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ORIGINAL RESEARCH

THE RELATIONSHIP BETWEEN Y-BALANCE TEST SCORES AND KNEE MOMENTS DURING SINGLE-LEG JUMP-LANDING IN NETBALL

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ABSTRACT

Background: Using 3-dimensional motion analysis to derive knee moments that may contribute to non-contact anterior cruciate ligament (ACL) injuries during single-leg jump-landing is expensive and time consuming. Severe ACL injuries that are inappropriately rehabilitated can potentially end athletes' careers. Consequently, a quick-and-simple to administer screening tool that can be used to infer knee moments during single-leg jump-landing could be useful for regular screening of netballers' predispositions to increased knee loading during single-leg jump-landing.

Purpose: The purpose of this study was to investigate whether knee moments during weight-acceptance phase of a forward single-leg jump for maximal distance were correlated with reach scores in the Y-Balance Test (YBT).

Study Design: Cross-sectional, Correlation.

Methods: Twenty-one female national-level netballers performed two and three successful trials on the YBT and forward single-leg jump-landing, respectively, with the non-dominant leg. A three-dimensional motion analysis system captured trunk and lower limb kinematics and ground reaction forces of the non-dominant leg during landing. Averages of peak knee flexion-extension, valgus-varus and internal-external rotation moments across jumps were calculated and correlations with peak directional reach scores were examined.

Results: A strong positive correlation existed between posteromedial reach with externally applied flexor moments (r = 0.56, p = ≤ 0.01). A moderate negative correlation existed between anterior reach distances with internal rotation moments (T_b = -0.32, p = 0.05). No correlation was found between valgus moments and YBT reaches.

Conclusions: The YBT shows potential to indicate externally applied flexion- and internal rotation moments during forward jump-landing on the non-dominant leg.

Level of Evidence: 3

Key Words: Jump landing, knee moments, Netball, movement system, Y-balance test

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INTRODUCTION

Single-leg jump-landing and sidestepping are common in team sports like basketball and netball and contribute to majority of non-contact ACL injuries.[1,2] These movements can result in large externally applied flexion, internal rotation and valgus moments at the knee joint that can strain the ACL if one displays poor neuromuscular control of the lower extremities during dynamic movements.[2,3] A cadaveric study using simulated jump landing found that the independent increment of internal rotation and valgus moments strained the ACL more than flexion moments, with the combination of all three straining the ACL the most.[4] A ruptured ACL can be detrimental to an athlete's sporting career as it takes six to twelve months of rehabilitation before return to sport.[1,5]

Females are four to six times more likely to sustain a non-contact ACL injury than males due to anatomical, hormonal and neuromuscular reasons, especially on their non-dominant leg.[1,2,6] Netball, commonly participated in by females, contributes to high rates of non-contact ACL injury mainly from jump landing and sidestepping.[7] In a study reviewing ACL injury occurrences, 21 out of 29 incidences occurred at initial foot contact during single-leg weight bearing activities.[8] Compared with double-leg landings, single-leg jump-landing was reported to result in greater knee valgus and reduced knee flexion angles, both contributors to non-contact ACL injuries.[9] The strict footwork rules that require netballers to stop within one and a half steps upon landing on one leg restricts attenuation time and increases the rate of loading on the knee compared with taking an additional step, thereby increasing the risk of lower limb injuries.[10,11] With over 20 million people around the world playing netball, regular screening for ACL injury risk is vital.[12]

The current gold standard for measuring knee joint moments during sporting movements involve the use of three-dimensional (3D) motion analysis systems; an expensive and time-consuming process that is unavailable to many. There is an increasing demand for simple-to-administer screening tools to replace sophisticated laboratory-based tests that are used to assess movement and by inference, sporting performance and injury risk. The Landing Error Scoring System and Tuck Jump Assessment assess knee flexion and valgus angles during double-legged landing to identify high-risk movement patterns that may injure the ACL.[13,14] These assessment tools require assessors to be proficient in using two-dimensional video cameras to film knee movements in the sagittal and frontal planes, and identify specific anatomical landmarks on the lower limbs to assess knee movements in a valid and repeatable manner. These requirements are not trivial and if not met may misrepresent injury risks. Furthermore, these tools do not assess knee rotation; one of three knee movements that can strain the ACL.[4] In another study, Myers and colleagues suggested that reach distances achieved by patients post-ACL reconstruction during the simple-to-administer Y-Balance Test (YBT) could periodically be monitored to assess their readiness to return-to-sport, as reach scores had moderate to strong correlations with peak isokinetic knee flexion-extension torques assessed using a laboratory-based dynamometer.[15] In the context of this study, it would be beneficial to identify a simple-to-administer screening tool that is representative of knee joint moments as assessed by a 3D motion analyses system during single-leg jump-landing.

