Landing Error Scoring System scores change with knowledge of scoring criteria and prior performance

Abstract

Objective: To examine if the knowledge of scoring criteria and prior performance influence Landing Error Scoring System (LESS) outcomes.

Design: Cross-sectional.

Setting: Laboratory.

Participants: Thirty individuals.

Main outcome measures: The LESS was tested at *Baseline* and one week later under two conditions: *Pre* and *Post* information. For the *Post* condition, LESS items were explained to participants, as were their individual *Baseline* scores. Mean LESS scores and number of individuals categorized at high and low risk were compared between *Pre* and *Post* using paired *t*-tests and McNemar's tests, respectively. McNemar's tests were also used to compare proportions of specific LESS errors between *Pre* and *Post* conditions.

Results: Mean LESS *Post* scores (4.7 ± 1.2 errors) were significantly lower than *Pre* scores (6.6 ± 2.0 errors, $p < 0.001$) as was the number of individuals at high risk (25 vs 10 participants, $p < 0.001$). A significantly lower proportion of participants scored an error for the joint displacement item of LESS *Post* compared to *Pre* condition ($p < 0.001$).

Conclusion: When using the LESS, it is important that tested individuals have no knowledge of scoring criteria or previous errors for a valid assessment of innate jump-landing movement patterns and injury risk.

Highlights:

- Knowledge of scoring criteria and performance meaningfully improved LESS scores

- Knowledge of scoring criteria and performance altered LESS risk categorization
- Knowledge of scoring criteria and performance changed proportion of specific errors
- We caution against explaining the scoring criteria and errors to tested individuals

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

Introduction

Lower-extremity injuries are common in sport and are associated with health burden and socioeconomic costs (Knowles et al., 2007). Biomechanical and neuromuscular factors play an important role in non-contact lower-extremity injuries, and are potentially modifiable through preventive programs (Emery, Roy, Whittaker, Nettel-Aguirre, & Van Mechelen 2015; Webster & Hewett 2018). Therefore, several movement screens have been developed and are used daily to help clinicians identify individuals at high risk of non-contact injuries and inform injury prevention efforts (Cook, Burton, & Hoogenboom 2006; Dos'Santos et al., 2019; Myer, Ford, & Hewett 2008; Padua et al., 2009; Plisky et al., 2009).

The Landing Error Scoring System (LESS) is a movement-based injury risk screening tool that is easy to administer, suitable for testing large cohorts, and can be used both in clinics and in the field without expensive laboratory equipment (Padua et al., 2009). The LESS involves the performance of a double leg jump-landing task and relies on the use of two standard video cameras, one placed to capture frontal plane motion and the other to capture sagittal plane motion. Using the video recordings to score the LESS, an examiner visually evaluates movement patterns and notes the number of "movement errors" using a 17-item scoring sheet (Table 1). The movement errors are aberrant lower-extremity and trunk movement patterns that have been suggested as factors contributing to non-contact lower-extremity and Anterior Cruciate Ligament (ACL) injuries (Hewett, Ford, Hoogenboom, & Myer 2010). For instance, several LESS items (items: 1 to 4, 12 to 14, and 16, Table 1) are linked to a stiff landing technique, which results in increased ground reaction forces and loading of joint structures (Laughlin et al., 2011). The magnitude of ground reaction forces has been associated with increased lower-extremity injury risk, including to the ACL (de Noronha, Refshauge, Herbert, & Kilbreath 2006; Leppänen et al., 2017). Furthermore, knee valgus angle (items 5 and 15, Table 1) and lateral trunk flexion angle (item 6, Table 1) have been identified as strong predictors of knee ligament injuries in prospective studies (Hewett et al., 2005; Zazulak, Hewett, Reeves, Goldberg, & Cholewicki 2007). The remaining items (items 7 to 11, Table 1) are hypothesized to contribute to ACL injury; however, stronger evidence is still needed. LESS scores range from 0 to 17 errors, where greater scores indicate more movement errors and poorer landing biomechanics (Padua et al., 2015). A prospective study has identified a 10.7 times greater relative risk of sustaining a non-contact ACL injury in presence of a LESS score ≥ 5 errors versus < 5 errors (Padua et al., 2015).

