

## **Effect of an overhead goal on Landing Error Scoring System and jump height measures**

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## Abstract

**Objectives:** Compare overall Landing Error Scoring System (LESS) scores, risk categorisation, specific LESS errors, and double-leg jump-landing jump heights between overhead goal and no goal conditions. **Design:** Randomised cross-over. **Setting:** Laboratory. **Participants:** 76 (51% male). **Main outcome measures:** Participants landed from a 30-cm box to 50% of their body height and immediately jumped vertically for maximum height. Participants completed three trials under two random-ordered conditions: with and without overhead goal. Group-level mean LESS scores, risk categorisation (5-error threshold), specific landing errors, and jump heights were compared between conditions. **Results:** Mean LESS scores were greater (0.3 errors,  $p<0.001$ ) with the overhead goal, but this *small* difference was not clinically meaningful. Similarly, although the number of high-risk participants was greater with the overhead goal ( $p=0.039$ ), the 9.2% difference was *trivial*. Participants jumped 2.7 cm higher with the overhead goal ( $p<0.001$ ) without affecting the occurrence of any specific LESS errors. **Discussion:** Performing the LESS with an overhead goal enhances sport specificity and elicits greater vertical jump performances with minimal change in landing errors and injury-risk categorisation. Adding an overhead goal to LESS might enhance its suitability for injury risk screening, although the predictive value of LESS with an overhead goal needs confirmation.

**Keywords:** Anterior cruciate ligament; injury risk; jump-landing biomechanics; movement screen

## **INTRODUCTION**

Instructing individuals to “jump as high as possible” is standard when assessing vertical jump performances, whether it be from squat jumps, countermovement jumps, or double-leg jump landings (DLJL) (Padua, et al., 2009). Typically, this instruction is provided to individuals without a target height to reach or an overhead goal. Yet, setting targets can enhance motivation and intensity of dynamic tasks (Newton & Kraemer, 1994), and adding an overhead goal has been shown to enhance vertical jump performances during countermovement jumps (Król, Borzucka, & Rektor, 2016) and DLJL tasks (Ford, et al., 2005). Indeed, setting goals is an accepted strategy in physical activity to increase motivation or to achieve a performance target (Swann, et al., 2021). From a biomechanical perspective, Ford, et al. (2005) found that adding an overhead goal during a DLJL task was associated with greater jump heights alongside increases in knee extension moments at take-off. On the other hand, greater vertical jump heights of participants performing DLJL tasks with an external (“focus on getting as close to the ceiling as possible”) compared to a control (“jump as high as possible”), contact (“focus on spending as little amount of time on the floor as possible”), and quiet (“focus on being as quiet as possible when landing”) cue were achieved without increasing impact peak and changing landing biomechanics in a way that suggests increased injury risk (Oliver, Barillas, Lloyd, Moore, & Pedley, 2019). Hence, using an overhead goal may affect jump landing patterns more than using cues, the latter involving the use of verbal instructions to direct attentional focus to a particular feature of a movement (Wulf, Zachry, Granados, & Dufek, 2007).

Across sports, lower extremity injuries account for more than 50% of all injuries (Hootman, Dick, & Agel, 2007), with the knee being the most commonly injured region (Murphy, Connolly, & Beynon, 2003). Anterior cruciate ligament (ACL) injuries in particular are