The YBT is a simple-to-administer screening tool that assesses single-leg dynamic balance; a performance variable that associates with lower limb injury risk in athletes;[16] with high inter- (ICC: 0.99 – 1.00) and intra-rater reliabilities (ICC: 0.85 – 0.91).[17] Participants reach maximally in three directions (anterior, posteromedial and posterolateral) with each leg, and the distances achieved by the leg that reaches reflect the stance leg's functional strength and range of motion. Asymmetries in reach distances between legs have been linked with higher injury risk of the lower limbs although the types of injuries have not been specifically identified.[18,19] While one leg is reaching, especially in the anterior direction, the stance leg lowers the body like a single-leg squat movement.[20] The posteromedial and posterolateral reaches add variability to the knee loading patterns of the stance leg due to the different postural requirements to reach maximally.[21] Fox, Bonacci & Saunders reported that single-leg squat performances can be used to predict ACL injury risk during leap-landing in netball and should be administered as a regular screening tool for netballers.[22] Other researchers have, similarly, reported the

potential for the YBT to assess presence of specific lower limb injuries such as chronic ankle instability and strength imbalances between uninjured and ACL-reconstructed knees.[15,23] This raised the question: 'Can the YBT be used to indicate the risk of knee injuries by way of inference to knee moments during single-leg jump-landing?'.

The purpose of this study was to investigate whether knee moments during weight-acceptance phase of a forward single-leg jump for maximal distance were correlated with reach scores in the YBT. The presence of correlations may identify a screening tool that can be used to infer knee moments during single-leg jump-landing in netball and by extension, risk for non-contact ACL injury.

METHODS

Participants

Twenty-one female netballers (age: 23.2 ± 3.8 y; height: 1.73 ± 0.1 m; mass: 62.7 ± 5.1 kg) were recruited from the Singapore national team. All participants had no pre-existing lower limb injury and were proficient in reaching maximally on the YBT and performing single-leg jump-landings with their non-dominant leg. Participants were briefed that they would perform both the forward single-leg jump-landing for maximal distance and YBT with the order randomized to eliminate sequencing effects. For this correlational study, a minimum of 19 subjects were necessary to achieve a statistical power of 0.8 and $p < 0.05$. All procedures and forms were approved by the Singapore Sport Institute Institutional Review Board, and all participants provided their informed written consent before data was collected.

Instrumentation & Procedures

Participants were required to perform forward single-leg jumps for maximal distance (Figure 1), pushing off with their dominant leg and landing within the force platform with their non-dominant leg. Participants verbally indicated their preferred leg to push-off after performing a self-selected number of single-leg jumps. This leg was determined as the participants' dominant leg while the other leg was determined as their non-dominant leg for the single-leg jump-landings. Maximal jump distances were ascertained by asking participants to jump slightly further each time until they reached a distance that they could not improve on in two subsequent jumps during familiarization. A cone was used to demarcate each individual's starting position from the force platform based on the maximal jump distances achieved during familiarization. After familiarization, participants performed three test trials. A trial was considered successful when participants were able to maintain balance upon landing for at least 2 seconds and had their foot planted within the area of the force platform.[24] Thirty seconds of rest between trials was provided to prevent fatigue from affecting performance.[24]

Although the single-leg hop test, which involves a participant pushing off and landing on the same leg while trying to cover maximal distance, has been reported to reliably assess lower limb function and return-to-sport readiness post-ACL injury rehabilitation,[25–27] this study employed the forward single-leg jump-landing task whereby participants pushed off with their dominant leg and landed on their non-dominant leg. The single-leg jump-landing task was employed as it was deemed to be more representative of the movement performed during netball when the athlete pushes off one leg to catch or intercept a ball and lands on the other leg. As most non-contact ACL injuries occur during single-leg landing, assessment of the landing biomechanics would provide deeper insights into ACL injury risk compared to mere hop distance alone.[28]

