Maximise or normalise? Examining single-leg drop-land-cut distances in young athletes. A pilot study.

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Abstract

This study investigated differences in leap distance for a single-leg drop-land-cut (CUT) task based on using either a maximal or normalised (150% leg length) method and the influence of condition order and leg dominance on distance achieved. Twenty-six young court and field sport athletes (61.5% female) completed the CUT task on the dominant and non-dominant leg under maximal and normalised conditions in a randomised order. Multivariate repeated measures ANOVA tests with post-hoc pairwise comparisons were used to determine the effect of condition (maximal, normalised), leg dominance (dominant, non-dominant), and interaction effect on leaping distance. Potential order effects were explored as a between subjects factor within the ANOVA. Our findings showed significantly larger leap distances under the maximal condition ($p < 0.001$, $\eta_p^2 \geq 0.417$) with the maximal mean being 154.5 ± 24.7 cm (175.1 ± 18.6% leg length) and the normalised mean being 140.7 ± 19.7 cm (159.0 ± 5.8% of leg length). Furthermore, greater distances were achieved during the maximal task when performed following the normalised task ($p < 0.001$, 24.5% further). Practically, the normalised task may be better suited for heterogeneous samples, yet the maximal task may be more suitable for homogeneous samples or pre-post study designs.

Keywords: acl, puberty, injury screening

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Introduction

Anterior cruciate ligament (ACL) injuries are becoming increasingly common in youth athletes[1,2]. The annual number of ACL injuries reported in young people has risen exponentially. In particular, females aged 5-14 years have demonstrated an 10.4% annual growth rate in ACL injury incidence from 1998 to 2018 in Australia[2]. In New Zealand, claims from male and female individuals aged 15-29 years contributed to over 50% of the $100 million cost of ACL injuries to taxpayers in 2021 alone[3]. Representing 45% of all internal knee injuries[4], ACL injuries are associated with prolonged recovery periods (e.g., return to play at least 9 months post-surgery[5]), a substantial financial cost of care[6], impaired functional sporting performance[7], and an increased risk of early-onset posttraumatic osteoarthritis[8,9].

The demands of court and field sports require frequent accelerations, decelerations, changes of direction, rotations, and single-leg landings, all of which are movements associated with ACL injury incidence[10,11]. Additionally, side-cutting manoeuvres are responsible for most non-contact ACL injuries in sports such as football and handball[12,13], likely due to the multi-planar nature of the movement that exposes the knee joint to high loads[14]. In response, screening for biomechanical injury risk factors is becoming common practice in team sports, particularly in high injury risk populations such as young female court and field sport athletes[15]. However, for widespread adoption, the task needs to be suitable for implementation in clinical settings and on the field. A task that involves a single-leg landing followed by an immediate and explosive side-cut may suit these requirements and may better resemble manoeuvres associated with ACL injury than what is typically used[16], such as double-leg drop vertical jumps[17], single-leg squats[17], and tuck jumps[18]. Double-leg drop vertical jump tasks have been frequently used to assess ACL injury risk factors in team sport athletes[17,19] despite generally being determined as unsuitable for predicting ACL injury risk[15,20]. Although run and cut manoeuvres might be better in the context of screening for risk of ACL injury and commonly assessed in laboratory settings[20], they are often not practical in clinical environments and can be difficult to standardise in terms of approach speed and angle of cut.

The design of the single-leg drop-land-cut (CUT) task should consider variation in the perception of maximal effort[21] with respect to subjective and anthropometrical factors. Previous research has observed differences in performance and biomechanics between individuals of different maturational groups using both a maximal effort method[22] and a normalised cutting distance to 150% of leg length[23]. Although rationales for each of these methods are justifiable, their suitability may depend on the circumstance and purpose of implementation. For example, the maximal condition may be appropriate in a more homogeneous sample of athletes of similar body sizes, however, a normalised condition may be better to compare a more heterogeneous sample as the task is relative to body size. It is currently difficult to select one method over the other as there is a lack of studies directly comparing the two methods. Such information would allow practitioners to make an informed decision on test parameters for this task and enable a more appropriate comparison of performance between groups or individuals. This study focused on exploring the differences in performance of two conditions of the same task that have previously been used with participants in different pubertal maturation stages to inform development and implementation of injury risk screening tasks in this population. Additionally, if performance from both tasks are assessed, the order of condition of tasks may impact performance as it has been suggested that, in younger populations, some participants can believe they are performing maximally, but once given a target, may achieve further distances[21]. The raw values in cm and these values expressed as a percentage of leg length are included to provide perspective of the absolute and relative values. Furthermore, leg dominance can influence biomechanical risk factors[24] and performance[25] during sport-specific tasks that warrant consideration in establishing test parameters, interpreting outcomes, and comparing between groups or individuals. The potential effect of limb dominance on functional performance could impact clinical outcomes for injury risk or recovery screening, particularly considering the influence of perceived task difficulty[26].