A recent systematic review of the literature concluded that the overall LESS score has good to excellent intrarater (intraclass correlation coefficient [ICC], 0.82-0.99), interrater (ICC, 0.83-0.92), and intersession (ICC, 0.81) reliability (Hanzlíková & Hébert-Losier 2020). Validity of the overall LESS score against 3-dimensional (3D) jump-landing biomechanics was good when individuals were divided into four quartiles based on LESS scores, although the validity of the individual LESS items was item dependent (Onate, Cortes, Welch, & Van Lunen 2010; Padua et al., 2009). However, most of the items addressing key risk factors for ACL showed moderate-to-excellent validity versus 3D motion capture data (Onate et al., 2010). Padua et al., (2015) identified 5 errors as an optimal cutoff point for non-contact ACL injury in a prospective investigation, yielding a sensitivity of 86%, specificity of 64%, and 10.7 times greater relative risk.

For any clinical assessment, it is essential that testing methods provide outcomes that are valid and that changes in scores reflect meaningful changes in function of individuals and identify individuals with differing abilities. Previous studies showed that knowledge of scoring criteria can potentially compromise the clinical utility of the injury risk screening tool (Bryson, Arthur, & Easton 2018; Frost, Beach, Callaghan, & McGill 2015). Frost et al. (2015) demonstrated that professional firefighters could significantly improve their performance on the Functional Movement Screen™ (FMS) once provided with information regarding the scoring criteria.

Bryson, Arthur and Easton (2018) confirmed Frost et al. (2015) findings employing a randomized control trial design involving male professional soccer players. The FMS evaluates imbalances in mobility and stability during seven fundamental movement patterns, which are rather slow and controlled movements in nature compared to the more dynamic jump-landing task employed during the LESS.

Besides knowledge of scoring criteria, feedback on performance is able to alter movement patterns (Myer et al., 2013). A meta-analysis exploring the effect of intervention on ACL injury incidence (Sugimoto et al., 2016) highlighted the importance of plyometrics and technique feedback in intervention programs. Therefore, jump-landing technique feedback is commonly used in clinical practice and research and is also emphasized in injury prevention programs which meaningfully improved LESS scores by 2.4 to 3.0 errors (O'Malley, Murphy, Persson, Gissane, & Blake 2017; Pfile, Gribble, Buskirk, Meserth, & Pietrosimone 2016). Examples of instructions used to improve jump-landing technique include: land softly, on your toes and your knees bend; bend hips, knees, and ankles slightly and lean upper body forward; do not let your knee buckle inward; keep upper body stable (O'Malley et al., 2017; Pfile et al., 2016). All these instructions closely correspond with items assessed during LESS scoring (Table 1).

It is common in clinical practice and sport settings to explain LESS items and give feedback on individual’s landing technique after the LESS test. Furthermore, jump-landing technique feedback has been shown to meaningfully improve LESS scores when integrated as part of injury prevention programs (O'Malley et al., 2017; Pfile et al., 2016). It may be that feedback on prior performance may instantly improve LESS scores regardless of adhering to a specific injury prevention program. Similar to the FMS, it is possible that participants are able to alter performance during the LESS with knowledge of scoring criteria albeit being more dynamic in nature than the FMS tasks. Therefore, our aims were to compare LESS scores, risk categorization, and specific LESS errors before and after the provision of the LESS scoring criteria and information on individuals' performance. We hypothesized that knowing the scoring criteria and individuals' movement errors would lead to lower LESS scores, a lower number of participants being classified at high risk of injury and alter the proportion of specific errors on the LESS.

