.88], P = .859) were similar between conditions. However, individual-level risk categorization was inconsistent in 33% of participants, as was the occurrence of specific errors.

Conclusions: Using das during the LESS might lead to different LESS errors and risk categorizations at an individual level than using da50%. Given that individual LESS scores are of primary interest in clinical and sport settings and the injury-risk threshold has not been validated for das, we recommend use of the original LESS protocol. When only group mean LESS scores or proportions of at-risk individuals are of interest, using das is feasible to facilitate the testing of large cohorts.

Key Words: injury risk, jump-landing biomechanics, movement screen

Key Points

• The original Landing Error Scoring System (LESS) requires individuals to jump forward from a 30-cm box to 50% of their body height; however, some researchers use different landing distances during LESS assessment.

• At a group level, LESS scores were similar between landing conditions, though at an individual level, specific movement errors and risk categorizations were inconsistent.

• We recommend clearly documenting the landing distance and using the original LESS protocol when feasible for baseline testing, when individual LESS scores are of specific interest.

The Landing Error Scoring System (LESS) is a clinical assessment tool that examines the presence of biomechanical “errors” during a jump-landing task with two linked to noncontact anterior cruciate ligament (ACL) injury. Clinicians evaluate frontal- and sagittal-plane videos of jump landings and visually evaluate aberrant lower extremity and trunk kinematics at initial ground contact and peak knee flexion. Subjective assessment of movement quality between initial ground contact and peak knee flexion is also considered during LESS scoring. The scientific literature and clinical community use a range of terms to describe the jump-landing task used to score the LESS, including jump landing, drop jump, drop landing, and drop vertical jump. Because the jump-landing task of the original LESS is fundamentally active in nature (ie, requires an individual to jump forward), in contrast to the more passive nature of the drop-jump task, we will use the term jump landing in this article.

The LESS scores range from 0 to 17 errors. A higher score indicates a greater number of landing errors, poorer landing biomechanics, and a greater risk of sustaining a noncontact ACL injury. In a recent systematic review, researchers concluded that the LESS was a valid and reliable screening tool; however, based on current scientific evidence, the predictive value of the LESS for ACL injury remains uncertain. In a prospective study, Padua et al evaluated elite youth soccer players and concluded that LESS scoring had good sensitivity (86%) and acceptable specificity (64%) for identifying the risk of noncontact ACL injury. The relative risk was 10.7 times greater when LESS scores were ≥5 errors compared with <5 errors. In contrast, Smith et al found no significant relationship between LESS scores and ACL injury incidence. Differences in sampled populations in terms of age, main sporting
event, and previous injury status, as well as the lack of statistical power in both studies\textsuperscript{10,11} are underlying factors that may have contributed to the divergent findings on the predictive value of the LESS. Despite these different results, the LESS is commonly used in research and practice to evaluate faulty movement patterns, the effect of interventions on neuromuscular control, and rehabilitation outcomes.\textsuperscript{8} Furthermore, among the existing field-based injury-screening methods, the LESS is most often recommended for use based on reviews of the literature.\textsuperscript{8,9}

The jump-landing task during LESS assessment involves jumping forward from a 30-cm-high box to a distance of 50\% of an individual’s body height and immediately jumping upward for maximal vertical height.\textsuperscript{1} Although the majority of authors\textsuperscript{1,4,7,10} who used the LESS set the jump distance according to the original protocol, variations existed. For instance, Onate et al\textsuperscript{6} standardized landing distance to 30 cm from the box, and DiStefano et al\textsuperscript{12} implemented a landing distance equal to 25\% of each participant’s body height, although no rationale was provided. Moreover, anecdotal observations and discussions with clinicians and practitioners in health and sports indicated that the landing distance was often not set for the LESS; rather, the more passive “dropping down” instead of the active “jumping from” the box method was used to reflect the strength and conditioning drop-jump approach to assess the mechanical outputs of the lower extremity.\textsuperscript{12}

Changes in clinical tests and protocols can exert nontrivial effects on outcomes and their interpretations.\textsuperscript{13}

It is essential in both research and practice that outcomes from assessments are reproducible and comparable among studies to improve health care management and scientific inference. If the LESS scores and risk categorizations remain unaffected by landing distance, testing of large cohorts would be facilitated and less time consuming if the landing distance did not need to be adjusted to 50\% of each individual’s height. We aimed to explore whether the landing distance would influence LESS scores and risk categorizations. The null hypothesis was that landing distance would exert no significant effect on mean LESS score, group-level risk categorization, or individual-level risk categorization.