The primary purpose of this pilot study was to determine if differences in leap distance (i.e., performance outcome) exist for the CUT task metrics based on using either a maximal or normalised (150% leg length) methodology in young court and field sport athletes. A secondary purpose was to determine whether the order of conditions or leg dominance would influence the distance achieved. It was hypothesised that participants would leap further using the maximal method, on the maximal task when presented second, and when using the dominant leg.

Methods

Given the exploratory nature of the pilot study and the overall lack of data on the examined tasks in the target population, no formal sample size was conducted a priori. To account for drop-out or data-loss, a sample size between 20-30 participants was targeted based on previous pilot studies stating 12 participants to be appropriate[27,28]. Ultimately, twenty-six healthy young court or field sport male and female athletes aged between 7 and 20 years volunteered to participate (Table 1), providing an 80% power to detect an effect size *f* of 0.24 at a 5% significance level based on the ANOVA: repeated measures, within-between interaction setting of G*Power 3.1.9.7. The calculation considered the collection of four measurements (dominant and non-dominant for maximal and normalised conditions) and two groups to account for a potential order effect on leap distances. All participants were right leg dominant determined by the leg used to kick a ball. The participants had no history of serious back or leg injuries within the 12 months prior to testing. All participants and their parents/legal guardians (if under 16 years) provided informed consent prior to participating in this study, which was approved by the University of Waikato Human Research Ethics Committee (HREC (Health) 2022#53) and adhered to the Code of Ethics of the World Medical Association (Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects) and the Health Research Council's guidelines relating to research involving children and UNICEF's principles guiding ethical research involving children[29].

Table 1 Baseline characteristics of the participants, mean ± SD.

Characteristic	Males (*n* = 10)	Females (*n* = 16)	Total (*n* = 26)
Age (y)	13.9 ± 3.6	13.0 ± 4.4	13.5 ± 4.1
Height (cm)	154.5 ± 33.6	145.0 ± 30.0	155.4 ± 19.1
Body mass (kg)	49.4 ± 17.1	47.1 ± 16.3	48.5 ± 16.2
BMI (kg/m^2)	18.9 ± 2.8	20.1 ± 5.2	19.6 ± 4.0
Leg length (cm)	88.4 ± 19.4	85.7 ± 18.4	88.6 ± 12.8

Note: Abbreviations: BMI, body mass index.

Equipment

A high-speed video camera with a focal length of 8.8 to 73.3 mm (35-mm equivalent focal length of 24-200 mm) captured the CUT trials at 120 frames per second (Sony RX10 II, Sony Corporation, Tokyo, Japan). The camera was placed 3.5 m in front of the landing area on a tripod with a 1.3 m lens-to-ground distance.

Procedures

The participants attended a single testing session where they first had their leg length measured until two identical measurements were recorded. For leg length, a tape measure was used to record the distance from the anterior superior iliac spine (ASIS) to the medial malleoli on the right (dominant) leg in a supine position[30]. Participants then completed a standardised five-minute warm up involving jogging at a self-selected pace on a turf surface for two minutes, dynamic stretching (8 reps of each per leg; leg swings, walkouts, lunges, and lateral reaches), and jump-landing drills (15 reps per leg of submaximal vertical hopping, 5 reps of double-leg landing, and 5 reps per leg of single-leg landing).

For the CUT task, participants were required to stand on one foot, drop down from a 30 cm box, land on the same foot to a marked distance placed 30 cm in front of the box, and to immediately leap 90° laterally to land on the opposite foot[31] along a marked line on the floor (Figure 1). For instance, participants dropping down and landing on their right foot would leap towards the left to land on their left foot. Participants completed the task in the two experimental conditions: 1) normalised distance to 150% of leg length, and 2) maximal distance. For the normalised CUT condition, the leg length normalised distance was indicated on the floor using a line of tape. For the maximal distance CUT condition, participants were asked to leap as far as possible, aiming to maximise distance, with no leap distance indicated on the floor. In both conditions, participants were required to maintain balance upon landing and were encouraged to keep their body facing forwards. The participants were allowed 2-3 practice trials of each condition directly before the test of that same condition for familiarisation, following a standardised explanation and demonstration from the primary researcher (AB).

Condition order was randomised, as was the use of the dominant or non-dominant leg within the condition. For each leg and condition, three successful efforts were performed. The individual efforts were separated by 20 seconds of rest for both legs and between legs, whereas individuals rested for 2 minutes between conditions. Participants wore their own footwear that they would usually wear during sporting participation[32]. A pictorial representation of the CUT phases is presented in Figure 1, and a flow chart of the data collection procedure is presented in Figure 2 along with the possible orders of conditions.