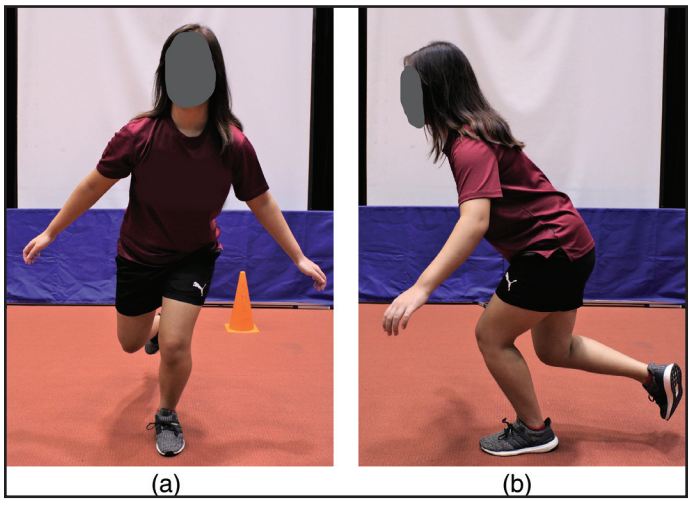

Figure 1. *Single-leg Jump Landing for Maximal Distance. a) Front View, (b) Side View*

Three-dimensional body kinematics during the forward single-leg jump-landing were captured using 12 Vicon 3D motion capture cameras (Vicon Industries Inc., Edgewood, NY, USA) at a sampling rate of 250 Hz. Ground reaction forces were captured synchronously at 1000 Hz using a 0.6 m by 0.9 m Kistler force platform (Kistler 9287CA Piezoelectric, Winterthur, Switzerland). Thirty-two retro-reflective markers, following the University of Western Australia (UWA) Lower Limb Model and Marker Set, were affixed to selected anatomical landmarks on each participant to facilitate 3D motion analysis.[29] Detailed description of data collection with this marker set set-up and calibration can be found from previous research by Besier and colleagues.[29]

Captured kinematic and kinetic data were analyzed in Vicon Nexus (version 2.3, Oxford Metric Group, Oxford, UK). Knee joint moments were calculated through inverse dynamics, using a custom Matlab (The Mathworks, Inc., Natick, MA) program during the weight-acceptance phases for the forward single-leg jump-landing task.[30] Output moments calculated were externally applied and as follows: flexion (+) /extension (-), valgus (+)/varus (-), internal rotation (+)/external rotation (-). Marker trajectories and force plate data were filtered with a low-pass (4th order, zero-lag) Butterworth digital filter at a cut-off frequency of 18 Hz after residual analysis and visual inspection of the data.[31] Peak values for externally applied knee flexor-, valgus- and internal rotation-moments were ascertained from each trial. Knee moments for all participants were normalized to height and mass, and presented as the mean of peaks from three successful trials.

Participants performed the YBT (Perform Better Inc, Cranston, RI) (Figure 2), a test of single-leg dynamic balance before or after performing the forward single-leg jump-landing. Participants were required to balance on their non-dominant leg, barefooted, and push the measurement blocks as far as possible with their dominant leg. The distances achieved by the dominant leg that is reaching were dependent on the functional strength and range of motion of the non-dominant leg in unilateral stance. A trial was voided and retaken if the participant (1) failed to maintain unilateral stance, (2) lifted the stance foot from the platform, (3) failed to maintain constant reach on the block while it was in motion, (4) used the block for support, or (5) lifted arm(s) off the hips.[19] Sequences of directions were randomized and counterbalanced to minimise sequencing effects. Four familiarization and two successful trials in all directions were required from all participants. Familiarization was necessary to achieve maximal reach distances and remove learning effects during test trials.[19] Length of the non-dominant leg was measured with participants in supine, from the anterior-superior iliac spine to lateral malleolus, using a standard cloth tape measure and used for normalisation of reach scores.[19] Maximal reach distances of the dominant leg; while balancing on the non-dominant leg; in all three directions were measured to the nearest half-centimetre. Reach distances were normalised to limb length and multiplied by 100 for representation as a percentage.

