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Context: There is a need for reliable clinical assessment tools that can be used to identify individuals who may be at risk for injury. The Landing Error Scoring System (LESS) is a reliable and valid clinical assessment tool that was developed to identify individuals at risk for lower extremity injuries. One limitation of this tool is that it cannot be assessed in real time and requires the use of video cameras. *Objective:* To determine the interrater reliability of a real-time version of the LESS, the LESS-RT. *Design:* Reliability study. *Setting:* Controlled research laboratory. *Participants:* 43 healthy volunteers (24 women, 19 men) between the ages of 18 and 23. *Intervention:* The LESS-RT evaluates 10 jump-landing characteristics that may predispose an individual to lower extremity injuries. Two sets of raters used the LESS-RT to evaluate participants as they performed 4 trials of a jump-landing task. *Main Outcome Measures:* Intraclass correlation coefficient ($ICC_{2,1}$) values for the final composite score of the LESS-RT were calculated to assess interrater reliability of the LESS-RT. *Results:* Interrater reliability ($ICC_{2,1}$) for the LESS-RT ranged from .72 to .81 with standard error of measurements ranging from .69 to .79. *Conclusions:* The LESS-RT is a quick, easy, and reliable clinical assessment tool that may be used by clinicians to identify individuals who may be at risk for lower extremity injuries.

Keywords: anterior cruciate ligament, movement assessment, injury risk

Clinical assessment tools are popular in sports-medicine settings and are commonly used to evaluate balance, movement dysfunctions, and muscle imbalances.[1–4] The goal of some clinical assessment tools is to provide a brief and easily implementable method to identify problems in the musculoskeletal system that may lead to athletic injury.[5,6] Such tools provide an efficient method for clinicians to identify individuals who may be at risk for injury. In addition, sports-medicine clinicians

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can use the results from clinical assessment tools to develop injury-prevention and -rehabilitation programs.

Because of the time demands placed on clinicians, it is important for valid and reliable clinical assessment tools to be developed that can be evaluated in real time, wherein the individual is evaluated through direct visual observation. However, few of the clinical assessment tools available to sports-medicine clinicians allow for real-time analysis. The Balance Error Scoring System and the Star Excursion Balance Test are examples of real-time tools that evaluate balance ability and have demonstrated good reliability.[1,2] Although balance is important to evaluate in select clinical settings,[5] it does not directly provide information about an individual's movement technique during sport-specific tasks. The Functional Movement Screen and the Overhead Squat Test can be evaluated in real time but lack reliability and validity information. Although these real-time assessment tools evaluate movement technique during squatting, stepping, and lunging tasks,[3] they do not assess it during more dynamic, sport-specific tasks that are associated with injury mechanisms, such as landing from a jump.[7] Several studies have described methods to assess jump-landing biomechanics, but these assessments are not scored in real time and require instrumentation such as force plates,[8] video cameras,[9–12] and video-editing software.[9–11] As such, these previously described jump-landing assessments are not performed in real time. The tuck jump assessment, which evaluates jumping and landing mechanics in real time, was recently introduced by Myer et al.[13] Although this clinical assessment tool allows for real-time analysis of a jump-landing task, it lacks scientific evidence regarding the reliability, validity, and predictive value of the tool.

The Landing Error Scoring System (LESS) is a clinical assessment tool that has demonstrated concurrent validity against 3-dimensional motion analysis, good interrater and intrarater reliability,[4] and preliminary predictive evidence for iden- tifying individuals who are at high risk for injury.[6] In addition, the LESS can suc- cessfully evaluate changes in landing technique resulting from an injury-prevention program.[14] A clinician can score the LESS quickly, but it requires 2 video cameras and video analysis. The utility of the LESS might be enhanced if it were modified to allow real-time analysis in a clinical setting. Therefore, the purpose of this study was to determine the reliability of a modified LESS, the Landing Error Scoring System-Real Time, or LESS-RT. The LESS-RT was designed to be scored in real time in a clinical setting and provide information about an individual's movement technique during a jump-landing task.

Methods

Participants

In all, 43 healthy participants (24 women, 19 men; height 172.11 ± 6.85 cm, mass 70.33 ± 10.11 kg) volunteered for this investigation. All participants were freshmen at the US Military Academy and free from any injury or illness that restricted their physical activity at the academy.