associated with high costs and burden (Rekik, et al., 2018; Webster, Hewett, & Feller, 2021), and can considerably affect individuals' activity levels and quality of life (Filbay, Culvenor, Ackerman, Russell, & Crossley, 2015). **Noncontact ACL injuries account for up to 70% of ACL injuries in certain sporting populations (Boden, Dean, Feagin, & Garrett, 2000; Kobayashi, et al., 2010)** and are considered preventable (Waldén, Atroshi, Magnusson, Wagner, & Hägglund, 2012), with research indicating a reduced incidence of ACL injuries when individuals undertake neuromuscular training programmes (Webster & Hewett, 2018). The most common situations for noncontact ACL injuries in sports are decelerations due to changing direction or landing from jumps (Belcher, Whatman, & Brughelli, 2022; Griffin, et al., 2006). The Landing Error Scoring System (LESS) screening tool detects individuals at greater risk of noncontact ACL (Padua, et al., 2015) and musculoskeletal injuries (Everard, Lyons, & Harrison, 2018), and identifies athletes who present high injury-risk biomechanical patterns during a DLJL task (Padua, et al., 2009). An overall LESS score is derived from clinicians scoring 17 items related to DLJL kinematics, with overall scores ranging from 0 to 17 errors. Fewer landing errors and lower overall LESS scores suggest fewer movement patterns linked with noncontact ACL injuries during the DLJL **task**. Items 1 to 15 are scored as 0 (error absent) or 1 (error present), whereas Items 16 and 17 are scored on a scale of 0 (soft/excellent landing), 1 (average landing), or 2 (stiff/poor landing). Some items cannot be present at the same time, e.g., Items 7 [stance width at initial contact (wide)] and 8 [stance width at initial contact (narrow)]. Therefore, the maximum possible LESS score is 17 errors. The odds of sustaining a noncontact ACL injury was 10.7 times greater (Padua, et al., 2015) and of sustaining a musculoskeletal injury was 16.1 times greater (Everard, et al., 2018) in individuals who scored five errors or more upon LESS assessment compared to individuals who scored less than five errors. Across the literature, the overall LESS score demonstrates good-to-excellent reliability and moderate-to-excellent validity for assessing key knee-injury

risk factors and overall landing biomechanics (Hanzlíková & Hébert-Losier, 2020a), and promise for detecting individuals at greater risk of noncontact ACL injuries and musculoskeletal injuries (Everard, et al., 2018; Padua, et al., 2015).

There are some limitations to the LESS. The overall LESS scores are sensitive to various factors. Hanzlíková, Athens, and Hébert-Losier (2021) conducted a meta-analysis examining the influence of previous injury, intervention programmes, and gender on LESS scores. Overall, LESS scores are 1.2 errors lower when individuals follow a neuromuscular training programme lasting at least six weeks; 1.2 errors lower in uninjured individuals than individuals with prior ACL injuries; and 0.6 errors lower in males than females (Hanzlíková, Athens, et al., 2021). In addition, research has identified final LESS score computational method (Hanzlíková, Athens, & Hébert-Losier, 2020) and jump landing distance (Hanzlíková & Hébert-Losier, 2021) can affect individual-level risk categorisation and LESS scores. To appropriately interpret LESS scores, clinicians and researchers should consider that several factors and procedural methods can affect outcomes.

Whilst studies have examined the effect of using an overhead goal on jump performance and landing mechanics of the DLJL task (Ford, et al., 2005); to our knowledge, no study has explored whether use of an overhead goal affects LESS outcomes. The DLJL task used in the LESS has been criticised in terms of lack of sport specificity (Kristianslund & Krosshaug, 2013). In addition to improving jump performance, using an overhead goal during the DLJL task can enhance sport specificity and the relevance of this task in screening for risk of injury in sports where players interact with an overhead ball, such as in American football, soccer, netball, volleyball, handball, and basketball. Therefore, we aimed to compare overall LESS scores, injury risk categorisation based on a five-error threshold, occurrence of specific LESS

errors, and DLJL jump heights between overhead goal and no goal conditions. We hypothesised that adding an overhead goal to the DLJL task would involve higher overall LESS scores, lead to a greater number of individuals classified at high risk of injuries, and influence specific LESS errors (Items 1, 4, 12, and 16) compared to performing the DLJL task without an overhead goal. We also anticipated higher jump heights when using an overhead goal during LESS assessment based on prior research (Ford, et al., 2005; Król, et al., 2016; Mok, Bahr, & Krosshaug, 2017).

## **MATERIALS AND METHODS**

### **Experimental approach**

We used a randomised cross-over experimental study design to examine the effect of using an overhead goal on LESS scores, risk categorisation, specific errors, and jump heights. A priori sample size calculations were performed using G\*Power 3.1.9.7. We applied a standard two-tailed hypothesis, 5% significance level ( $\alpha = 0.05$ ), 99% power ( $\beta = 0.01$ ), 1-error LESS difference in paired means (Hanzlíková, Athens, et al., 2021; Padua, et al., 2009), and 5.6 errors as mean LESS score for the no goal condition based on similar research using comparable procedures and participants with potentially comparable demographic characteristics (Hanzlíková & Hébert-Losier, 2021). A sample size of 76 participants was needed to detect a moderate effect size difference (Cohen  $d = 0.5$ ) between goal and no goal conditions according to these assumptions.

