Journal of Athletic Training 2021;56(6):572–577
doi: 10.4085/1062-6050-068-20

www.natajournals.org

Clinical Implications of Landing Distance on Landing Error Scoring System Scores

Ivana Hanzlíková, PT; Kim Hébert-Losier, PhD, PT

Division of Health, Engineering, Computing and Science, Te Huataki Waiora School of Health, Adams Centre for High Performance, University of Waikato, New Zealand

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 ($d_{50\%}$), (2) self-selected distance (d_{ss}).

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 d_{ss} 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 d_{ss} during the LESS might lead to different LESS errors and risk categorizations at an individual level than using $d_{50\%}$. Given that individual LESS scores are of primary interest in clinical and sport settings and the injury-risk threshold has not been validated for d_{ss}, we recommend use of the original LESS protocol. When only group mean LESS scores or proportions of at-risk individuals are of interest, using d_{ss} 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 that have been linked to noncontact anterior cruciate ligament (ACL) injury.[1] 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,[2–5] drop jump,[6] drop landing,[7] and drop vertical jump.[8–10] Because the jump-landing task of the original LESS is fundamentally active in nature (ie, requires an individual to jump forward),[1] 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[5] 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[11] 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[10] 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[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.[5] Furthermore, among the existing field-based injury-screening methods, the LESS is most often recommended for use based on reviews of the literature.[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.[1] Although the majority of authors[1,4,7,10] who used the LESS set the jump distance according to the original protocol, variations existed. For instance, Onate et al[6] standardized landing distance to 30 cm from the box, and DiStefano et al[3] 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.[12] Changes in clinical tests and protocols can exert nontrivial effects on outcomes and their interpretations.[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)[10] and the second using a modified protocol (25% body height).[3] Both investigations involved similar cohorts (29 and 20 physically active males, age = 18.5 ± 2.5 and 20 ± 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[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,[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_{ss}) 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.[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

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	Mean (95% CI)			P Value
	Landing Condition			
	$d_{50\%}$	d_{ss}	Difference	
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[a]	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.)			
High risk[b]	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 $d_{50\%}$.

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).[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 binominal 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 risk exclusively in the $d_{50\%}$ condition divided by the number of participants at high risk exclusively in the d_{ss} condition. We calculated the McNemar test to compare 2 proportions, ie, whether the proportions of participants at high risk significantly differed between conditions. McNemar tests were also used to compare the proportions of specific LESS movement errors for LESS items 1 to 15 (scored 1 = error present, 0 = error absent) between conditions. Due to different scoring of items 16 and 17 (0 to 2 errors), we used the 2-sided Wilcoxon signed rank test to compare these items between conditions.

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.

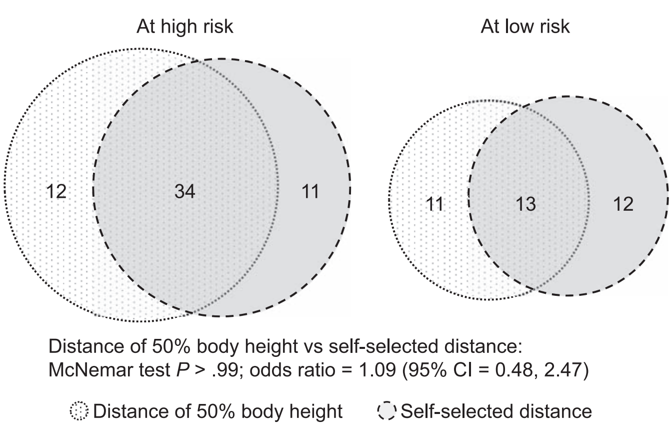

Figure. Number of participants at high (≥ 5 errors) or low (< 5 errors) risk of injury for each landing distance condition based on the Landing Error Scoring System.