Methods

Participants

Sample size requirements were calculated using a G*Power software (Faul, Erdfelder, Lang, & Buchner 2007) from paired *t*-test two-tailed hypothesis equations using an 80% power (β = 0.20), 5% significance level (α = 0.05), critical values of the *t* distribution, and the data from previous studies (Hanzlíková & Hébert-Losier 2020; Padua et al., 2009). These studies indicated one error as a clinically meaningful difference in LESS scores (Padua et al., 2009) and 1.7 errors as the typical LESS standard deviation (Hanzlíková & Hébert-Losier 2020). The equations indicated that we needed 25 individuals to identify clinically meaningful differences in LESS score before and after the provision of the scoring criteria and information on an individual's own performance. To account for 20% of potential withdrawals and missing data, we recruited 30 participants.

Thirty young adults (15 males, 15 females) volunteered to participate in the study. Age, height, and mass (mean ± standard deviation) for males were 21.8 ± 4.8 years (range 19 to 39 years), 179.4 ± 6.5 cm, and 81.3 ± 14.4 kg; and for females were 21.3 ± 3.7 years (range 19 to 32 years), 168.7 ± 7.0 cm, and 68.6 ± 9.4 kg. All participants were involved in physical activity 3 times per week (median) for on average 6.7 ± 6.3 hours a week. Participants had to be free from injury, pain, or any other issues that would limit physical activity participation. 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.

Procedures

We used a repeated measure study design to examine whether individuals' awareness of the LESS scoring criteria and performance would alter LESS scores, risk categorization, and specific LESS errors. Thirty participants performed 3 x 30-cm double leg jump-landing tasks (DLJL) for LESS scoring at *Baseline.* A qualified physiotherapist (IH) who completed over 400 LESS evaluations replayed the videos using the Kinovea software (version 0.8.15, www.kinovea.org) and scored all three trials using the 17-item LESS scoring sheet (Table 1). One week later, the participants performed three DLJL again, once *Pre* information and once *Post* information. Following the *Pre* condition, all 17 items used for scoring (Table 1) were explained to participants with pictures showing errors for each item. The participants were also given their individual LESS scores from *Baseline* testing that specified their own movement errors for each one of the three *Baseline* jumps. After the 20-minute education session, participants performed three DLJL to obtain LESS scores *Post* information. The identical verbal instructions were given to participants in all three session, i.e. participants were not specifically instructed to change their landing technique based on their individual's errors. The same assessor (IH) collected data and scored LESS trials in all three instances. A random subsample of 10 jump-landings was scored three times by the assessor to determine the intra-rater reliability. Assessments were separated by a minimum of one week, with the assessor blinded to the previous assessment scores. The intraclass correlation coefficient was 0.96 and the standard error of the measurement was 0.23 error. The assessor was blinded to participants *Baseline* scores and to *Pre* and *Post* time points.

The original LESS protocol and scoring per Padua et al. (2009) were used in all three instances (*Baseline*, *Pre*, and *Post*). Participants jumped horizontally from a 30-cm box to a line placed at 50% of their body height, and immediately jumped upward for maximal vertical height. Participants were instructed to jump off the box with both feet, land in front of the designated line, jump as high as possible upward upon landing, and complete the task in fluid motion. No feedback on landing technique was provided unless participants were performing the task incorrectly. Participants were given as many practice trials as needed to become comfortable with the task (typically one) and were allowed to rest between trials until they felt ready to perform the DLJL again to limit fatigue. In all instances, the DLJL were recorded by two standard video cameras capturing at 120 Hz (Sony RX10 II, Sony Corporation, Tokyo, Japan) with an actual focal length of 8.8 to 73.3 mm (35-mm equivalent focal length of 24-200 mm). 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.