### **Participants**

Seventy-six participants (39 males and 37 females, Table 1) were recruited and volunteered to participate. Participants were invited to participate from a convenience sample of healthy university students, and tested within a 1-month period. Individuals had to be free from illness, injury, or conditions that may affect landing mechanics and movements. Participants were excluded if presenting with a recent (less than three months) lower extremity, back, or pelvis injury. All participants were either moderately or highly physically active except for one. Participants signed informed consent documents that explained potential risks of participation (e.g., injury or delayed onset muscle soreness due to physical activity) prior to the study. Participants were informed of the study aims. The research protocol was approved by the University of Waikato Human Research Ethics Committee (HREC(Health)#2017-41) before data collection.

*Table 1.* Demographic characteristics of participants. Values are means  $\pm$  standard deviations or counts.

Characteristics	Males ( $n = 39$ )	Females ( $n = 37$ )	Both ( $n = 76$ )
Age (y)	20.7 $\pm$ 6.4	19.7 $\pm$ 2.5	20.2 $\pm$ 4.9
Height (cm)	182.1 $\pm$ 5.9	168.4 $\pm$ 7.0	175.0 $\pm$ 9.4
Mass (kg)	83.2 $\pm$ 13.5	68.2 $\pm$ 11.1	75.7 $\pm$ 14.4
BMI (kg/m <sup>2</sup> )	24.5 $\pm$ 3.0	23.9 $\pm$ 2.8	24.2 $\pm$ 2.9
IPAQ (high:mod:low)	33:5:0 <sup>a</sup>	26:8:1 <sup>a</sup>	60:13:1 <sup>b</sup>

*Notes.* <sup>a</sup>Missing data from 1 participant. <sup>b</sup>Missing data from 2 participants. BMI, body mass index; IPAQ, International Physical Activity Questionnaire; mod, moderate.

## **Procedures**

Participants' baseline characteristics were collected following informed consent, which included measuring body mass using an electronic floor scale (seca model ESE813, Medical Measuring Systems and Scales, Mount Pleasant, South Carolina) and height using a stadiometer (seca model 0123, Medical Measuring Systems and Scales, Mount Pleasant, South Carolina). Participants were categorised as having high, moderate, or low physical activity levels based on their responses to the self-administered short-form International Physical Activity Questionnaire (Craig, et al., 2003).

For experimentation, participants completed three DLJL trials in the two experimental conditions (overhead goal and no goal) allocated in a block randomised order. Specifically, each participant performed three trials in each condition with 30 seconds rest between trials and 15 minutes rest between conditions to limit fatigue. Half of the participants performed the overhead goal condition first, with the other half beginning with the no goal condition. Three familiarisation trials were permitted before formal LESS assessment in both the overhead goal and no goal condition. **All participants performed at least one familiarisation trial prior to each condition, with some participants performing a second trial and none needing a third familiarisation trial.** Participants wore their own athletic footwear during testing.

As per the original LESS testing protocol (Padua, et al., 2009), participants were required to jump horizontally from a 30-cm box to 50% of their body height and jump vertically as high as possible upon landing. A strip of tape on the floor indicated the individualised landing distance **where individuals were expected to land**. In the no goal condition, participants were instructed to jump upwards as high as possible upon landing, as per the original LESS protocol (Padua, et al., 2009). In the overhead goal condition, participants were instructed to jump upwards as high as possible upon landing reaching for the ball **with both hands, as if trying to**

grab it. These instructions were based on those used elsewhere (Almonroeder, et al., 2018; Ford, et al., 2005). The overhead ball was taped to the ceiling immediately above the landing area, and was not present in the no goal condition. The bottom of the ball was 2.7 m from the floor. A DLJL trial was disregarded when participants did not perform the task in one fluid motion or did not reach the prescribed horizontal landing distance. Unless the task was performed inadequately and disregarded, no feedback on performance was provided to avoid influencing outcomes (Hanzlíková & Hébert-Losier, 2020b).