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

Table 2. Landing Error Scoring System (LESS) Specific Errors During 210 Jump-Landing Tasks

No.	Items	Errors, No. $d_{50\%}$	Errors, No. d_{ss}	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	.004[b]
5.	Knee valgus at initial contact	13	42	<.001[b]
6.	Lateral trunk flexion at initial contact	140	121	.070
7.	Stance width (wide)	16	23	.092
8.	Stance width (narrow)	108	132	.002[b]
9.	Foot position (toe in)	1	0	1.000
10.	Foot position (toe out)	53	38	.008[b]
11.	Symmetric foot contact at initial contact	147	157	.314
12.	Knee-flexion displacement	12	19	.167
13.	Hip flexion at maximal knee flexion	6	4	.754
14.	Trunk flexion at maximal knee flexion	47	38	.122
15.	Knee-valgus displacement	103	82	.001[b]
16.	Joint displacement	116	116	1.000
17.	Overall impression	237	236	.871

Abbreviations: $d_{50\%}$, 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}.[11] 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 $d_{50\%}$.[1] However, scientists have implemented various landing distances for LESS assessment[3,6] other than the $d_{50\%}$ originally described by Padua et al[1] without knowing how protocol variations influence outcomes. Moreover, anecdotal observations and discussions with clinicians and practitioners in health care and sports indicated that 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.[3] 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%[6]; 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 cm[22,24] 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 al[25] 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.[1] 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 box[28] and tested participants barefoot[29] 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 players[11] 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 active young 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 $d_{50\%}$ 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.

REFERENCES

1. Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett WE Jr, Beutler AI. The Landing Error Scoring System (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: the JUMP-ACL study. *Am J Sports Med*. 2009;37(10):1996–2002. doi:10.1177/0363546509343200
2. DiStefano LJ, Beltz EM, Root HJ, et al. Sport sampling is associated with improved landing technique in youth athletes. *Sports Health*. 2018;10(2):160–168. doi:10.1177/1941738117736056
3. Distefano LJ, Casa DJ, Vansumeren MM, et al. Hypohydration and hyperthermia impair neuromuscular control after exercise. *Med Sci Sports Exerc*. 2013;45(6):1166–1173. doi:10.1249/MSS.0b013e3182805b83
4. Everard EM, Harrison AJ, Lyons M. Examining the relationship between the Functional Movement Screen and the Landing Error Scoring System in an active, male collegiate population. *J Strength Cond Res*. 2017;31(5):1265–1272. doi:10.1519/JSC.0000000000001582
5. Hanzlíková I, Hébert-Losier K. Is the Landing Error Scoring System reliable and valid? A systematic review. *Sports Health*. 2020;12(2):181–188. doi:10.1177/1941738119886593
6. Onate J, Cortes N, Welch C, Van Lunen BL. Expert versus novice interrater reliability and criterion validity of the Landing Error Scoring System. *J Sport Rehabil*. 2010;19(1):41–56. doi:10.1123/jsr.19.1.41
7. Kuenze CM, Foot N, Saliba SA, Hart JM. Drop-landing performance and knee-extension strength after anterior cruciate ligament reconstruction. *J Athl Train*. 2015;50(6):596–602. doi:10.4085/1062-6050-50.2.11
8. Fox AS, Bonacci J, McLean SG, Spittle M, Saunders N. A systematic evaluation of field-based screening methods for the assessment of anterior cruciate ligament (ACL) injury risk. *Sports Med*. 2016;46(5):715–735. doi:10.1007/s40279-015-0443-3
9. Read PJ, Oliver JL, De Ste Croix MBA, Myer GD, Lloyd RS. A review of field-based assessments of neuromuscular control and their utility in male youth soccer players. *J Strength Cond Res*. 2019;33(1):283–299. doi:10.1519/JSC.0000000000002069