Statistical analysis

The mean LESS score from the three DLJL trials, number of individuals categorized at high (LESS ≥ 5 errors) and low (LESS < 5 errors) injury risk (Padua et al., 2015), and number of specific LESS errors were used for statistical analysis. Group mean LESS scores between *Pre* and *Post* conditions were compared using mean differences (MD) with 95% confidence intervals [lower, upper], two-tailed paired *t*-tests, and corresponding effect sizes (Hedge's *g*) with 95% confidence intervals. Thresholds for interpreting the magnitude of Hedge's *g* were set at 0.2, 0.5, and 0.8 for *small*, *medium*, and *large* effects (Lakens 2013). Effect sizes < 0.2 were considered *trivial* (Lakens 2013).

McNemar's tests were used to compare the proportion of participants categorized at high and low injury risk between *Pre* and *Post* conditions. McNemar's test compares proportions; in our case, the proportion of participants at high risk exclusively for one condition compared to the proportion of participants at high risk exclusively for a second condition. McNemar's tests were also used to compare the proportion of specific LESS movement errors between *Pre* and *Post* conditions. For LESS items 1 to 15 (Table 1), an error was marked as present when the specific LESS error was present in at least 2 of 3 trials. For items 16 and 17 (Table 1), error was marked as present when the "*Average*" rating was present in at least 2 of 3 trials or "*Poor/Stiff*" rating in at least 1 of 3 trials (Padua et al., 2009).

Statistical significance level was set at $\alpha \leq 0.05$. Given the number of statistical comparisons used to compare the proportion of specific LESS movement errors between conditions (n = 17), the Bonferroni-corrected p-value ($p \leq 0.003$) was used to infer statistical significance in this analysis to reduce the likelihood of type 1 errors. The statistics were computed using Microsoft Excel® for Office 365 MSO and RStudio® Version 1.1.463 with R version 3.5.2.

Results

All participants finished the study and the complete data set was analyzed. The mean LESS scores of individuals ranged from 1.7 to 11.0 errors. *Post* information mean LESS scores were significantly lower than *Pre,* with a mean difference of -1.9 [-2.9 to -1.0] errors ($p < 0.001$, Figure 1). The effect of condition on mean LESS scores was large (Hedge's g 1.2 [0.5 to 1.9]). The number of participants at high injury risk was significantly lower *Post* information compared to *Pre* information condition (McNemar's test $p < 0.001$, Figure 2). *Post* information, 17 (57%) participants changed their injury risk categorization from high to low, 11 (37%) participants remained in the same category, and 2 (6%) participants went from low to high injury risk compared to the *Pre* information condition. Table 1 presents the proportion of specific LESS errors during the *Pre* and *Post* information conditions. Proportion was significantly lower for item 16: Joint displacement *Pre* compared to *Post* condition ($p < 0.001$).

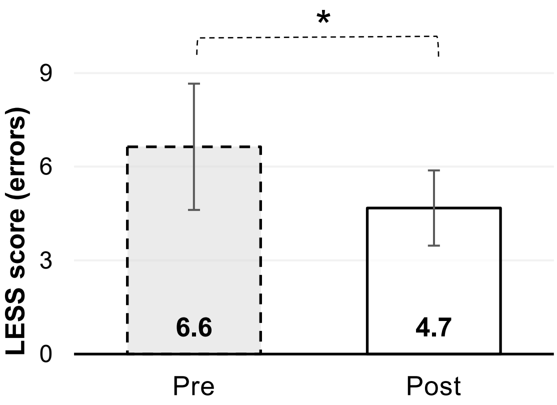

Figure 1. Group mean Landing Error Scoring System (LESS) scores. Error bars represent standard deviations. * Indicate paired *t*-test $p < 0.001$.