Data processing

Leap distances were extracted from frontal videos using Silicon Coach (Silicon Coach Pro, version 8, Dunedin, NZ) and displacement calibration was performed to a marked 1 m distance along the line where the participants leapt. SiliconCoach Pro has been commonly used to provide accurate data for coaching[33], and has been assessed for displacement agreement against VICON in pelvis measures (r^2 = 0.92)[34] and against 3D measures in golf kinematic parameters (ICC = 0.929)[35]. A marker was placed in the middle of the toe box (proximal point of the 2nd phalange) of participants' shoes and leap distance was calculated from the marker on the initial landing foot upon ground contact to the marker on the opposite foot upon the second ground contact. For each participant, the mean leap distance of three trials per leg for each condition were used in further analysis. The normalised to leg length units were calculated using the equation (distance leapt (cm)/ leg length (cm)) x 100.

Statistical analysis

Using IBM SPSS Statistics (version 29.0.0.0(241)), descriptive statistics were calculated and reported as means, standard deviations, and ranges. Multivariate repeated measures ANOVA tests with post-hoc pairwise comparisons were used to determine the within-subject effect of condition (maximal, normalised to leg length), leg dominance (dominant, non-dominant), and interaction effect on leaping distance outcomes, both in raw (cm) and normalised to leg length (%) units. Mean differences (MD) are reported alongside their *p* values and 95% confidence intervals (CI's). Potential order effects between completing the maximal or normalised condition or the dominant or non-dominant leg first were explored as between-subject factors within the ANOVA. Assumption checks for normality of distribution, sphericity of data, and outliers were completed in SPSS using the Shapiro-Wilk test, Mauchly's test of sphericity, and visual inspection of studentised residuals for values ± 3 standard deviations, respectively. Partial eta squared (η_p^2) effect sizes are used to express the magnitude of differences between conditions using the following interpretations: 0.01 as a small effect, 0.06 as a medium effect, and 0.14 as a large effect[36]. Variances were compared using the modified Levene's test by calculating the absolute deviations of each value from the group mean ($d_{i1} = |x_{i1} - \bar{x}_1|$, $d_{i2} = |x_{i2} - \bar{x}_2|$) and the deviations across conditions were compared using paired *t*-tests. Statistical significance was set to $p \leq 0.05$. Individual measures were plotted on a scatter plot for the two conditions to visualize individual performance for the dominant and non-dominant legs separately (Figures 3 and 4, respectively).

Results

Repeated measures ANOVA assumptions were met for distance leapt expressed in raw units and normalised to leg length, and no outliers were detected. The results for the repeated measures ANOVA are reported in Table 2. For both measures, there were no significant interaction effects between side and condition ($p \geq 0.429$, $p \geq 0.547$, raw and normalised respectively) or main effects for leg dominance ($p \geq 0.247$, $p \geq 0.282$, raw and normalised respectively). The main effect of condition was statistically significant for distance leapt expressed in both raw and normalised units ($p < 0.001$, for both) with large effect size differences ($\eta_p^2 \geq 0.417$, $\eta_p^2 \geq 0.432$, respectively). The distance leapt was 13.9 [7.1, 20.6] cm and 16.1 [8.5, 23.7] % of leg length greater in the maximal than normalised to leg length CUT condition, with all participants leaping further in the maximal than normalised conditions. Participants leapt an average of 154.5 ± 24.7 cm (175.1 ± 18.6% of leg length) during the maximal task and 140.7 ± 19.7 cm (159.0 ± 5.8% of leg length) during the normalised task. All but two participants leapt greater than or equal to the 150% of leg length distance during the maximal trials.

There was no interaction effect between (order and dominance) ($p = 0.644$) and no main effect of order ($p = 0.197$). There was an interaction effect between order and condition for both the raw ($F_{(1,25)} = 5.767$, $p = 0.024$, $\eta_p^2 = 0.194$) and normalised units ($F_{(1,25)} = 6.195$, $p < 0.001$, $\eta_p^2 = 0.205$). Results from the order of conditions are presented in Table 3. For the raw values, pairwise comparisons revealed no statistically significant differences when considering order within conditions ($p > 0.062$); however, when considering condition within order, the maximal trial was significantly further than the normalised trial when the normalised task was completed first (MD = 21.1 cm, $p < 0.001$, 95% CI [12.3, 29.8]), but the maximal trial was not significantly further than the normalised trial if the maximal trial was completed first (MD = 6.7 cm, $p = 0.130$, 95% CI [-2.1, 15.4]). For the normalised values, pairwise comparisons revealed statistically significant differences when considering order within condition suggesting that within the maximal condition, if normalised was completed first then the maximal trial was further than if the maximal trial was completed first (MD = 14.0%, $p = 0.042$, 95% CI [0.5, 27.5]). Furthermore, when considering condition within order, the maximal trial was significantly further than the normalised trial when the normalised task was completed first (MD = 24.5%, $p < 0.001$, 95% CI [14.7, 34.3]). However, the maximal trial was not significantly further than the normalised trial if the maximal trial was first (MD = 7.7%, $p = 0.117$, 95% CI [-2.1, 17.5]).