METHODS

Participants

The sample-size calculation for this study was based on data from 2 previous studies of the LESS, one according to the original protocol (50\% body height)\textsuperscript{10} and the second using a modified protocol (25\% body height).\textsuperscript{3} Both investigations involved similar cohorts (29 and 20 physically active males, age = 18.5 $\pm$ 2.5 and 20 $\pm$ 2.0 years, respectively). We applied standard 2-tailed hypothesis equations, 95\% power ($\beta = .05$), 5\% significance level ($\alpha = .05$), critical values of the $t$ distribution, and data from these studies\textsuperscript{3,10} to calculate the required sample size. These equations indicated that 64 participants were needed to identify group differences in mean LESS scores between the jump distances. To account for 10\% potential withdrawals and missing data, we recruited 70 participants.

Participants had to be 16 to 30 years old, regularly engaged in physical activity (at least once a week) at any level, and free from injury, pain, or any other concern that would limit physical activity. Both sexes (males and females) were included. Previous injuries were not an exclusion criterion. The study protocol was approved by our institution’s health research ethics committee (HREC [Health] #41) and adhered to the Declaration of Helsinki. All participants signed a written informed consent document that explained the potential risks associated with testing.

Testing Procedure

The testing procedure in both experimental conditions was identical to that described by the developers of the LESS,\textsuperscript{1} with the exception of the landing distance from the box. During the jump-landing task, we required participants to jump from a 30-cm-high box under 2 landing conditions: (1) set distance of 50\% of their body height ($d_{50\%}$), and (2) self-selected distance ($d_w$) for which landing distance was not set. We instructed participants to immediately jump upward for maximal vertical height upon landing. We emphasized actively jumping (not dropping) off the box with both feet, jumping as high as possible straight up on landing from the box, and completing the task in a fluid motion. We did not provide any feedback on landing technique unless a participant was performing the task incorrectly. After receiving the task instructions and practicing jumps for familiarization (typically 1), each person performed 3 successful jump-landing trials under each landing condition. The order of the 2 landing conditions was randomized. We allowed participants to rest between trials within conditions to limit fatigue until they felt ready to perform the task (typically 1 minute); at least 15 minutes of seated rest was allowed between conditions. All tests were completed in a single experimental session.

Two standard video cameras capturing images at 120 Hz (model RX10 II; Sony Corporation) with an actual focal length of 8.8 to 73.3 mm (35-mm equivalent focal length of 24–200 mm) recorded the jump-landing tasks. We mounted the cameras on tripods placed 3.5 m in front of and to the right side of the landing area with a lens-to-floor distance of 1.3 m. A qualified physiotherapist who had conducted more than 400 LESS evaluations replayed the videos using the Kinovea software (version 0.8.15) and scored all 6 trials using the 17-item LESS scoring sheet.\textsuperscript{1} The mean LESS score from the 3 trials completed under each condition was used for statistical analysis. The physiotherapist could not be blinded to the landing condition due to the visibility of the landing distance on the videos; however, the assessor was blinded to the participants’ scores under the alternate condition. The physiotherapist also used the Kinovea video-analysis software to measure the length of the jump (distance from the box to the heel closest to the box during landing) for each trial after calibrating the video to a 1-m ruler.