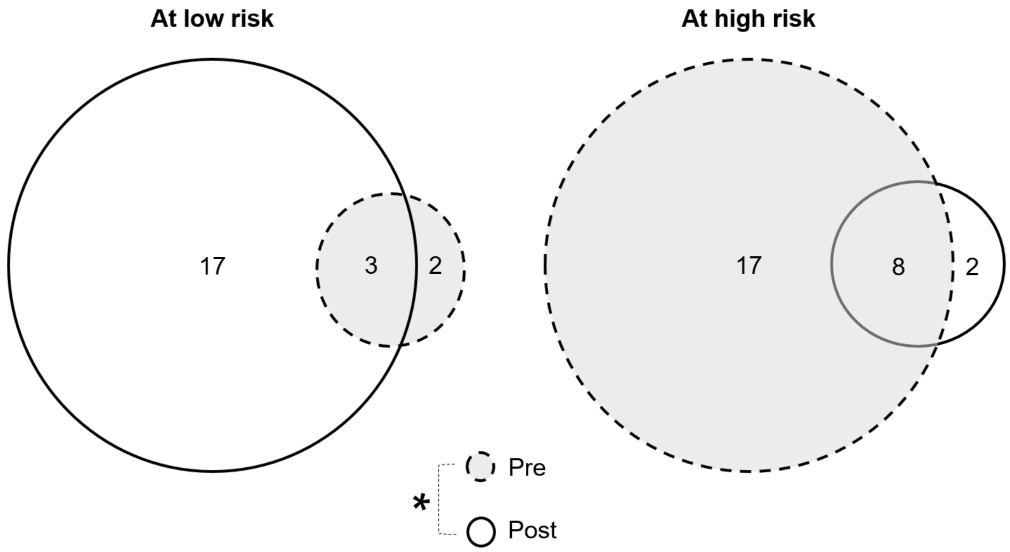

Figure 2. Venn diagrams representing the number of participants at high (LESS ≥ 5 errors) and low (LESS < 5 errors) injury risk for each condition. The sum of all values within one circle represents the number of participants categorized at high/low injury risk for given condition. Overlapping circles show the number of participants consistently scored at high/low risk within both conditions. LESS, Landing Error Scoring System. * Indicate McNemar's test $p < 0.001$.

Table 1. Landing Error Scoring System (LESS) specific errors.

No	**Item**	**Definition of error**	**Number (percentage) of errors[a]**		***p*-value[b]**
			Pre	***Post***	
1.	Knee flexion at IC	Knee flexion < 30°	11 (37%)	13 (43%)	0.791
2.	Hip flexion at IC	Thigh is in line with the trunk (hips not flexed) at IC	0 (0%)	0 (0%)	1.000
3.	Trunk flexion at IC	Trunk is vertical or extended at the hips (i.e., not flexed) at IC	0 (0%)	0 (0%)	1.000
4.	Ankle plantar flexion at IC	Heel-to-toe or flat foot landing at IC	8 (27%)	3 (10%)	0.125
5.	Knee valgus at IC	Centre of the patella is medial to the midfoot at IC	10 (33%)	14 (47%)	0.289
6.	Lateral trunk flexion at IC	Midline of the trunk is flexed to the left or the right side of the body at IC	11 (37%)	14 (47%)	0.607
7.	Stance width (wide)	Feet are positioned greater than shoulder width apart (acromion processes) at IC	7 (23%)	14 (47%)	0.065
8.	Stance width (narrow)	Feet are positioned less than shoulder width apart (acromion processes) at IC	10 (33%)	5 (17%)	0.125
9.	Foot position (toe-in)	Foot is externally rotated more than 30° between IC and MKF	0 (0%)	0 (0%)	1.000
10.	Foot position (toe-out)	Foot is internally rotated more than 30° between IC and MKF	12 (40%)	9 (30%)	0.065
11.	Symmetric foot contact at IC	One foot lands before the other foot or 1 foot lands heel to toe and the other foot lands toe to heel	21 (70%)	12 (40%)	0.064
12.	Knee flexion displacement	Knee flexes less than 45° between IC and MKF	5 (17%)	0 (0%)	0.063
13.	Hip flexion at MKF	Thigh does not flex more on the trunk between IC and MKF	1 (3%)	0 (0%)	1.000
14.	Trunk flexion at MKF	Trunk does not flex more between IC and MKF	9 (30%)	0 (0%)	0.004
15.	Knee valgus displacement	At the point of maximum medial knee position, the center of the patella is medial to the midfoot	16 (53%)	9 (30%)	0.065