The modified Levene's test revealed a significant difference in variances between the absolute deviations of the maximal and normalised conditions for the raw data (maximal mean residual = 20.3 cm, normalised mean residual = 16.4 cm, MD = 4.0 cm, $p = 0.048$, 95% CI [0.6, 7.3]) and for the normalised to leg length data (maximal mean residual = 14.1%, normalised mean residual = 4.6%, MD = 9.5%, $p < 0.001$, 95% CI [6.4, 12.5]). No significant differences in variance were observed between order of condition for raw ($p = 0.755$) or normalised data ($p = 0.694$).

Regarding the individual measures on the scatter plot, one participant for the dominant leg and non-dominant leg and one participant for the non-dominant leg did not achieve a cut distance of 150% leg length during the maximal trial, but did during the normalised trial. Also, one participant for the dominant leg and the non-dominant leg did not achieve a cut distance of 150% leg length during the normalised trial, but did during the maximal trial. These observations suggest that for both legs, all participants were able to achieve the 150% leg length target during either or both conditions.

Table 2 Raw and percentage of leg length leap distances for maximal and normalised to 150% of leg length conditions for the single-leg drop-land-cut task. Data are mean ± SD, range (minimum, maximum), and 95% confidence interval [lower, upper].

CUT task	**Maximal**		**Normalised**		**Effects *p* value, η_p^2**		
Distance	**Non-dom**	**Dom**	**Non-dom**	**Dom**	**Condition**	**Dominance**	**Interaction**
Raw (cm)	153.5 ± 24.9	155.5 ± 24.5	140.4 ± 20.4	140.9 ± 19.0	p <0.001*	p = 0.282	p = 0.429
	(115, 197)	(123, 206)	(105, 181)	(104, 170)	η_p^2 0.417 [0.161, 0.580]	η_p^2 0.046 [0.000, 0.219]	η_p^2 0.025 [0.000, 0.181]
Normalised (%)	174.0 ± 20.2	176.2 ± 17.0	158.5 ± 5.8	159.5 ± 5.7	p <0.001*	p = 0.247	p = 0.547
	(122, 219)	(138, 216)	(147, 172)	(143, 167)	η_p^2 0.432 [0.175, 0.591]	η_p^2 0.053 [0.000, 0.230]	η_p^2 0.015 [0.000, 0.156]

Note: Abbreviations: Dom = dominant, Non-dom = non-dominant, * indicates statistical significance ($p \leq 0.05$), negative values indicate larger right value. Effect size: *small* (0.01), *medium* (0.06), *large* (0.14)[36].

Table 3 Leap distances by condition and order. Data are mean ± SD, range (minimum, maximum), and mean difference with 95% confidence interval [lower, upper].

	Maximal				Normalised			
	First	**Second**	**MD [95% CI]**	***p* value, η_p^2**	**First**	**Second**	**MD [95% CI]**	***p* value, η_p^2**
Raw (cm)	145.7 ± 23.8 (115, 206)	163.3 ± 22.1 (130, 201)	17.7 [-1.0, 36.3]	$p = 0.062$, η_p^2 0.138 [0.000, 0.338]	142.2 ± 20.6 (104, 181)	138.9 ± 18.6 (111, 169)	3.2 [-12.8,19.3]	$p = 0.681$, η_p^2 0.007 [0.000, 0.131]
Normalised (%)	168.2 ± 16.5 (122, 200)	182.1 ± 18.1 (141, 219)	14.0 [0.5, 27.5]	$p = 0.042$*, η_p^2 0.161 [0.003, 0.363]	157.6 ± 4.8 (150, 171)	160.3 ± 6.3 (143, 172)	2.7 [-1.2, 6.6]	$p = 0.171$, η_p^2 0.076 [0.000, 0.267]

Note: Abbreviations: MD = mean difference, CI = confidence interval, * indicates statistical significance ($p \leq 0.05$), negative values indicate larger right value. Effect size: *small* (0.01), *medium* (0.06), *large* (0.14)[36].

Discussion

There is currently a lack of standardisation of the CUT task. Given the incidence of ACL injury in young athletes[2], it is important to understand the differences that exist for these tasks when used to explore potential injury risk factors linked to single-leg landings. Our aim was to compare the distances leapt during a CUT task under maximal and normalised conditions (set to 150% leg length) in young court and field sport athletes, and to determine the effect of leg dominance and order of tests on outcomes. In agreement with our hypotheses, the distance leapt was significantly further with the maximal condition compared to the normalised condition (mean difference: 13.9 cm or 16.1% of leg length), however, contrary to our hypothesis, no significant differences were observed between dominant and non-dominant legs. The significantly large differences in effect size observed between the normalised and maximal conditions values emphasises that, although both conditions have their benefits and limitations, the condition selected for assessment warrants consideration as they are fundamentally different.