10. Smith HC, Johnson RJ, Shultz SJ, et al. A prospective evaluation of the Landing Error Scoring System (LESS) as a screening tool for anterior cruciate ligament injury risk. *Am J Sports Med*. 2012;40(3):521–526. doi:10.1177/0363546511429776
11. Padua DA, DiStefano LJ, Beutler AI, de la Motte SJ, DiStefano MJ, Marshall SW. The Landing Error Scoring System as a screening tool for an anterior cruciate ligament injury–prevention program in elite-youth soccer athletes. *J Athl Train*. 2015;50(6):589–595. doi:10.4085/1062-6050-50.1.10
12. Bobbert MF, Huijing PA, van Ingen Schenau, GJ. Drop jumping. II. The influence of dropping height on the biomechanics of drop jumping. *Med Sci Sports Exerc*. 1987;19(4):339–346.
13. Hébert-Losier K. Clinical implications of hand position and lower limb length measurement method on Y-balance test scores and interpretations. *J Athl Train*. 2017;52(10):910–917. doi:10.4085/1062-6050-52.8.02
14. Liang KY, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika*. 1986;73(1):13–22.
15. Simpson KJ, Pettit M. Jump distance of dance landings influencing internal joint forces: II. Shear forces. *Med Sci Sports Exerc*. 1997;29(7):928–936. doi:10.1097/00005768-199707000-00012
16. Sell TC, Akins JS, Opp AR, Lephart SM. Relationship between tibial acceleration and proximal anterior tibia shear force across increasing jump distance. *J Appl Biomech*. 2014;30(1):75–81. doi:10.1123/jab.2012-0186
17. Simpson KJ, Kanter L. Jump distance of dance landings influencing internal joint forces: I. Axial forces. *Med Sci Sports Exerc*. 1997;29(7):916–927. doi:10.1097/00005768-199707000-00011
18. Bakker R, Tomescu S, Brenneman E, Hangalur G, Laing A, Chandrashekar N. Effect of sagittal plane mechanics on ACL strain during jump landing. *J Orthop Res*. 2016;34(9):1636–1644. doi:10.1002/jor.23164
19. Shimokochi Y, Shultz SJ. Mechanisms of noncontact anterior cruciate ligament injury. *J Athl Train*. 2008;43(4):396–408. doi:10.4085/1062-6050-43.4.396
20. Yu B, Garrett WE. Mechanisms of non-contact ACL injuries. *Br J Sports Med*. 2007;41(suppl 1):i47–i51. doi:10.1136/bjsm.2007.037192
21. Dufek JS, Bates BT. Models incorporating height, distance and landing technique to predict impact forces. *J Biomech*. 1989;22(10):1005.
22. Dufek JS, Bates BT. Biomechanical factors associated with injury during landing in jump sports. *Sports Med*. 1991;12(5):326–337. doi:10.2165/00007256-199112050-00005
23. Dufek JS, Bates BT. The evaluation and prediction of impact forces during landings. *Med Sci Sports Exerc*. 1990;22(3):370–377.
24. McNitt-Gray JL. Influence of impact speed on joint kinematics and impulse characteristics of drop landings. *J Biomech*. 1989;22(10):1054.
25. Huston LJ, Vibert B, Ashton-Miller JA, Wojtys EM. Gender differences in knee angle when landing from a drop-jump. *Am J Knee Surg*. 2001;14(4):215–220.
26. Bates NA, Ford KR, Myer GD, Hewett TE. Kinetic and kinematic differences between first and second landings of a drop vertical jump task: implications for injury risk assessments. *Clin Biomech (Bristol, Avon)*. 2013;28(4):459–466. doi:10.1016/j.clinbiomech.2013.02.013
27. Hébert-Losier K, Schelin L, Tengman E, Strong A, Häger CK. Curve analyses reveal altered knee, hip, and trunk kinematics during drop–jumps long after anterior cruciate ligament rupture. *Knee*. 2018;25(2):226–239. doi:10.1016/j.knee.2017.12.005
28. Kraus K, Schütz E, Doyscher R. The relationship between a jump-landing task and functional movement screen items: a validation study. *J Strength Cond Res*. 2019;33(7):1855–1863. doi:10.1519/JSC.0000000000002121
29. O'Malley E, Murphy JC, Persson UM, Gissane C, Blake C. The effects of the Gaelic Athletic Association 15 training program on neuromuscular outcomes in gaelic football and hurling players: a randomized cluster trial. *J Strength Cond Res*. 2017;31(8):2119–2130. doi:10.1519/JSC.0000000000001564
30. Lehr ME, Plisky PJ, Butler RJ, Fink ML, Kiesel KB, Underwood FB. Field-expedient screening and injury risk algorithm categories as predictors of noncontact lower extremity injury. *Scand J Med Sci Sports*. 2013;23(4):e225–e232. doi:10.1111/sms.12062
31. Pryor JL, Root HJ, Vandermark LW, et al. Coach-led preventive training program in youth soccer players improves movement technique. *J Sci Med Sport*. 2017;20(9):861–866. doi:10.1016/j.jsams.2017.01.235

Address correspondence to Ivana Hanzlíková, PT, Division of Health, Engineering, Computing and Science, Te Huataki Waiora School of Health, Adams Centre for High Performance, University of Waikato, 52 Miro Street, Mount Maunganui, Tauranga, New Zealand 3116. Address email to xhanzlikova@gmail.com.