The DLJL trials were recorded at 120 frames per second using two high-speed cameras (Sony RX10 II, Sony Corporation, Tokyo, Japan) with a focal length of 8.8 to 73.3 mm (35-mm equivalent focal length of 24-200 mm). One camera was placed to the right-side of participants to record sagittal plane motion and the other camera was placed in front of participants to record frontal plane motion. Each camera was positioned 3.5 m away from the landing area and mounted on tripods with a 1.3 m lens-to-ground distance. The Kinovea software (version 0.9.4, [www.kinovea.org](http://www.kinovea.org)) was used to analyse videos. Jump height was computed from the flight time of the maximal vertical jump extracted from the sagittal plane videos using the following equation (Linthorne, 2001; Moir, 2008):

$$h = \frac{1}{8} \cdot g \cdot t^2 \cdot 100$$

where  $h$  is the jump height (cm),  $g$  is gravitational acceleration constant ( $9.81 \text{ m/s}^2$ ), and  $t$  is the flight time (s).

### **Data processing**

A single expert rater (CBS) – who had scored over 500 LESS videos – completed all analyses, **scoring the sagittal-plane LESS items from the right leg of participants and the frontal-plane LESS items considering both legs of participants.** Videos from a subset of 10 participants were used to examine intra-rater and inter-rater reliability of the overall LESS scores. Based on intra-class correlation coefficient (ICC) and 95% confidence interval [lower, upper] values, intra-rater reliability was excellent for both overhead goal ( $ICC_{(3,1)} = 0.978 [0.912, 0.995]$ ) and no goal ( $ICC_{(3,1)} = 0.976 [0.909, 0.994]$ ) conditions. Inter-rater reliability was also excellent for both overhead goal ( $ICC_{(2,1)} = 0.979 [0.917, 0.995]$ ) and no goal ( $ICC_{(2,1)} = 0.982 [0.935, 0.996]$ ) conditions.

### **Statistical analysis**

The effect of an overhead goal on group mean LESS scores, injury risk categorisation (high risk  $\geq$  five errors, low risk  $<$  five errors), individual-level risk categorisation, and jump heights was examined. The average of participants three trials was computed and used as the overall LESS score and jump height measure for each participant. Group mean LESS score and jump height differences between the overhead goal and no goal conditions were examined using mean differences, two tailed paired *t*-tests, and Cohen's *d* effect sizes for paired samples using an average variance with 95% confidence intervals [lower, upper]. Cohen's *d* effect sizes were considered *small*, *medium*, and *large* when reaching thresholds of 0.20, 0.50, and 0.80, respectively, and *trivial* when less than 0.20 (Cohen, 2013).

Differences in the number of participants categorised at high and low risk of injury between the two conditions based on a five-error LESS threshold (Padua, et al., 2015) were assessed using McNemar's tests and odds ratio with 95% confidence intervals. The odds ratio reflects

the number of participants exclusively at high risk in the overhead goal condition versus those exclusively at high risk in the no goal condition. Therefore, an odds ratio  $> 1.0$  reflects a higher proportion of individuals at high risk in the overhead goal condition. McNemar's tests were also used to examine differences in the occurrence of specific LESS errors between the two conditions. For each participant, an error was considered present when present in two of the three trials for Items 1-15. For Items 16-17, an error was considered present when the "average" rating was present in two of three trials or when the "poor/stiff" rating was present in one of three trials (Hanzlíková & Hébert-Losier, 2021; Padua, et al., 2009). Changes in frequency were considered *small*, *medium*, and *large* when reaching thresholds of 10%, 30%, and 50%, respectively, and *trivial* when less than 10% (Hopkins, Marshall, Batterham, & Hanin, 2009). Lastly, to confirm whether or not an order effect was present despite implementing a block randomisation, a secondary analysis was performed using the same statistical procedures than those described above on outcomes grouped based on randomised order sequence (i.e., first condition versus second condition).