Additionally, when examining the significant interaction effect between condition and order ($p = 0.024$), it was observed that if participants completed the normalised condition first, they then leapt significantly further during the respective maximal condition compared to those who completed the maximal condition first ($p < 0.001$). As the normative value was set, it was not influenced by the maximal condition being performed first. These results highlight the potential variation in perceptions of effort in this population of young athletes as they were able to achieve a further distance once they had jumped to the set distance previously. It is possible that the participants were able to hop further when performing the maximal condition second as they would have practiced the task more times, albeit sub-maximally, by performing the normalised condition first. In a clinical or research setting, employing a normalised trial prior to a maximal effort trial could lead to a 'truer' result for the maximal effort trial. Furthermore, no significant differences were observed between variances of the order of condition which suggests similarities in this outcome between participants (*p* = 0.755 and *p* = 0.694) for raw and normalised respectively. Perception of maximal effort and consistency in motor control during the maximal effort trials may be more varied in younger populations. As demonstrated by Lamb, et al. [21], some participants can believe that they are performing maximally, but once given a target, may achieve further distances. The maximal condition may be better suited when observing pre-test post-test performance differences within a given individual or when the group has similar physical abilities, perceptions of effort, and anthropometric characteristics. The normalised method may be better when seeking to compare groups with a wider range of abilities, varied perceptions of effort, and differences in anthropometric characteristics. Furthermore, selecting the normalised task may be better if the task goal is completion oriented rather than performance oriented.

The range of individual ability for the maximal condition and how different the distance was from the standardised condition are also noteworthy. Landing distance was more variable under the maximal condition, as demonstrated by the large standard deviations and significant differences in variance between the maximal and normalised conditions ($p = 0.048$ for raw and $p < 0.001$ for normalised). These results demonstrate that there were variations in ability and/or effort applied between participants, which should be considered in task selection and result interpretation. It is possible that the presence of a floor tape marker in the normalised condition served as a visual target which introduces a potential confounding factor when comparing the normalised condition to the maximal condition. A visual target may reduce movement variability by providing participants with an external reference point, which may influence motor planning and execution[37]. Contrastingly, the lack of a target in the maximal effort condition could inherently allow for more variability. This discrepancy could have contributed to observed differences in movement consistency between conditions. Researchers have suggested that children often adopt different movement patterns from trial-to-trial, possibly in attempt to learn how their bodies produce more force and therefore achieve a better performance outcome, but nonetheless, altering their biomechanics each time[38]. Raffalt, et al. [38] found higher intra-subject variability in the movement patterns of children compared to adults when assessing reaction force components and angular biomechanics during maximal effort jumping tasks. Previous research has suggested greater variability in jump length in a pre-peak height velocity group during a broad jump task[39] and greater jump height variability during a vertical jump task in younger participants, which diminishes with maturation and growth[40-42]. Selection of the normalised condition in our target population of young field and court sport athletes may encourage more consistency in performance and movement patterns leading to a more natural demonstration of how the participant would typically perform the task in a sporting situation. However, the variation in physical ability that exists in youth populations and that is demonstrated by the variance under the maximal condition, may influence the level of challenge provided by the normalised test condition.

All participants except for two leapt to the 150% of leg length distance during the maximal trials, which seems like an appropriate distance based on the lower end of the maximal distance values (122% non-dominant and 138% dominant, Table 2). When set to 150%, all participants were close to the set target (lower end 147% non-dominant and 143% dominant). Research has previously suggested that normalising tasks can be considered good practice in research as it allows standardisation in an individualised sense[43]. Practically, setting the same absolute distance or requiring a maximal landing distance may be unsuitable for comparing individuals of different heights, ages, maturation, sexes, and abilities. In a heterogeneous sample, using a CUT task normalised to leg length allows greater standardisation and facilitates valid comparisons between individuals. Whether 150% of leg length is the most appropriate has not been established, but it appears reasonable and achievable based on our dataset. Setting the distance to 175% might be more reflective of a maximal effort, but it is unlikely that all participants could reach this threshold based on the performance of participants in the current study.