Testing Procedures

Two separate sessions were used to evaluate the reliability of the LESS-RT. Three raters evaluated participants' landing mechanics using the LESS-RT. All of the raters were certified athletic trainers with over 5 years of clinical experience and

had previous training and experience with scoring the original LESS from video replay (each rater has scored over 200 separate subjects). Twenty-four participants (11 women, 13 men) were evaluated by raters 1 and 2 during a morning testing session, and 19 participants (13 women, 6 men) were evaluated by raters 1 and 3 during an afternoon session. All participants signed an informed consent approved by the university's institutional review board before entering this study.

Administration of the LESS-RT

All participants performed 4 trials of a standardized jump-landing task. The task required participants to jump forward from a 30-cm-high box, which was set at a distance of 50% of their height away from the target landing area; land in the target landing area; and immediately rebound by jumping to maximal vertical height on landing (Figure 1). During task instruction, emphasis was placed on participants starting the jump in a neutral position (ie, feet shoulder width apart and toes pointing forward) and jumping as high as they could after their initial landing from the box. Participants were not provided any feedback or coaching on their landing technique

Figure 1 — Standardized jump-landing task performed by subjects during the Landing Error Scoring System-Real Time. Subjects jumped down from the box and landed on the ground and then immediately jumped vertically upward as high as possible. Raters scored jump-landing technique while the subject was in contact with the ground after landing from the box. Subjects were scored from raters' observations in both the sagittal and the frontal plane.

other than task instructions. They were allowed as many practice trials as needed (typically 2) to perform the task successfully. A successful jump was characterized by both feet simultaneously leaving the box; jumping forward off the box, without a large upward motion after takeoff from the box, to reach the target landing area below; and completing the task in a fluid motion (no pause in movement of body's center of mass after making contact with the ground until takeoff for subsequent jump). If a jump was unsuccessful the subject was simply instructed to repeat the task and did not receive additional instructions.

The LESS-RT was derived from the original LESS. The LESS evaluates 17 jump-landing characteristics and is scored by reviewing a recorded video of a jump-landing task over 3 trials. The LESS-RT includes 10 jump-landing characteristics and is scored over 4 trials of the jump-landing task. An additional trial is required to allow the rater to observe all 10 jump-landing characteristics.

Table 1 provides operational definitions and scoring details for each item. During each trial, raters evaluate specific motions at the feet, knees, and trunk. For trials 1 and 2, raters scored participants from the front. The first trial was used to evaluate stance width, foot rotation, and initial foot contact (ie, whether the feet landed symmetrically; LESS-RT items 1–3). The second trial was used to evaluate knee and trunk frontal-plane motion (LESS-RT items 4 and 5). For trials 3 and 4, raters evaluated the participants from the side. The third trial was used to assess how participants landed from the jump (ie, toe to heel, heel to toe, or flat-footed) and knee sagittal-plane motion (LESS-RT items 6 and 7). The fourth trial was used to evaluate trunk sagittal-plane motion (LESS-RT item 8). LESS-RT items 9 and 10 were scored based on the raters' impression of total motion across all 4 trials of the jump-landing task. Item 9 was scored as an overall impression of sagittal-plane joint motion (ie, whether the individual landed "softly"). Item 10 was scored as an overall impression of both frontal- and sagittal-plane motion. The LESS-RT scoring sheet is provided in Figure 2.

Raters viewed both lower extremities when scoring the LESS-RT. If one lower extremity demonstrated an error (ie, foot was externally rotated) and the other lower extremity did not (ie, toes pointed forward), the rater would score the specific item as an error. Each participant received a final composite score, which was calculated by summing all the items on the LESS-RT. Testing and scoring with LESS-RT took approximately 2 minutes per subject.

Statistical Analyses

Intraclass correlation coefficient (ICC) and standard error of measure (SEM) values were determined to assess interrater reliability ($ICC_{2,1}$) of the LESS-RT's final composite score during the 2 separate testing sessions. All data were analyzed using SPSS (version 15.0, SPSS Inc, Chicago, IL) with an a priori alpha level of .05.