Statistical Analysis

We assessed the effect of landing condition on (1) group mean LESS score, (2) group-level risk categorization (proportion of participants categorized as high [LESS: $\geq$ 5 errors] and low [LESS: $<$ 5 errors] injury risk), and (3) individual-level risk categorization (consistency of high or low injury risk category). The landing distance (in cm and
expressed as a percentage of body height) and the proportions of specific LESS errors in the 2 conditions were also compared.

The influence of the landing condition on group mean LESS score, group-level risk categorization, and landing distance was estimated using a generalized estimating equation (GEE).\textsuperscript{14} The GEE approach provides an estimate of the average effect in a population, applying robust standard errors to account for within-individual correlations. We used the GEE model with a Gaussian (normal) distribution to explore the influence of the landing condition ($d_{50\%}$ versus $d_{ss}$) on the group mean LESS score and landing distance. We applied a binomial distribution to explore the influence of landing condition on group-level risk categorization to estimate the odds ratio (OR) of being categorized as high injury risk in the $d_{ss}$ compared with the $d_{50\%}$ condition. Both GEE models applied an exchangeable correlation structure.

To explore the individual-level risk categorization, we assessed the agreement (n and %) in risk categorization between the landing conditions using ORs and the 2-tailed McNemar test. The OR indicates whether a landing condition was more likely to categorize individuals as high injury risk: specifically, the number of participants at high injury risk exclusively for the landing condition was more likely to categorize individuals as high injury risk than with $d_{50\%}$.

We set the significance level at $P \leq .05$ for all analyses. The statistics were computed using Microsoft Excel for Office (version 365) and RStudio (version 1.1.463) in R (version 3.5.2). All participants finished the study, and the complete dataset was analyzed.

**RESULTS**

A sample of 70 young adults (34 males, 36 females) participated in this study. Age, height, and mass (mean ± SD) for males were 18.9 ± 0.8 years (range = 18–21 years), 180.3 ± 6.7 cm, and 80.1 ± 14.4 kg and for females were 19.6 ± 2.4 years (range = 17–26 years), 169.0 ± 6.9 cm, and 64.5 ± 7.1 kg, respectively. All participants were physically active an average of 3.7 times per week for 6.8 hours per week and for at least 2 years. Their levels of engagement with sport were 51% club level, 20% school level, 19% national level, and 10% recreational.

Participants landed at the prescribed 50% of body height in $d_{50\%}$ and closer to the box in the $d_{ss}$ condition ($P < .001$, Table 1). The group LESS score (mean ± SD) was 5.58 ± 1.79 errors (range = 1.67–11.00 errors) for the $d_{50\%}$ and 5.57 ± 1.74 errors (range = 1.30–10.7 errors) for the $d_{ss}$ condition, with 66% and 64% of participants, respectively, categorized as having a high risk of injury based on the threshold of ≥5 errors (Table 1). Given the GEE estimates, the group mean LESS scores ($P = .969$) and odds of being classified as high injury risk at a group level (OR = 0.94 [95% CI = 0.47, 1.88], $P = .859$) were similar between conditions.

At an individual level, the risk categorization was inconsistent for 33% (n = 23) of participants between conditions (Figure). Twelve participants were categorized as at high risk of injury exclusively for $d_{50\%}$ (Figure). Their mean difference in LESS scores between conditions was 1.85 errors. In contrast, 11 participants were categorized as at high risk of injury exclusively for $d_{ss}$ (Figure). Their mean difference in LESS scores between conditions was

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**Table 1. Comparison of Landing Distances, Landing Error Scoring System Scores, and Group-Level Risk Categorization Between 2 Landing Conditions Using Generalized Estimating Equations**

| Variable                        | $d_{50\%}$ | $d_{ss}$ | Difference | $P$ Value |
|---------------------------------|------------|----------|------------|-----------|
| Landing distance, cm\(^{a}\)    | 86.19 (82.98, 89.40) | 45.42 (40.87, 49.97) | -40.77 (−45.32, −36.32) | <.001     |
| Landing distance, % height\(b\) | 49.39 (47.57, 51.21) | 26.11 (23.54, 28.67) | -23.28 (−20.73, −25.81) | <.001     |
| Errors, No.                     | 5.58 (5.17, 5.99) | 5.57 (4.98, 6.16) | -0.01 (−0.59, 0.57) | .969      |
| Percentage (No.)                | 65.71 (46) | 64.29 (45) | 0.94\(c\) (0.47, 1.88) | .859      |

**Abbreviations:** $d_{50\%}$, distance of 50% body height; $d_{ss}$, self-selected distance.

\(a\) Distance between box and heel landing closer to the box.