RESULTS

Data Analysis

Linear regressions were performed to assess the predictive relationship between YBT scores and 1) PKF-, 2) PKV-, and 3) PKIR- moments using StatsDirect Statistical Software (Version 3. 1. 20; StatsDirect Ltd., England, UK) with significance level set at $p \leq 0.05$. Simple linear regression with correlation was performed on parametric variables while the nonparametric linear regression was used for nonparametric variables, and presented as an equation with components b (median slope) and c (y-intercept). Correlation coefficients, r (Pearson's product-moment correlation) and T_b (Kendall's tau-b correlation coefficient), are presented for the parametric and nonparametric variables, respectively. The strength of association is as follows: $0.1 < r$

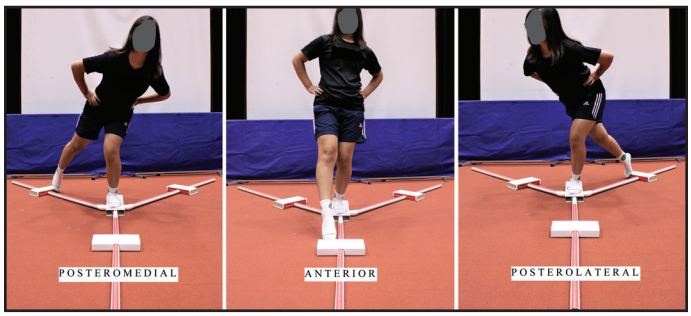

Figure 2. *Y-Balance Test Reach Directions.*

< 0.3 (small correlation), 0.3 < r < 0.5 (moderate correlation), and r > 0.5 (strong correlation). Means ± standard deviations are also presented for each variable. All variables were tested for normality and outliers. Variables were considered outliers if they exceeded >3 standard deviations from the mean.[32]

Descriptive Statistics

All variables were normally distributed with the exception of PKIR that was tested using the non-parametric alternative. Table 1 presents the normalized means for YBT scores and PKF-, PKV- and PKIR-moments during forward single-leg jump-landing. Posteromedial reach was a significant and strong predictor of PKF moments, m = 2.78, c = -1.01, p = <0.01, r = 0.56, with simple linear regression equation estimated as PKF = 2.78*(posteromedial) – 1.01 (Figure 3a). Anterior reach was a significant and moderate predictor of PKIR moments, b = -1, c = 0.84, p = 0.05 with the stepwise-regression equation estimated as PKIR = -1*(anterior) + 0.84, T_b = -0.32 (Figure 3b). There were no significant relationships between PKV moments and individual reach scores (0.15 < p < 0.92).

DISCUSSION

This exploratory study investigated whether scores on the YBT were correlated with PKF-, PKV- and PKIR moments during a forward single-leg jump-landing for maximal distance of the non-dominant leg. Moderate to strong correlations between YBT scores and knee moments during single-leg jump-landing would suggest that the simple-to-administer YBT could be used as a screening tool to infer knee moments during single-leg jump-landing. Coaches could administer this throughout a season and if changes in reach distances are observed from the baseline measurements, then that would warrant further investigations of the knee loading profiles of netballers via 3D motion analysis. From the results, a strong positive correlation was found between PKF moments and posteromedial reach distance; a moderate negative correlation was found between PKIR moments and anterior reach distance; whereas no association between PKV with any reach directions was found.

Table 1. *Normalized Results of Bilateral YBT Scores and Externally Applied Peak Knee Valgus (PKV), Flexor (PKF), and Internal Rotation (PKIR) Moments*

n = 21	Non-Dominant Leg		
YBT Score*	Mean	±	SD
Anterior [%]	62.6	±	5.1
Posterolateral [%]	98.1	±	8.3
Posteromedial [%]	104.7	±	6.9
PKV Moment [N/kg]†	0.94	±	0.56
PKF Moment [N/kg]†	1.91	±	0.34
PKIR Moment [N/kg]†	0.25	±	0.14