Results

Means and standard deviations for total LESS-RT scores are presented in Table 2 for each rater. The $ICC_{2,1}$ and SEM values for interrater reliability between raters 1 and 2 were .81 (95% confidence interval = .56–.92) and .69, respectively. Similar values were observed between raters 1 and 3; $ICC_{2,1}$ and SEM values were .72 (95%

Table 1   Operational Definitions of Individual Items on the Landing Error Scoring System Real-Time (LESS-RT)

LESS-RT item	Operational definition	Rater view	Jump # from which item is scored
Stance width	If the subject lands with a wide or narrow stance when evaluated from the frontal plane, he/she receives an error. An error is only scored if the stance is observed to be very wide or very narrow (+1).	Front	1
Maximum foot-rotation position	If a subject's feet are moderately externally rotated or slightly internally rotated at any point during the jump landing, he/she receives an error (+1).	Front	1
Initial foot-contact symmetry	If 1 foot lands before the other or if 1 foot lands heel-to-toe and the other lands toe-to-heel, the subject receives an error (+1).	Front	1
Maximum knee-valgus angle	If the subject moves into a small amount of knee valgus, he/she receives an error (+1). If the subject moves into a large amount of knee valgus, he/she receives an error (+2).	Front	2
Amount of lateral trunk flexion	If the subject is leaning to the right or left side so that the trunk is not vertical in the frontal plane, he/she receives an error (+1).	Front	2
Initial landing of feet	If the subject lands heel to toe or with a flat foot, he/she receives an error (+1).	Side	3
Amount of knee-flexion displacement	If the subject goes through a small (+2) or average amount (+1) of knee-flexion displacement, he/she receives an error.	Side	3
Amount of trunk-flexion displacement	If the subject goes through a small (+2) or average amount (+1) of trunk-flexion displacement, he/she receives an error.	Side	4
Total joint displacement in the sagittal plane	If the subject goes through large displacement of the trunk and knees, then score *soft* (0). If the subject goes through an average amount of trunk and knee displacement, then score *average* (+1). If the subject goes through a small amount of any trunk and knee displacement, then score *stiff* (+2).	Side	All
Overall impression	Score *excellent* (0) if the subject displays a soft landing and no frontal-plane motion at the knee. Score *poor* (+2) if the subject displays a stiff landing and large frontal-plane motion at the knee, or only large frontal-plane motion at the knee. All other landings, score *average* (+1).	N/A	All

Frontal-Plane Motion	**Sagittal-Plane Motion**
1. Stance width	**6. Initial landing of feet**
☐ Normal (0)	☐ Toe to heel (0)
☐ Wide (1)	☐ Heel to toe (1)
☐ Narrow (1)	☐ Flat (1)
2. Maximum foot-rotation position	**7. Amount of knee-flexion displacement**
☐ Normal (0)	☐ Large (0)
☐ Externally rotated (1)	☐ Average (1)
☐ Internally rotated (1)	☐ Small (2)
3. Initial foot contact	**8. Amount of trunk-flexion displacement**
☐ Symmetric (0)	☐ Large (0)
☐ Not symmetric (1)	☐ Average (1)
	☐ Small (2)
	9. Total joint displacement in the sagittal plane
4. Maximum knee-valgus angle	☐ Soft (0)
☐ None (0)	☐ Average (1)
☐ Small (1)	☐ Stiff (2)
☐ Large (2)	
5. Amount of lateral trunk flexion	**10. Overall impression**
☐ None (0)	☐ Excellent (0)
☐ Small to moderate (1)	☐ Average (1)
	☐ Poor (2)

Figure 2 — Scoring sheet for the Landing Error Scoring System-Real Time (LESS-RT) assessment tool.

Table 2   Scores Between Raters (Mean ± SD) on the Landing Error Scoring System-Real Time

Session	Rater	Mean	SD
Morning session	1	5.8	1.6
	2	6.2	1.5
Afternoon session	1	5.3	1.3
	3	4.9	1.5

confidence interval = .42–.88) and .79, respectively. We also assessed the reliability between rater 1 (LESS-RT scores from morning and afternoon sessions) and raters 2 (morning session LESS-RT scores) and 3 (afternoon session LESS-RT scores) combined. The reliability between rater 1 and raters 2 and 3 combined was $ICC_{2,1}$ = .79 (95% confidence interval = .64–.88) and SEM = .76. These findings indicate that the LESS-RT has good interrater reliability and precision.

Discussion

There is a need to identify individuals at elevated risk for lower extremity injury given the associated high financial costs[14] and elevated risk of osteoarthritis after injury.[15] The ability to successfully and rapidly identify individuals at increased risk for lower extremity injury would allow clinicians to target these individuals for injury-prevention training that may reduce their risk for future injury. Select jump-landing biomechanical characteristics have been shown to differ in individuals who go on to sustain an anterior cruciate ligament (ACL) injury, compared with those who do not become injured.[16] However, these traditional, biomechanical testing procedures require the use of motion-analysis equipment that are not readily accessible in a clinical setting. The LESS has been shown to be a valid clinical assessment of jump-landing biomechanical characteristics.[4] A limitation of the LESS is that testing is performed by recording an individual performing a jump-landing task using standard video cameras and then later scored from review of video recordings. Modified scoring and testing criteria were developed to score individuals' jump-landing movement patterns in real time (LESS-RT) while they performed 4 separate jump-landing trials to further improve the clinical utility of the LESS. Based on the findings of this investigation, the LESS-RT can be performed and scored in real time with good interrater reliability.