\(b\) Five or more errors.

\(c\) Odds ratio; values <1.00 indicate lower odds of high injury risk than with $d_{50\%}$.

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**Figure.** Number of participants at high (≥5 errors) or low (<5 errors) risk of injury for each landing distance condition based on the Landing Error Scoring System.
Table 2. Landing Error Scoring System (LESS) Specific Errors During 210 Jump-Landing Tasks

| No. | Items                                             | Errors, No. | $d_{ss}$ | $d_{50\%}$ | $P$ | Value $^a$ |
|-----|--------------------------------------------------|-------------|----------|-------------|-----|------------|
| 1.  | Knee flexion at initial contact                   | 142         | 141      | 1.000       |     |            |
| 2.  | Hip flexion at initial contact                    | 0           | 0        | 1.000       |     |            |
| 3.  | Trunk flexion at initial contact                  | 2           | 1        | 1.000       |     |            |
| 4.  | Ankle plantar flexion at initial contact          | 16          | 4        | 0.04$^b$    |     |            |
| 5.  | Knee valgus at initial contact                    | 13          | 42       | <0.01$^b$   |     |            |
| 6.  | Lateral trunk flexion at initial contact          | 140         | 121      | 0.070       |     |            |
| 7.  | Stance width (w)                                  | 16          | 23       | 0.92        |     |            |
| 8.  | Stance width (narrow)                             | 108         | 132      | 0.002       |     |            |
| 9.  | Foot position (toe in)                            | 1           | 0        | 1.000       |     |            |
| 10. | Foot position (toe out)                           | 53          | 38       | 0.008$^b$   |     |            |
| 11. | Symmetric foot contact at initial contact         | 147         | 157      | 0.314       |     |            |
| 12. | Knee-flexion displacement                         | 12          | 19       | 0.167       |     |            |
| 13. | Hip flexion at maximal knee flexion              | 6           | 4        | 0.754       |     |            |
| 14. | Trunk flexion at maximal knee flexion            | 47          | 38       | 0.122       |     |            |
| 15. | Knee-valgus displacement                          | 103         | 82       | 0.001$^b$   |     |            |
| 16. | Joint displacement                                | 116         | 116      | 1.000       |     |            |
| 17. | Overall impression                                | 237         | 236      | 0.871       |     |            |

Abbreviations: $d_{ss}$, distance of 50% body height; $d_{ss}$, self-selected distance.

$^a$ McNemar test $P$ values for the proportions of errors scored for LESS items 1–15 and Wilcoxon signed rank test $P$ values for LESS items 16 and 17 between conditions.

$^b$ Different between conditions ($P < .05$).

1.82 errors. The difference in the proportion of participants at high or low injury risk was not significant between conditions (McNemar test $P = 1.000$), with slightly greater odds of being at high injury risk (OR = 1.09 [95% CI = 0.48, 2.47]) in the $d_{50\%}$ condition (Figure). The proportion of specific LESS errors was different for ankle plantar flexion at initial contact ($d_{50\%} > d_{ss} P = .004$), knee valgus at initial contact ($d_{50\%} < d_{ss} P < .001$), narrow stance width ($d_{50\%} < d_{ss} P = .002$), toe-out foot position ($d_{50\%} > d_{ss} P = .008$), and knee-valgus displacement ($d_{50\%} > d_{ss} P = .001$; Table 2).