Significance was set at  $p \leq 0.05$  for all analyses, except for when comparing the proportion of specific LESS errors between conditions where the Bonferroni-corrected  $p$ -value ( $n = 17$  comparisons,  $p \leq 0.003$ ) was used to infer statistical significance. All statistical analyses were conducted using Microsoft Excel for Microsoft 365 MSO (version 2109, Microsoft Corp, Redmond, WA, USA) and RStudio® version 1.1.463 with R version 4.0.5 (R Core Team, 2021).

## **RESULTS**

The group mean LESS scores in the overhead goal condition (6.2 errors, range: 2.7 to 10.0) was significantly greater (0.3 errors,  $p < 0.001$ ) than in the no goal condition (5.9 errors, range: 2.7 to 10.0), as shown in Table 2. The magnitude of the difference was *small* (Cohen  $d = 0.24$  [0.10, 0.37]). The number of individuals classified at high risk differed between conditions (65 participants overhead goal versus 58 participants no goal,  $p = 0.039$ ), with eight participants categorised at high risk exclusively for the overhead goal condition and only one for the no goal condition (Figure 1). However, the 9.2% difference between conditions was *trivial*. At an individual level, the risk categorisation was conflicting for nine participants (11.8%, *small* difference, Figure 1). Mean jump height in the overhead goal condition (33.3 cm, range: 16.5 to 49.7) was significantly higher (2.7 cm,  $p < 0.001$ ) than in the no goal condition (30.5 cm, range: 7.7 to 47.4 cm), as shown in Table 2. The magnitude of the difference was *small* (Cohen  $d = 0.34$  [0.24, 0.44]). The occurrence of errors was similar between conditions for the 17 LESS items, as shown in Table 3.

Table 2. Comparison of Landing Error Scoring System (LESS) mean scores and group-level risk categorisation between the overhead goal and no goal conditions in 76 participants. Data are means  $\pm$  standard deviations and differences with 95% confidence intervals [lower, upper].

Outcome	Goal	No goal	Difference	$p$ -value
LESS score (errors)	6.2 $\pm$ 1.4	5.9 $\pm$ 1.5	0.3 [0.2 to 0.5]	<0.001 <sup>*a</sup>
High risk (%)	85.5%	76.3%	8.00 [1.00 to 63.97]	0.039 <sup>*b</sup>
Jump height (cm)	33.3 $\pm$ 7.9	30.5 $\pm$ 8.0	2.7 [2.1 to 3.4]	<0.001 <sup>*a</sup>

Note. <sup>\*</sup>Significant difference between conditions ( $p \leq 0.05$ ). <sup>a</sup> Difference in means and  $p$ -value from paired  $t$ -test. <sup>b</sup> Odds ratio and  $p$ -value from McNemar's test.