The CUT task has not been used extensively in previous research to explore movement performances based on maturation phases[16], hence further research is required as there are no tools unequivocally agreed to be linked with ACL injury incidence. It has been suggested that a larger lateral step distance in a cutting task increases hip and knee extension, and ankle plantar flexion torques[44]. Additionally, Havens and Sigward [45] noted greater knee abduction moments during cutting with wider lateral foot plants. Therefore, the distance of the cutting task could be an important factor to consider in rendering a task more sensitive and specific for assessing risk of ACL injury. A normalised method for setting distance during a CUT is yet to be explored, however, previous research has used maximal effort methods. Hass, et al. [22] used a maximal effort CUT task alongside a landing task and a vertical jump task for assessing lower extremity injury risk in pre-pubertal and post-pubertal females. Their study found significant interactions between maturation phase and landing sequence for post-pubertal compared to pre-pubertal participants who demonstrated biomechanics linked with ACL injury incidence. The researchers suggested these results to be a consequence of differences in motor and neuromuscular control strategies (such as reflex and voluntary muscle activation) at different maturational phases and they emphasised the need to study multiple landing strategies. It is logical to assume that instructing participants to perform a task using a maximal effort would create a relatively consistent challenge level between participants; however, differences in effort perception and neuromuscular ability may influence their ability to produce a maximal or close to maximal effort repeatedly. It is also currently unknown whether performing the maximal version of this or any jump-landing task is injury-risk specific. It is possible that a threshold exists where a normalised distance is challenging enough to elicit biomechanical patterns similar to a maximal effort, but determining this threshold would require further biomechanical research. Typically, athletes are not required to leap laterally as far as possible in a sporting situation as they are usually only required to leap far enough to evade a player or to make a play, indicating that a normalised distance may suffice for assessment of movement competency in the context of ACL injury risk.

Our study is not without limitations. Although the order of tests (normalised or maximal) was randomised, an order effect was observed. Therefore, it is possible that the participants gave different levels of effort across the trials, but not necessarily produced a true maximal effort owing to factors such as fatigue, familiarisation, perception of effort, or attention. Perceived difficulty was not collected in this study, limiting our ability to quantify the participants' perceptions of the task demands. Furthermore, the CUT task was anticipated (i.e., participants knew which leg to land on and perform the task with), limiting generalisation to unanticipated tasks that are more reflective of ACL injury mechanisms[46]. It has been suggested that individuals use different strategies to execute planned versus unplanned movements, specifically, greater implications of overuse injuries are apparent in planned compared to unplanned movements. Future research should examine whether biomechanics are affected based on whether the task is set or involves a reactive component, as well as how biomechanics change with increase in leaping distance. A further limitation is the sample size (n = 26), which represented a cross-section of the maturation stages for both sexes. With a larger sample size than 26 participants based on detecting differences between CUT tasks, it would have been possible to further explore additional factors, such as the effect of maturation on outcomes or between sex differences. Furthermore, the mean hop distance of the normalised condition was 159% of leg length, exceeding the 150% target. There are several potential underlying factors to this overshooting: the landing distance was too easy; participants had difficulty seeing the target in their peripheral vision while facing forwards; the Hawthorne effect[47] and the testing environment incited participants to perform better than the requirement; or the decision to measure the distance based on a marker placed on the toes rather than the midfoot or heel. It is generally common in sports and jump tests involving horizontal components for individuals to be instructed to “reach” a set landing distance (Padua et al., 2009), inferring they must get to or exceed the set target. Reinforcing the importance of landing on the target or re-doing trails which were too far off the target would likely bring the mean value closer to the target.

Further research is required to determine if 150% leg length is the most appropriate distance for normalisation or if perhaps closer to our mean maximal values of 175% would be more suitable and achievable. Furthermore, it would be beneficial to determine if an ideal percentage of leg length exists for the normalised CUT which best represents that of a high ACL injury risk sporting situation, particularly in different maturational groups or in groups with different abilities. Assessing what the average cutting distance is across the course of a game, considering fatigue, within different sports and quantifying this in relation to percentage of leg length may inform the development of screening tools which are more specific to the demands of the sport.

To conclude, on average, participants leapt significantly further during the CUT task when requiring a maximal effort compared to when normalising the distance to 150% of leg length, suggesting significantly different performance demands of the conditions. However, a more variable landing distance was observed during the maximal condition, as indicated by larger standard deviations and significant variance in absolute deviations. We recommend that normalising leaping distance to leg length allows for standardisation of the CUT task and facilitates comparisons between individuals deriving from a heterogeneous sample. However, the normalised condition may not elicit a maximal response or sufficiently represent an injury-risk specific situation. Hence, selection of a protocol specific to the study goals is important. A normalised distance based on a percentage of leg length may be better suited when examining individuals presenting with a wide range of heights, maturation stages, sexes, or physical abilities, yet a maximal distance may be more suitable for a more homogeneous sample or pre-post study designs. Future research should investigate whether lower-extremity kinematics and kinetics differ between normalised and maximised CUT tasks and explore the specificity of these manoeuvres to biomechanics related to ACL injury risk.