DISCUSSION

We explored the influence of landing at a distance of 50% of body height ($d_{50\%}$, as prescribed in the original LESS protocol$^1$) versus a self-selected distance ($d_{ss}$, as typically prescribed by strength and conditioning coaches, athletic trainers, and physiotherapists) on mean LESS score, group-level risk categorization, individual-level risk categorization, and the occurrence of specific LESS errors. Landing distance did not influence the mean LESS score or the proportions of participants categorized as at high (LESS $\geq$ 5 errors) or low (LESS $< 5$ errors) injury risk; however, the occurrence of specific LESS errors and individual-level risk categorization were inconsistent between the landing conditions. Based on these results, researchers can consider using $d_{ss}$ to facilitate the testing of large cohorts when only the group mean LESS score or the proportions of participants at high or low injury risk in a given population are of interest, with the caveat that the injury-risk threshold of 5 errors for the LESS has not been validated for $d_{ss}$. However, in clinical and sport environments, the specific movement errors and injury-risk categorizations are of primary interest and using $d_{ss}$ during the LESS might lead to different LESS errors and a different risk categorization at an individual level than $d_{50\%}$. Given that the LESS at $d_{50\%}$ is the protocol that has shown some value in predicting the ACL injury risk at an individual level,11 this protocol should be used in clinical and sport settings as a baseline test until the predictive ability of LESS at $d_{ss}$ is prospectively examined. In any circumstance, explicit documentation of landing distance is encouraged to ensure the reproducibility of protocols and outcomes.

The original LESS requires individuals to perform a jump-landing task from a 30-cm-high box to $d_{50\%}$. However, scientists have implemented various landing distances for LESS assessment$^3,6$ other than the $d_{50\%}$. In our study, the landing distance was often not set when using the LESS. On average, $d_{50\%}$ equated to a landing distance of 86.19 cm in our study. In contrast, when individuals self-selected their landing distance, they landed at a distance equaling 26.11% of their body height (the equivalent of 45.42 cm), close to the 25% used by DiStefano et al. For us, this landing distance was approximately 40 cm closer to the box than $d_{50\%}$.

The mean LESS scores and group-level risk categorizations were similar between the 2 landing distances. Changing the landing distance of jumps has been shown to alter landing biomechanics.$^{15–17}$ As the jump distance increased from 20% to 80% of body height$^{16}$ (35.2–140.7 cm) during the double-legged stop-jump task and from 30% to 90% of maximal jump distance (42–163 cm) during a travelling jump in dancers, anterior tibial shear force, peak forward acceleration of the tibia, peak posterior ground reaction shear force, and vertical ground reaction force (GRF) have been reported to increase.$^{15,17}$ These biomechanical variables have been associated with ACL strain and are considered important risk factors for noncontact ACL injury.$^{18–20}$ As such, one would expect increased ACL strain and worse LESS scores under $d_{50\%}$ than $d_{ss}$ due to the increased landing distance, which we did not observe. However, the number of LESS movement errors changed between conditions. Specifically, from the 210 jump-landing tasks (70 participants $\times$ 3 tasks) scored, 12 more errors for ankle plantar flexion at initial contact (item 4), 18 more errors for toe-out foot position (item 10), and 21 more errors for knee-valgus displacement (item 15) were scored under the $d_{50\%}$ than the $d_{ss}$ condition (Table 2). Yet 29 more errors for knee valgus at initial contact (item 5) and 24 more errors for narrow stance width (item 8) were scored under the $d_{ss}$ than the $d_{50\%}$ condition. Intrarater agreement for these LESS movement errors was 80% to 100%; hence, these differences between landing distances would probably not be due to poor intrarater reliability of individual LESS items. The change in the occurrence of specific LESS errors confirmed that altering the jump distance affected gross movement patterns. Nonetheless, the change in movement errors was distributed quasi-equally between the distances (ie, certain errors increased, and others decreased), and the mean LESS scores and group-level risk categorizations were not affected.