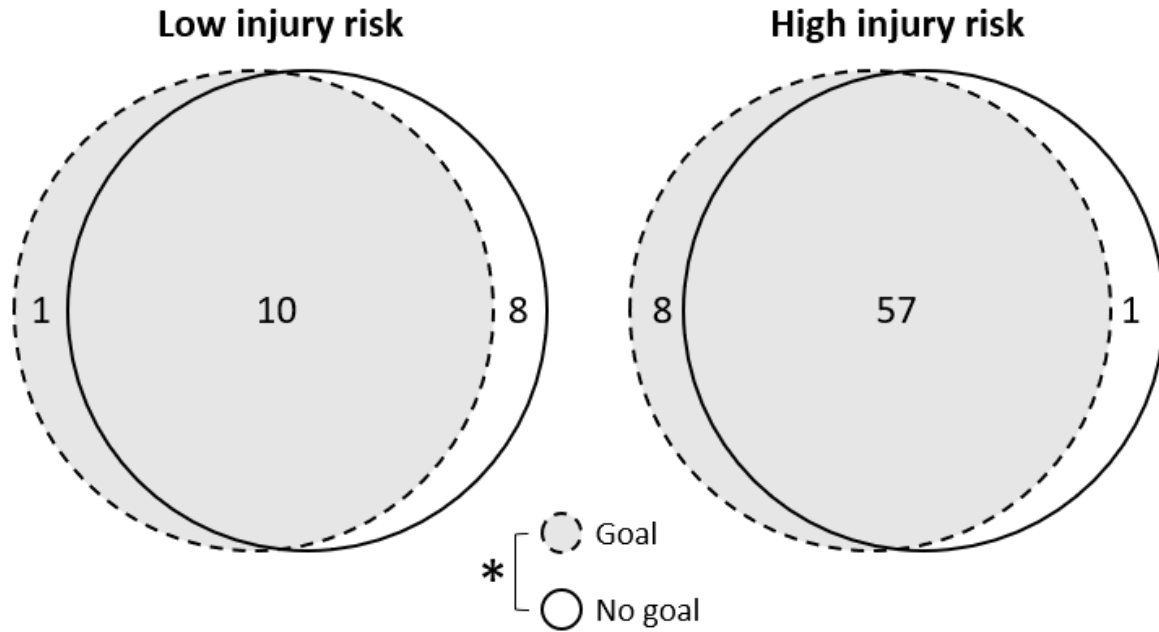


Figure 1. Venn diagrams representing data from 76 participants when categorised at low risk (less than five errors) and high risk (five errors or more) of injury for both the overhead goal (hashed grey circles) and no goal (white circles) conditions. The number in the circle represents the sum of participants categorised at low or high risk for each condition. The overlapping area represents the number of participants at low or high risk in both conditions. \*Significant difference in the proportion of individuals at high and low risk based on McNemar's tests ( $p \leq 0.05$ ).

Table 3. Occurrence of specific Landing Error Scoring System errors for the 76 participants under the overhead goal and no goal conditions.

No.	Items	Number of errors		<i>p</i> -value <sup>a</sup>
		Goal	No goal	
1	Knee flexion at initial contact	38	32	0.238
2	Hip flexion at initial contact	0	0	1.000
3	Trunk flexion at initial contact	0	0	1.000
4	Ankle plantar flexion at initial contact	9	10	1.000

5	Knee valgus at initial contact	68	69	1.000
6	Lateral trunk flexion at initial contact	1	0	1.000
7	Stance width (wide) at initial contact	11	12	1.000
8	Stance width (narrow) at initial contact	20	18	0.688
9	Foot position (toe-in)	0	0	1.000
10	Foot position (toe-out)	18	11	0.923
11	Symmetric foot contact at initial contact	50	42	0.215
12	Knee flexion at maximal knee flexion	11	7	0.219
13	Hip flexion at maximal knee flexion	0	0	1.000
14	Trunk flexion at maximal knee flexion	2	4	0.625
15	Knee valgus displacement	69	67	0.688
16	Joint displacement	62	57	0.180
17	Overall impression	76	75	1.000

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*Note.* <sup>a</sup>McNemar's test *p*-values for differences between conditions. **Statistical significance based on the Bonferroni-corrected *p*-value ( $n = 17$  comparisons,  $p \leq 0.003$ ).**

The secondary analysis confirmed that there was no significant order effect. Specifically, group mean LESS scores, number of individuals classified at high risk, jump heights, and the occurrence of the individual LESS errors were similar between the first and second condition (Supplementary material, Table S1 and Table S2).

## **DISCUSSION**

We examined the effect of an overhead goal on LESS scores, risk categorisation, and jump heights. Congruent with our hypothesis, mean LESS scores were significantly greater in the overhead goal condition compared to the no goal condition. Despite the magnitude of the

difference between conditions being *small* based on effect size statistics, it is debatable whether the 0.3 error difference in means between conditions is clinically meaningful as less than one error (Padua, et al., 2009). A greater number of participants were categorised at high risk of injury with an overhead goal, also in line with our hypothesis. However, the 9.2% difference in the number of participants classified at high risk between condition was *trivial*. Furthermore, there were no differences in the occurrence of specific landing errors between conditions making it difficult to determine how landing mechanics were influenced. Lastly, jump heights were significantly improved with an overhead goal, as hypothesised and in agreement with previous literature (Ford, et al., 2005; Król, et al., 2016; Mok, et al., 2017). The 2.7 cm improvement in DLJL jump height is considered clinically meaningful as above the 2 cm typical error associated with this measure (Gallardo-Fuentes, et al., 2016; Markwick, Bird, Tufano, Seitz, & Haff, 2015). Overall, these results indicate that using **an overhead goal compared to no goal** when performing the DLJL task improved jump height without meaningfully changing landing mechanics as assessed using the LESS, although a more detailed biomechanical assessment would be needed to explain the mechanism behind the increased jump heights and conflicting categorisation between conditions in 11.8% of individuals.