Padua et al[4] examined the interrater reliability of the original LESS (when scored from video replay) and found good reliability (ICC = .84) and precision (SEM = .71). The LESS-RT appears to have comparable interrater reliability (ICC range .72–.81) and precision (SEM range .69–.79). In addition, the average overall LESS score obtained using the LESS-RT (5.6 ± 1.4) is similar to that of the original LESS in the cadet population (4.9 ± 1.6).[4]

Padua et al[4] also examined the validity of the original LESS by comparing lower extremity biomechanics between individuals with high LESS scores (poor jump-landing technique) and low LESS scores (excellent jump-landing technique). However, we did not compare lower extremity biomechanics in this study. Future research is needed to investigate whether the LESS-RT demonstrates validity similar to that of the original LESS.

Each of the items assessed on the LESS-RT was selected based on the underlying assumption that specific movement patterns may increase one's risk for noncontact ACL injury. Thus, potentially injurious movement patterns in the sagittal, frontal, and transverse planes are identified using the LESS-RT. Sagittal-plane movement patterns on the LESS-RT are assessed in items 6 through 9 (Table 1). These movement patterns are believed to be important; video analyses have repeatedly shown the body to be in an erect posture (eg, decreased knee, hip, and trunk flexion) during noncontact ACL-injury events.[7,17–19] Retrospective studies that interviewed individuals who sustained an ACL injury also indicate that the knee was at or near full extension during the injury event.[17] Decreased knee flexion is also believed to be an important factor, given how it influences ACL loading (LESS-RT item 7). Decreased knee-flexion angle leads to a greater anterior tibial shear force by increasing the patellar tendon–tibial shaft angle.[20] As the patellar tendon–tibial shaft angle increases, the quadriceps-induced anterior tibial shear force is also increased.[21] Thus, small knee-flexion angles may allow for greater quadriceps-induced anterior tibial shear force. Decreased knee-flexion angle also

minimizes the hamstrings' ability to produce posterior tibial shear force and limits the muscle's ability to offset anterior tibial shear forces.[21] Trunk and hip flexion are also important sagittal-plane movement patterns; small amounts of trunk and hip flexion are associated with increased vertical ground-reaction force[22] and decreased knee-flexion angle (LESS-RT item 8).[23] Females, who are at greater risk for ACL injury than males, have also been repeatedly shown to demonstrate less knee, hip, and trunk flexion than their male counterparts.[24–26] The foot position at initial contact is also believed to be important because landing with a heel-to-toe movement pattern (landing on heel of foot) results in significantly greater vertical ground-reaction force and rate of force development, external knee- and hip-flexion moment, and quadriceps activation than a forefoot landing movement pattern (landing on metatarsal heads; LESS-RT item 6).[27] Thus, jump-landing movement patterns consisting of decreased sagittal-plane joint flexion (decreased knee, hip, and trunk flexion) and a heel-to-toe landing pattern were thought to be high-risk movement patterns for noncontact ACL injury and were included as movement errors on the LESS-RT.

Frontal-plane movement patterns are assessed on LESS-RT items 1, 4, and 5. Based on video analysis, forceful valgus collapse (LESS-RT item 4) with the knee near full extension is reported during noncontact ACL-injury events.[7,17] It is not clear whether the knee valgus reported to occur during noncontact ACL-injury events is an isolated frontal-plane motion resulting in medial joint opening (true knee valgus) or the combined motion of hip internal rotation and adduction as the foot is fixed on the ground (apparent knee valgus). Cadaver-based research indicates that isolated knee-valgus moment increases ACL loading[28,29]; however, the magnitude of ACL loading because of isolated knee-valgus moment is small compared with isolated anterior tibial shear force or tibial internal-rotation moments. Although isolated knee-valgus moment does not place a large load on the ACL, knee valgus is believed to be an important ACL-injury mechanism because the amount of ACL loading is greatly magnified when knee-valgus moment is applied in combination with anterior tibial shear force or tibial internal-rotation moments.[28,30,31] In addition, the combination of knee valgus and tibial external rotation also facilitates ACL loading by causing impingement of the ACL against the intercondylar notch.[32] Thus, the combination of knee valgus with both tibial internal rotation and external rotation may be an important cause of ACL injury.[33] Video analysis of noncontact ACL injuries further suggests knee valgus to be an important factor because dynamic valgus collapse is observed as the most common movement pattern during noncontact ACL-injury events in female handball and basketball athletes.[7,19] Research has also repeatedly shown females, who are at greatest risk for ACL injury, to display significantly greater knee valgus than males.[25,26,34–37] Stance width (LESS-RT item 1) and lateral trunk flexion (LESS-RT item 5) also influence knee-valgus loading during functional tasks.[38] Individuals performing a side-step cutting task with increased lateral trunk flexion (away from direction of cut) and stance width (foot placed farther away from body) experienced greater external knee-valgus moment.[38] Lateral trunk flexion and stance width influence the body's center of mass relative to the knee joint, hence facilitating external knee-valgus moments. Increased stance width has also been shown to cause greater external knee-flexion and internal-rotation moments during side-step cutting.[38] Knee-valgus motion (knees move medial past great toe),