Other than landing distance,$^{21–23}$ jump-landing biomechanics and neuromuscular control can be influenced by...
Box height,21–25 footwear,22 instructions,21,23 subsequent movement,26 and history of ACL rupture.27 For instance, the vertical GRF was 1.1 times greater barefoot than shod during netball landings,22 and increasing the heights of boxes from 32 to 72 to 128 cm22,24 increased the vertical GRF during landing from 3.9 to 6.3 to 11 times body weight, respectively. When vertical GRF increases, individuals are more prone to land with greater knee-flexion displacement to moderate forces and protect the body against high impact loads.25 Huston et al25 showed that the knee angle at initial contact increased from 7° to 12° and maximum knee-flexion angle increased from 88° to 104° when landing height increased from 20 to 60 cm during drop-jump tasks. The “softness” of landing (item 16, Table 2), knee-flexion angle at initial contact (item 1), and knee-flexion displacement (item 12) during the jump-landing task are scored during the LESS.3 Changes in box height would likely affect LESS scores to a greater extent than changes in landing distance. Some authors have used a 40-cm rather than a 30-cm box28 and tested participants barefoot29 during the LESS, but the clinical implications of these alterations compared with the original protocol are unknown.1

Whereas the odds of being classified as at high injury risk were similar between the $d_{50\%}$ and $d_{ss}$ conditions at a group level ($P = .859$) based on the established cutoff score of 5 errors,1 only a subset of individuals (n = 34, 49%) were categorized as at high risk under both conditions. The difference in landing biomechanics and related difference in the number of specific LESS errors between conditions is the most probable source of inconsistency in risk categorization. The mean differences in LESS scores between conditions for participants who scored at high risk exclusively for $d_{50\%}$ and $d_{ss}$ were 1.85 and 1.82 errors, respectively. The psychometric properties of the LESS were as follows: standard error of measurement (SEM) for intrarater reliability = 0.19 to 0.52, interrater reliability = 0.71, and test-retest reliability = 0.81 errors.5 These SEM values indicate that the magnitude of the difference in LESS scores between participants who were categorized as at high risk exclusively for a given landing condition is clinically meaningful. Therefore, we caution against using $d_{ss}$ when individual errors and individual-level risk categorization are of interest.

The main limitation of our study was that group-level and individual-level risk categorization were set at 5 errors based on a prospective study from Padua et al.11 Research on other functional movement screens, ie, the Y-Balance Test and Functional Movement Screen, indicated that injury risk thresholds should take sex, sport, and age into account.30 The threshold of 5 errors derives from a population of young (age = 13.9 ± 1.8 years) elite soccer players11 and might not be appropriate for our population of young physically active adults (age = 19.3 ± 1.8 years). However, to date, no other population-specific cutoff score has been established for the LESS. Furthermore, it is important to note that the predictive ability of the LESS for noncontact ACL injury is uncertain based on current evidence.5 We also caution that our sample population of 70 young active individuals may limit the generalizability of our findings to younger and older athletes or less active groups.

CONCLUSIONS

Group mean LESS scores and the proportions of participants categorized as at high or low risk of injury based on a threshold of 5 errors were similar when landing at a distance of 50% of an individual’s height compared with a self-selected distance. The LESS data are commonly averaged and compared between (eg, males versus females, injured versus uninjured participants) or within (eg, preintervention versus postintervention) groups to draw clinical inferences.2,10,31 In such cases, using $d_{ss}$ could facilitate the testing of large cohorts by removing the need to individualize landing distances to 50% of body height. However, the change in the occurrence of specific LESS errors confirms that altering the jump distance affected gross movement patterns. Injury risk thresholds for $d_{ss}$ have not been validated and might provide inconsistent and inaccurate comparisons at an individual level versus LESS findings based on $d_{50\%}$. In clinical and sport settings, specific movement errors and injury-risk categorizations are of primary interest. Therefore, using the validated protocol of $d_{ss}$ is recommended until the psychometric properties of LESS at $d_{ss}$ have been established, given that our data showed differences in occurrence of specific LESS errors between $d_{ss}$ and $d_{50\%}$ protocols and inconsistent individual-level risk categories in 33% of participants.

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