We conducted this study with the knowledge that performing a DLJL task with an overhead goal could influence landing mechanics and jump performance (Ford, et al., 2005; Król, et al., 2016; Mok, et al., 2017) with no specific investigation on the effect of an overhead goal on LESS scores as used in screening for injury risk. Furthermore, the DLJL task used in the LESS without an overhead goal has been criticised for lack of sport specificity (Kristianslund & Krosshaug, 2013). Adding an overhead goal has been used to enhance sport specificity elsewhere (Almonroeder, et al., 2018; Fíltér, et al., 2021), which can increase relevance in the

context of injury risk screening and performance testing. When using three-dimensional (3D) motion capture and force plate measuring devices, significant differences in DLJL biomechanics between overhead goal and no goal conditions have been observed and suggest increased loading of the ACL under the goal condition (Almonroeder, et al., 2018). That said, the difference in peak knee flexion ( $\sim 5^\circ$ ) and adduction ( $\sim 1^\circ$ ) angles between conditions captured using 3D methods would be difficult to discern reliability using 2D methods and the LESS scoring template. Hence, although differences in the biomechanics of the DLJL task have been identified under laboratory settings (Almonroeder, et al., 2018; Ford, et al., 2005; Oliver, et al., 2019), differences are more challenging to observe using clinical methods. This challenge is reflected in the inability of the LESS to detect changes in the occurrence of specific LESS errors between the overhead goal and no goal conditions at a group-level despite changes in jump height performances and greater odds of being categorised at high risk when using an overhead goal.

Our mean LESS scores for the no goal condition ( $5.9 \pm 1.5$  errors), which followed the original LESS protocol (Padua, et al., 2009), are in line with mean values from similar cohorts of young healthy participants (Hanzlíková, et al., 2020; Hanzlíková & Hébert-Losier, 2021), although at the higher end of mean LESS score values reported across the literature for non-injured individuals (Hanzlíková, Athens, et al., 2021). These higher mean LESS scores resulted in a considerably large proportion of our participants being categorised at high risk (>75%) based on the five-error threshold, **which might be due to the cohort not necessarily participating in jump-landing based sports**. In addition, it is debatable whether the five-error threshold is an appropriate cut-off to define injury risk. Although results from some investigations support the predictive value of this threshold (Everard, et al., 2018; Padua, et al., 2015), others have failed to support the predictive value of the LESS and the five-error threshold (de la Motte, Clifton,

Gribbin, Beutler, & Deuster, 2019; Smith, et al., 2012). Furthermore, it is important to highlight that the predictive value of the LESS while using an overhead goal has not been examined, which would help to confirm whether enhancing the sport-specific nature of the DLJL using an overhead goal would also enhance its usefulness in screening for risk of injury in sports.

Jump height of participants was 2.7 cm higher with the overhead goal compared to no goal, in line with the average increase in performance reported elsewhere (2.4 to 3.2 cm) comparing similar experimental conditions (Mok, et al., 2017; Oliver, et al., 2019). The observed 2.7 cm improvement in jump height is considered clinically meaningful as above the between-day typical error of 2 cm associated with this measure (Gallardo-Fuentes, et al., 2016; Markwick, et al., 2015). The instruction used in the overhead goal condition (i.e., jump upwards as high as possible upon landing reaching for the ball with both hands, as if trying to grab it) might have encouraged individuals to adopt an external focus and direct their attention away from their body movements towards the outcome of the movement (i.e., effects of their movement on the environment) (Bredin, Dickson, & Warburton, 2013; Wulf, McNevin, & Shea, 2001), in this case, the ball. The constrained-action hypothesis is a commonly cited mechanism that suggests an external focus promotes greater movement control automaticity, whereas an internal focus that directs ones attention to their body movements constrains this automaticity and hinders motor performance (Vance, Wulf, Töllner, McNevin, & Mercer, 2004; Vidal, Wu, Nakajima, & Becker, 2018; Wulf, et al., 2001). External focus may in fact promote the self-organisation of motor tasks (Wulf, et al., 2001) and enhance movement efficiency (Vance, et al., 2004; Wulf, Dufek, Lozano, & Pettigrew, 2010). It is also possible that the overhead goal simply acted as an extrinsic motivator and incentivised participants to jump higher as setting goals can enhance motivation, focus, and performance (Swann, et al., 2021). From a biomechanical perspective, higher jump heights likely involved changes in kinetic measures,