References

1. Hosseinzadeh S, Kiapour AM. Age-related changes in ACL morphology during skeletal growth and maturation are different between females and males. *Journal of Orthopaedic Research®*. 2021;39(4):841-849.
2. Maniar N, Verhagen E, Bryant AL, Opar DA. Trends in Australian knee injury rates: An epidemiological analysis of 228,344 knee injuries over 20 years. *The Lancet Regional Health–Western Pacific*. 2022;21
3. ACC analytics and reporting. Data from: ACL Injury Claims from 2019 to 2022. 2022.
4. Majewski M, Susanne H, Klaus S. Epidemiology of athletic knee injuries: A 10-year study. *The Knee*. 2006;13(3):184-188.
5. Kaplan Y, Witvrouw E. When is it safe to return to sport after ACL reconstruction? Reviewing the criteria. *Sports Health*. 2019;11(4):301-305.
6. Janssen KW, Orchard JW, Driscoll TR, van Mechelen W. High incidence and costs for anterior cruciate ligament reconstructions performed in Australia from 2003-2004 to 2007-2008: time for an anterior cruciate ligament register by Scandinavian model? *Scandinaian Journal of Medicine and Science in Sports*. Aug 2012;22(4):495-501. doi:10.1111/j.1600-0838.2010.01253.x
7. Paterno MV, Weed AM, Hewett TE. A Between Sex Comparison of Anterior-Posterior Knee Laxity after Anterior Cruciate Ligament Reconstruction with Patellar Tendon or Hamstrings Autograft. *Sports Medicine*. 2012;42(2):135-152.
8. Nebelung W, Wuschech H. Thirty-five years of follow-up of anterior cruciate ligament—deficient knees in high-level athletes. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*. 2005;21(6):696-702. doi:10.1016/j.arthro.2005.03.010
9. Lohmander L, Östenberg A, Englund M, Roos H. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. *Arthritis & Rheumatism: Official Journal of the American College of Rheumatology*. 2004;50(10):3145-3152. doi:10.1002/art.20589
10. Boden BP, Torg JS, Knowles SB, Hewett TE. Video analysis of anterior cruciate ligament injury: abnormalities in hip and ankle kinematics. *The American journal of sports medicine*. 2009;37(2):252-259. doi:10.1177/0363546508328107
11. Koga H, Nakamae A, Shima Y, et al. Mechanisms for noncontact anterior cruciate ligament injuries: knee joint kinematics in 10 injury situations from female team handball and basketball. *The American Journal of Sports Medicine*. 2010;38(11):2218-2225.
12. Faude O, Junge A, Kindermann W, Dvorak J. Injuries in female soccer players: a prospective study in the German national league. *The American Journal of Sports Medicine*. 2005;33(11):1694-1700.
13. Olsen O-E, Myklebust G, Engebretsen L, Bahr R. Injury mechanisms for anterior cruciate ligament injuries in team handball: a systematic video analysis. *The American Journal of Sports Medicine*. 2004;32(4):1002-1012.
14. Kristianslund E, Faul O, Bahr R, Myklebust G, Krosshaug T. Sidestep cutting technique and knee abduction loading: implications for ACL prevention exercises. *British Journal of Sports Medicine*. 2014;48(9):779-783. doi:10.1136/bjsports-2012-091370
15. Krosshaug T, Steffen K, Kristianslund E, et al. The vertical drop jump is a poor screening test for ACL injuries in female elite soccer and handball players: a prospective cohort study of 710 athletes. *The American Journal of Sports Medicine*. 2016;44(4):874-883.

16. Butcher AJ, Ward S, Clissold T, Richards J, Hébert-Losier K. Maturation and biomechanical risk factors associated with Anterior cruciate ligament injury: Is there a link? A systematic review. *Physical Therapy in Sport*. 2024;

17. Petushek E, Nilstad A, Bahr R, Krosshaug T. Drop jump? Single-leg squat? Not if you aim to predict anterior cruciate ligament injury from real-time clinical assessment: a prospective cohort study involving 880 elite female athletes. *Journal of Orthopaedic & Sports Physical Therapy*. 2021;51(7):372-378.

18. Fox AS, Bonacci J, McLean SG, Spittle M, Saunders N. A systematic evaluation of field-based screening methods for the assessment of anterior cruciate ligament (ACL) injury risk. *Sports Medicine*. 2016;46:715-735.

19. Hanzlíková I, Hébert-Losier K. Is the landing error scoring system reliable and valid? a systematic review. *Sports Health*. 2020;12(2):181-188.

20. Kristianslund E, Krosshaug T. Comparison of drop jumps and sport-specific sidestep cutting: implications for anterior cruciate ligament injury risk screening. *The American Journal of Sports Medicine*. 2013;41(3):684-688.

21. Lamb KL, Eston R, Parfitt G. Effort perception. *Oxford Textbook of Children's Sport and Exercise Medicine, 3*

rd Ed. Oxford University Press; 2017.

22. Hass CJ, Schick EA, Tillman MD, Chow JW, Brunt D, Cauraugh JH. Knee biomechanics during landings: comparison of pre- and postpubescent females. *Med Sci Sports Exerc*. Jan 2005;37(1):100-7. doi:10.1249/01.mss.0000150085.07169.73

23. Nasseri A, Lloyd DG, Minahan C, et al. Effects of Pubertal Maturation on ACL Forces During a Landing Task in Females. Article. *American Journal of Sports Medicine*. 2021;49(12):3322-3334. doi:10.1177/03635465211038332

24. Wang J, Fu W. Asymmetry between the dominant and non-dominant legs in the lower limb biomechanics during single-leg landings in females. *Advances in Mechanical Engineering*. 2019;11(5):1687814019849794.