16.	Joint displacement	Joint displacement: *Soft, Average, Stiff*	25 (83%)	7 (23%)	< 0.001*
17.	Overall impression	Overall impression: *Excellent, Average, Poor*	30 (100%)	30 (100%)	1.000

Abbreviations: IC, initial contact; MKF, maximum knee flexion; No, number.

[a] Number (percentage) of participants scored error on specific LESS item. For items 1 to 15, error was marked as present when the specific LESS error was present in at least 2 of 3 trials. For items 16 and 17, error was marked as present when the "*Average*" rating was present in at least 2 of 3 trials or "*Poor/Stiff*" rating in at least 1 of 3 trials (Padua et al., 2009).

[b] McNemar's test *p*-values comparing the proportion of specific errors scored for LESS items.

* Significantly different between conditions based on Bonferroni-corrected p-value ≤ 0.003.

Discussion

The LESS is a clinical screening tool used to identify high injury risk movement patterns from a jump-landing task. Individuals can alter their performance on movement screens with prior knowledge of scoring criteria (Bryson et al., 2018; Frost et al., 2015) or feedback on their performance (Myer et al., 2013). Our results confirm that individuals can improve their LESS scores, alter their risk category, and affect specific LESS errors after being provided with scoring criteria and information regarding their own prior performance. These results highlight how knowledge of scoring criteria and feedback can affect changes in movement patterns acutely and might be a useful training tool to raise awareness and encourage lower-risk movement patterns. However, if the innate jump-landing movement patterns and injury risk of individuals are of interest, it is recommended to abstain from providing individuals with their individualized item scores following LESS testing or explaining LESS scoring criteria for a valid assessment of risk.

Post information, mean LESS scores were 1.9 errors lower than *Pre* information. This 1.9-error difference is clinically meaningful based on Padua et al. (2009) who identified one error change in total LESS score to be clinically meaningful as associated with moderate to large differences in biomechanical variables previously linked to ACL injury. Our results are supported by previous research showing meaningful improvements in kinetic and kinematic variables after training focusing on correct technique feedback (Storberget, Grødahl, Snodgrass, van Vliet, & Heneghan 2017). Previous literature reviews have emphasized the importance of incorporating technique feedback in ACL injury prevention programs (Sugimoto et al., 2016) and in the rehabilitation of musculoskeletal lower-extremity injuries (Storberget et al., 2017). Technique feedback has been shown effective in improving jump-landing biomechanics in a manner that would reduce ACL injury risk (Nyman & Armstrong 2015; Storberget et al., 2017). Furthermore, Myer et al., (2013) concluded that augmented feedback targeting deficits during the tuck jump assessment was effective in improving biomechanics during a different drop vertical jump task, which supports a transfer of skills and movement pattens across tasks after provision of feedback. Altogether, these studies indicate that technique feedback is a useful tool in prevention and rehabilitation of injuries.

Within one education session, our participants were able to decrease LESS scores to a greater extent than following neuromuscular training programs for several weeks (Owens et al., 2013; Padua et al., 2012; Pryor et al., 2017). In a study conducted by Root et al. (2015), participants improved their LESS scores by 0.5 error after a single 10 to 12-minute injury prevention session; however, no improvements were found after static or dynamic warm-up sessions of the same duration. Compared to static and dynamic warm-up programs, the injury prevention program included balance and plyometric exercises and concentrated on proper technique using cues, such as "land softly", "bend your knees and hips", "keep your toes facing forwards", and "keep your knees over your toes" (Root, Trojian, Martinez, Kraemer, & DiStefano 2015). These findings highlight the powerful impact of short interventions on changing movement patterns acutely when interventions focus on awareness of low-risk movement mechanics and feedback. It appears that explaining scoring criteria representing low and high-risk biomechanics and specific feedback on participant's prior performance used in our study is superior to improve LESS scores in the short term compared to real-time feedback provided during injury prevention programs, such as used in Root et al. (2015). However, further targeted research is needed to confirm these speculations.