lateral trunk flexion, and increased stance width during jump-landing maneuvers were included as movement errors on the LESS-RT because these may be high-risk movement patterns associated with noncontact ACL injury.

Initial foot-contact symmetry (LESS-RT item 3) was also included on the LESS-RT as a frontal-plane variable because it may influence the load distribution on the lower extremity. Individuals performing jump-landing maneuvers with asymmetric foot contact (1 foot contacts ground before the other) will place a greater load on the limb initially contacting the ground as the initial impact is absorbed by only 1 limb. Increased loading may place that limb at greater risk of injury. Video analyses of noncontact ACL injuries during team handball demonstrate that most injuries occurred with 1 foot in contact with the ground.[7] In addition, an asymmetric foot-contact pattern may cause the individual to land out of control/balance by minimizing the base of support at initial contact. Out-of-control landing maneuvers are often described as a common mechanism of noncontact ACL injury.[7]

Foot position (toe-in or toe-out; LESS-RT item 2) serves as a marker for tibial rotation during the jump-landing maneuver. The importance of foot position is demonstrated as Olsen et al[7] describe noncontact ACL injuries to occur as the knee undergoes internal or external rotation in combination with knee valgus. Tibial internal rotation creates greater tensile load on the ACL,[28] and external rotation of the tibia has been shown in MRI-based modeling studies to cause the ACL to impinge on the lateral wall of the femoral intercondylar notch.[32,39] Therefore, excessive or uncontrolled amounts of toe-in (tibial internal rotation) or toe-out (tibial external rotation) may produce ACL loading. The magnitude of ACL loading induced by tibial internal rotation (toe-in) is magnified when the loading is applied in combination with anterior tibial shear force[28] or knee-valgus moment.[28,31] Foot position has also been shown to influence knee loading; toe-out movement patterns increase laterally directed ground-reaction forces during landing[40] and increase external knee-flexion moments.[38] As a result, performing jump-landing tasks with either toe-in or toe-out movement patterns was included as a movement error on the LESS-RT. Our current investigation clearly shows that the LESS-RT is reliable and time-efficient and has carefully designed construct validity. However, the study has several important limitations. The LESS-RT has not been correlated with biomechanical data or injury outcomes. These studies are currently ongoing. In addition, raters for the LESS-RT in this investigation had extensive previous experience with traditional LESS scoring and other clinical assessment tools for human movement. Future investigations are needed to determine the reliability of the LESS-RT in individuals with less experience in human-movement analysis. We also acknowledge that the traditional reliability study would have involved all 3 raters scoring all subjects; however, because of the time constraints of the testing schedule, we elected to pursue 2 smaller 2-rater studies rather than 1 larger 1-rater study. We anticipate that this design modification had negligible effect on the study conclusions as evidenced by the overlap in 95% confidence intervals across ICC values between raters. Finally, participants were incoming male and female freshmen at the US Military Academy at West Point and were not exclusively female high-school- or college-age athletes. This should be considered when interpreting the generalizability of these findings.

Summary

The LESS-RT demonstrates good interrater reliability and compares very favorably with the original LESS, which required use of video cameras and replay of videotapes for scoring. We believe that with proper training, clinicians may be able to use the LESS-RT as a clinical screening tool to identify individuals who may be at greater risk for noncontact ACL or other lower extremity injuries. Training materials for the LESS-RT are located at the following Web site: www.unc.edu/sportmedlab/LESS-RT

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