YBT= Y-Balance Test

* Normalized to leg length
† Normalized to height & body mass

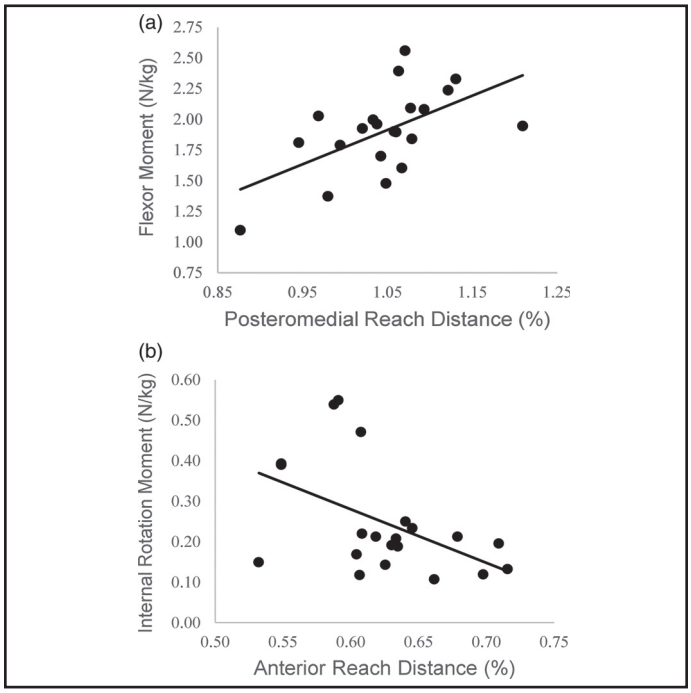

Figure 3. . *Moments and reach distances. a) flexor moment and posterormedial reach, b) internal rotation moment and anterior reach*

Higher PKF moment during single leg landing of the non-dominant leg was associated with increased posteromedial reach on the YBT. This finding is contradictory to previous studies that suggest further reaches in the YBT to be associated with decreased lower limb injury risk.[18,19] To better understand this relationship, the mechanics involved with performing the posteromedial reach has to be discussed. Greater knee flexion is required to reach further in all directions of the YBT.[33] As the body is lowered to reach further in the posteromedial direction, greater

eccentric contraction of the knee extensors/quadriceps, particularly the rectus femoris and vastus medialis, is required.[34] This results in higher internal extensor moments, or, by inference, externally applied flexor moments. Knee flexor strength has also been reported to positively correlate with posteromedial reach distance.[35] Maintaining postural stability during single-leg stance while reaching for distances using the contralateral leg requires co-contraction of both the knee flexors and extensors of the stance leg. How is this related to single-leg jump-landing mechanics?

Single-leg jump-landing requires co-contraction of the knee flexors and extensors in a similar manner as reaching for distances in the YBT for the maintenance of postural stability. To maintain balance when landing on one leg, the knee extensors and flexors contract eccentrically. These muscle activation patterns are similar when lowering oneself in unilateral stance to reach maximally with the contralateral leg during the YBT. Thus, internal knee extensor moments via quadriceps activation during single-leg jump-landing likely has implications on ACL strain.

Quadriceps activation during concentric knee extension causes anterior tibial translation, which can strain the ACL at knee flexion angles of less than 40°.[36] Podraza & White, however, reported that the accompaniment of increased internal knee extensor moments via eccentric quadriceps activation with increased knee flexion angles on landing was a strategy for better energy absorption at impact;[37] another study showed post-ACL-reconstruction participants displayed decreased peak knee internal extensor moment with reduced peak knee flexion angles in their affected knee compared to their contralateral uninjured knee.[28] Hewett and colleagues reported that healthy participants performing a drop vertical jump displayed a positive correlation between maximal knee flexion angle with peak vertical ground reaction force.[2] Prolonged energy absorption during landing reduces ACL strain as long as it is close to or within 40-50° knee flexion even if it results in higher internal knee extensor moments or peak vertical ground reaction force.[2,37–39]

Participants in this study landed with an average of 39° knee flexion that is close to the 40-50° range. Consequently, the positive correlation between the posteromedial reach distances on the YBT and externally applied PKF moments during single leg landing could represent the similar mechanics involved for the maintenance of postural stability. While speculative, posteromedial reach distances on the YBT could be used to infer PKF moments during single leg landing; however, the additional knowledge of an individual's landing knee flexion angle would paint a clearer picture as to whether these moments indicate a safer or more dangerous landing pattern.