which were not measured here. During DLJL tasks linked with greater jump heights due to presence of an overhead goal or use of an external focus; jump impulses, lower extremity joint moments, and peak vertical ground reaction forces were reported as significantly greater (Ford, et al., 2005; Wulf & Dufek, 2009). It is possible that some of these biomechanical factors contributed to the improved jump performance we observed with the overhead goal.

Other means of enhancing sport specificity of DLJL tasks include alternative divided attention scenarios, such as asking individuals to perform a counting task alongside the motor performance task. It is possible that the combination of quick powerful movements (e.g., DLJL and cutting) and cognitive loads increases the odds of sustaining an injury (Grooms & Onate, 2016; Mok, et al., 2017). When adding cognitive demands via counting to the DLJL task, Dai, et al. (2018) found increased ground reaction forces and decreased knee flexion angles while dual tasking, indicative of increased ACL loading. Hence, adding an overhead goal alongside cognitive demands might speculatively elicit further LESS score and DLJL biomechanical differences than using an overhead goal in isolation. However, research has shown that the isolated effects of overhead goals and cognitive demands on DLJL biomechanics are similar to each other and do not further influence DLJL biomechanics when combined (Almonroeder, et al., 2018). Therefore, it is unlikely that increasing the cognitive load during LESS assessment using a counting task would affect landing mechanics more than using an overhead goal, the latter being conceptually more sport specific than counting. Overall, despite adding an overhead goal, there is still a concern that the DLJL task is not challenging enough or sufficiently sport specific for injury risk screening (Almonroeder, et al., 2018; Hanzlíková, Richards, Athens, & Hébert-Losier, 2021), with single-leg rotated tasks potentially a more suitable alternative (Hanzlíková, Richards, et al., 2021).

There are limitations to the current study, notably that a set overhead goal height was implemented across participants as the ball was affixed to a relatively low-hanging ceiling **due to laboratory constraints and for testing efficiency**. As such, the overhead goal likely challenged individuals to different extents. Nonetheless, the stimulus was sufficient to elicit differences in jump height performances and provided a more sport-specific environment. Another limitation, as noted previously, the predictive value of the implemented five-error threshold to categorise injury risk is debated in the scientific literature (de la Motte, et al., 2019; Everard, et al., 2018; Padua, et al., 2015; Smith, et al., 2012).

## **CONCLUSIONS**

Overall, performing the LESS with compared to without an overhead goal resulted in significantly greater group mean LESS scores, odds of high-risk categorisation, and jump heights, but not in the occurrence of specific LESS errors. At an individual-level, consistency of risk categorisation was also conflicting between conditions. Of these differences, only changes in jump heights and individual-level risk categorisation may be considered as clinically meaningful. Using an overhead goal during LESS testing is deemed to enhance sport **specificity** and elicit greater jump performances, and hence might be more suitable and relevant for injury risk screening in sport. However, prospective studies are needed to confirm the predictive value of the LESS performed with an overhead goal in terms of ACL and musculoskeletal injury, with more challenging tasks than the DLJL potentially of greater relevance to the sporting environment.

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### **Declaration of competing interest**

None declared.

### **Ethical approval**

The University of Waikato Human Research Ethics Committee (HREC(Health)#2017-41) approved the study protocol prior to data collection, which adhered to the Declaration of Helsinki. All participants signed a written informed consent document that explained the potential risks and benefits associated with testing.

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### **Data availability statement**

The data that support the findings of this study are openly available in OSF at <https://doi.org/10.17605/OSF.IO/9GK CZ> (Hébert-Losier, 2022).

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