Individuals may perform better on clinical tests with knowledge of test scores and grading criteria without any long-lasting neuromuscular or physiological adaptations from training or rehabilitation and therefore reducing the screen's ability to identify individuals presenting high-risk movement patterns during jump-landing tasks. Previous study findings regarding the effect of internal and external focus instructions on the LESS indicated that instructions can significantly improve LESS scores immediately after a training session, and that improvements can persist in some – but not all – individuals one week post testing (Welling, Benjaminse, Gokeler, & Otten 2016). It is questionable whether one education session focusing on knowledge of scoring criteria and technique feedback is able to change innate movement patterns and injury risk factors, or whether participants are simply more aware of movement biomechanics needed to perform well during this particular injury risk screening task. Examining the performance of participants at a later date (e.g., 4 to 8 weeks) would have provided insight into the persistence of learnings or reversion to innate movements. Padua et al. (2012) compared the effectiveness of 3 and 9-month injury prevention programs that included landing technique feedback and concluded that improved LESS scores remained 3 months post intervention only in the 9-month program group. Therefore, it seems that long-lasting intervention programs specifically designed to change movement patterns are needed to alter LESS scores in the long term. To date, there is no evidence to our knowledge that links improvements in LESS scores with changes in the innate movement patterns of individuals or changes in high-injury risk sport-specific movement patterns, such as cutting or pivoting.

When seeking to identify individuals with high injury risk movement patterns, there is arguably more value in assessing innate movement behavior as opposed to immediate movement behavior influenced by knowledge of scoring criteria or prior performance. Therefore, before more evidence is available on persistence of LESS score improvements after one technique feedback session, we recommend clinicians abstain from providing individuals with their individualized item scores following LESS or from explaining LESS scoring criteria if the test is to be used to capture habitual jump-landing patterns to assess innate injury risk, monitor rehabilitation, or assess the effects of a preventive program.

Over half of our sample were reclassified from high to low injury risk categories between *Pre* and *Post* information conditions. It is interesting to consider that two participants changed injury risk categorization from low to high between *Pre* and *Post* information conditions. For certain individuals, a greater amount of feedback can lead to maladaptive short-term responses and changes in movement patterns in part due to over-intellectualization of the task (Lee, Swinnen, & Serrien 1994). Motor control literature has shown that certain individuals demonstrate a propensity to consciously control and correct their movement patterns more than others (Maxwell, Masters, & Poolton 2006). Consciously controlling and monitoring one's own movement can constrain or inhibit more effective automatic control processes and lead to greater movement disruption (Masters & Maxwell 2008). How individuals respond to feedback or consciously control their movements may explain why some participants worsen their LESS scores after being provided with feedback. Furthermore, it could be that those individuals who are unable to improve their LESS scores and remain at high risk of injury have a lesser ability to modify their movement patterns and are in fact at the greatest risk of injury and in most need of preventative programs. However, prospective studies with large cohorts are needed to confirm these speculations.