Decreased PKIR moments were associated with further reach ability in the anterior direction. Further anterior reach requires greater vastus medialis activation and knee flexor strength of the stance leg.[35,40] While vastus medialis contraction coupled with the natural structural mechanism of a bending knee can internally rotate the tibia, sufficiently strong biceps femoris; a knee flexor; can counteract this internal rotation of the tibia, especially during landing. [41–43] Activation of the biceps femoris plays an important role in resisting knee internal rotation caused by large eccentric quadriceps contraction during weight-acceptance phase of single-leg jump-landing.[44,45] The neuromuscular parameters that enabled the participants to reach further anteriorly in the YBT without losing their stability could have also contributed in the decreased knee internal rotation moments during forward single-leg jump-landing. This is positive from an injury prevention perspective as the combination of both translation and rotation can significantly strain the ACL.[3] While further research comprising a larger number of participants should be performed to confirm this relationship between anterior reach and externally applied PKIR, the current findings suggest that the anterior reach on the YBT could potentially serve as a simple-to-administer proxy to performing 3D motion analyses during single-leg jump-landing to gain an insight on PKIR moments; a contributor to ACL strain.

No correlation was found between PKV moments and YBT scores. This finding may not be surprising considering that the forward single-leg jump-landing is predominantly a sagittal plane movement. Lateral and diagonal jump landings have been shown to increase frontal plane knee loading significantly more than forward jump landings.[46] Other studies have also found increased knee valgus angles and

moments when landing in the following conditions: 1) with perturbations during landing (e.g. avoiding a defender);[47] and 2) landing from high-velocity activities (e.g. running into a take-off before landing).[48] The current research does not comprise any of the abovementioned conditions; more relationships may surface if these were included.

Although the YBT has been linked with lower extremity injury risk, no research has investigated the relationship between scores on the YBT with knee moments during single-leg jump-landing to the researchers' knowledge.[18,19,49,50] It should be noted, though, that compensatory mechanisms following injuries, tightness and/or weakness of muscles and/or joint structures about the hip, knee and ankles may result in different movement patterns displayed in order to reach far.[15,23] Assessment of lower limb injury status and physical condition prior to testing on the YBT should be conducted to identify any pathomechanical confounders. If it is indeed possible to reach far with postures that put the joints at risk of injury, that would raise more questions as to what exactly the YBT assesses in terms of injury risk as well as the relationship between scores on the YBT and knee joint moments during single-leg jump-landing.

Limitations

Firstly, unlike single-leg jump-landing, the YBT does not involve rapid weight-acceptance. The single-leg jump-landing involves the ability to counteract externally applied moments while YBT execution involves the ability to generate internally applied moments. Secondly, the movement task in this study was limited to only the forward single leg jump for maximal distance, which is one of several movements performed within team sports that exacerbates non-contact ACL injury. Inclusion of more variations of such movements may provide more information of the risks of these other frequently performed moves. Lastly, the sample population in this study comprised national team netballers, which, while targeted, represents only a small population of team sport athletes and not ranging across various skill levels.

Future Research

Future research exploring performing the YBT reach as quickly as possible may better tease out the lower extremity's neuromuscular ability to decelerate a quickly lowering center of mass similar to a single-leg jump-landing, and potentially find additional correlations with the forward single-leg jump-landing. Further exploration of knee moments during lateral jump landings, with perturbations and at high velocities with the different YBT reach directions may provide a better idea of how PKV moments can be inferred through the YBT. In order to make more definitive conclusions from the findings from this study, further research should also be conducted on a larger number of participants in order to see if the results can be replicated to other sports and the general population. Additionally, a follow up on the incidences of non-contact ACL injuries post-test could provide a direct indication of the significance of the results from this study.

CONCLUSIONS

This study provides insights into the relationship between individual reach scores in the various directions of the YBT and externally applied knee moments (PKF, PKV and PKIR) of the non-dominant leg during the weight-acceptance phase of a forward single-leg jump-landing for maximal distance; a movement performed in netball and associated with non-contact ACL injuries. The positive correlation between posteromedial reach and PKF moments, and negative correlation between anterior reach and PKIR moments suggest that results on these simple-to-perform lower limb reach tests could potentially be used to infer knee moments that have been reported to contribute to non-contact ACL injuries during single-leg jump-landing on the non-dominant leg. Additional information on landing mechanics, such as maximal knee flexion angles, would provide further insight on whether increased knee flexor moments pose higher injury risks to the ACL during single-leg jump-landing. With its ease of use, the YBT can be implemented regularly to monitor an athletes' scores compared with his/her baseline measurements. Significant changes in the reach distances from baseline measurements could serve as 'alarms' for further investigations into the knee loading profiles of netballers during single leg landing via 3D motion analysis; the current gold standard but a time-consuming process; from a knee injury prevention perspective.

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