25. McGrath TM, Waddington G, Scarvell JM, et al. The effect of limb dominance on lower limb functional performance–a systematic review. *Journal of Sports Sciences*. 2016;34(4):289-302.

26. Virgile A, Bishop C. A narrative review of limb dominance: Task specificity and the importance of fitness testing. *The Journal of Strength & Conditioning Research*. 2021;35(3):846-858.

27. Kunselman AR. A brief overview of pilot studies and their sample size justification. *Fertility and sterility*. 2024;121(6):899-901.

28. Julious SA. Sample size of 12 per group rule of thumb for a pilot study. *Pharmaceutical Statistics: The Journal of Applied Statistics in the Pharmaceutical Industry*. 2005;4(4):287-291.

29. Graham AP, Powell MA, Anderson D, Fitzgerald R, Taylor N. *Ethical research involving children*. UNICEF Office of Research Innocenti; 2013.

30. Neelly K, Wallmann HW, Backus CJ. Validity of measuring leg length with a tape measure compared to a computed tomography scan. *Physiotherapy Theory and Practice*. 2013;29(6):487-492.

31. Nasseri AL. Effects of pubertal maturation on ACL forces durin. 2021;

32. Hébert-Losier K, Boswell-Smith C, Hanzlíková I. Effect of Footwear Versus Barefoot on Double-Leg Jump-Landing and Jump Height Measures: A Randomized Cross-Over Study. *International Journal of Sports Physical Therapy*. 2023;18(4):845.

33. Ajithkumar L, Kumar P. Assessment of Scientific Tools for Kinematic Analysis in Sports Performance. *Indonesian Journal of Sport, Health and Physical Education Science*. 2025;3(1):18-25.
34. McDonald DA, Delgadillo JQ, Fredericson M, McConnell J, Hodgins M, Besier TF. Reliability and accuracy of a video analysis protocol to assess core ability. *PM&R*. 2011;3(3):204-211.
35. Hunter HH, Ugbolue UC, Sorbie GG, et al. An evaluation of temporal and club angle parameters during golf swings using low cost video analyses packages. *Scientific Reports*. 2022;12(1):14012.
36. Cohen J. Statistical power analysts for the behavioral sciences. 2nd edn Hillsdale. *NJL Erlbaum Associates*. 1988;
37. Cowin J, Nimphius S, Fell J, Culhane P, Schmidt M. A proposed framework to describe movement variability within sporting tasks: A scoping review. *Sports Medicine-Open*. 2022;8(1):85.
38. Raffalt PC, Alkjær T, Simonsen EB. Joint dynamics and intra-subject variability during countermovement jumps in children and adults. *Journal of Biomechanics*. 2016;49(13):2968-2974.
39. Meylan CM, Cronin JB, Oliver JL, Hughes MG, McMaster D. The reliability of jump kinematics and kinetics in children of different maturity status. *The Journal of Strength & Conditioning Research*. 2012;26(4):1015-1026.
40. Gerodimos V, Zafeiridis A, Perkos S, Dipla K, Manou V, Kellis S. The contribution of stretch-shortening cycle and arm-swing to vertical jumping performance in children, adolescents, and adult basketball players. *Pediatric Exercise Science*. 2008;20(4):379-389.
41. Harrison AJ, Gaffney S. Motor development and gender effects on stretch-shortening cycle performance. *Journal of Science and Medicine in Sport*. 2001;4(4):406-415.
42. Viitasalo JT. Evaluation of explosive strength for young and adult athletes. *Research Quarterly for Exercise and Sport*. 1988;59(1):9-13.
43. Jaric S, Mirkov D, Markovic G. Normalizing physical performance tests for body size: aproposal for standardization. *The Journal of Strength & Conditioning Research*. 2005;19(2):467-474.
44. Inaba Y, Yoshioka S, Iida Y, Hay DC, Fukashiro S. A biomechanical study of side steps at different distances. *Journal of Applied Biomechanics*. 2013;29(3):336-345.
45. Havens KL, Sigward SM. Cutting mechanics: relation to performance and anterior cruciate ligament injury risk. *Medicine and Science in Sports and Exercise*. 2015;47(4):818-824.
46. Weinhandl JT, Earl-Boehm JE, Ebersole KT, Huddleston WE, Armstrong BS, O'Connor KM. Anticipatory effects on anterior cruciate ligament loading during sidestep cutting. *Clinical Biomechanics*. 2013;28(6):655-663.
47. Sedgwick P, Greenwood N. Understanding the Hawthorne effect. *Bmj*. 2015;351