When considering the number and percentage of specific LESS errors *Post* vs *Pre* condition, most participants improved their LESS scores mostly via sagittal plane movement errors, with a significant reduction in the number of errors for item 16: Joint displacement ($p < 0.001$, Table 1). Our finding are supported by a systematic literature review showing that jump-landing training interventions combined with verbal or visual technique feedback were useful in reducing ACL injury parameters related to sagittal plane, but had little effect on frontal plane biomechanics (Neilson, Ward, Hume, Lewis, & McDaid 2019). Externally focused instructions have been shown to impact movement behaviors to a greater extent than internally focus ones (Peh, Chow, & Davids 2011). The LESS item number 16: Joint displacement is graded as: soft landing = 0 error, average landing = 1 error, and stiff landing = 2 errors. This item elicits a more external focused attention from individuals attempting to improve their scores. In comparison, certain items elicit more internal focus from individuals; for example, an error upon lateral trunk flexion (item 6) is attributed when the midline of the trunk is flexed to the left or to the right side of the body. It is possible that after explaining the scoring criteria, participants were more successful in using external focused cues and concentrated on overall landing more softly, which is associated with item 16: Joint displacement and also with other LESS errors in the sagittal plane. This assumption is in agreement with studies showing that participants were more successful in reducing the vertical ground reaction force during landing using instructions with an external focus (i.e., sound associated with foot impact) compared to internal focus (i.e., lower-extremity kinematics) (McNair, Prapavessis, & Callender 2000; Onate, Guskiewicz, & Sullivan 2001). Similarly, individuals have been shown to jump higher with external focus instructions compared to internal focus instructions or no instruction (Abdollahipour, Psotta, & Land 2016). The only sagittal plane item that did not demonstrate a lower occurrence after education was item 1: Knee flexion at initial contact. This finding agrees with a recent meta-analysis (Lopes et al., 2018) indicating no effect of injury prevention programs on increasing knee flexion angles at initial contact during landing task.

In the studies of Frost et al. (2015) and Bryson et al. (2018), participants were explained FMS scoring criteria after the first FMS testing session; however, unlike our study, participants were not aware of their specific scores, and still improved their FMS scores by 12.4%. Altogether, these studies indicate that merely knowing the screen's objectives or scoring criteria can modify results and performance. During the LESS assessment, individuals are asked to jump as high as possible after the first landing (Padua et al., 2009). This instruction is important to shift participants' focus to performance rather than landing mechanics and resemble sporting demands where performance is of primary interest. It has been shown that the verbal instructions have the ability to acutely alter the drop vertical jump biomechanics variables and influence assessment of athletic performance and injury risk (Khuu, Musalem, & Beach 2015).

Therefore, it is recommended to emphasize the maximization of jump height during LESS testing to shift attention to performance. Furthermore, clinicians could perhaps report jump height as metric to participants and address jump-landing movement errors detected by the LESS though training interventions. This solution would minimize impact of individual's awareness of the screening purpose on outcomes and improve the ability of clinicians to monitor the impact of their intervention strategy to elicit safe landing patterns.

Conclusion

The LESS is clinical tool used to screen for risk of non-contact lower-extremity and ACL injuries. The knowledge of scoring criteria and performance meaningfully improved LESS scores, altered risk categorization, and changed proportions of specific LESS errors. These findings confirm the potential for feedback to acutely affect movement patterns. However, knowledge of scoring criteria and individual performance may potentially compromise the clinical utility of the LESS to assess the habitual movement patterns of individuals during the jump-landing task and identify individuals at risk of injury in practice and research. Given that it is not clear whether a single feedback session may change habitual movement behavior in the long-term, we caution against explaining the scoring criteria and individual movement errors to tested individuals when there is an intention to use the screening tool to assess innate movement patterns or use the tool again to monitor progress over time. Given that it is likely that the screening task may lose its utility to evaluate injury risk when the individual is aware of the purpose of testing, we recommend that clinicians focus on maximizing jump height after the first landing to shift an individual's attention to performance rather than landing technique. These directives are more likely to reveal innate movement patterns that have been linked with a higher risk of sustaining non-contact lower-extremity and ACL injuries. On the other hand, providing feedback on LESS performance or information regarding scoring criteria may be a useful training tool to encourage lower injury risk movement patterns during jump-landing if employed on a regular basis. In this case, the ability of the LESS to screen for innate risk of injury in athletes may be compromised and transference to sport-specific tasks are not guaranteed.

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