Original research

Comparison of landing knee valgus angle between female basketball and football athletes: Possible implications for anterior cruciate ligament and patellofemoral joint injury rates

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**A R T I C L E   I N F O**

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**A B S T R A C T**

Objective: To evaluate landing strategies of female football and basketball athletes with relation to possible injury mechanisms and disparity in injury.

Design: Descriptive laboratory study.

Participants: 52 female football players and 41 female basketball players.

Main outcome measures: Frontal plane projection angle (FPPA) was measured during the single leg land (SLL) and drop jump (DJ) screening tasks.

Results: $2 \times 2$ mixed factorial ANOVA showed significant main effects were observed for sport, whilst significant interaction effects were seen between sport and task. Females in both sports exhibited significantly greater FPPA values during the SLL task than the DJ task ($p < 0.001$). Basketball players demonstrated significantly greater FPPA values during SLL than football players ($p < 0.001$), whilst no differences were found between sports in the DJ task ($p = 0.328$).

Conclusion: Female basketball players display greater FPPA values during unilateral landing tasks than female football players which may reflect the greater ACL injury occurrence in this population. Injury prevention programs in these athletes should incorporate unilateral deceleration and landing tasks and should consider the specific injury mechanisms in each sport.

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1. Introduction

A high prevalence of anterior cruciate ligament (ACL) and patellofemoral joint (PFJ) injuries in football (soccer) and basketball players has been widely reported, with females typically at least two times more likely to suffer an ACL or PFJ injury than males (Agel, Olson, Dick, Arendt, Marshall, & Sikka, 2007; Boling, Padua, Marshall, Guskiewicz, Pyne, & Beutler, 2010; Deitch, Starkey, Walters, & Moseley, 2006). Additionally, ACL and PFJ injuries result in a considerable amount of time-loss from sport participation and increased risk of osteoarthritis (Lohmander, Englund, Dahl, & Roos, 2007; Starkey, 2000; Utting, Davies, & Newman, 2005).

Most ACL and PFJ injuries occur during non-contact running, jumping and landing tasks (Agel, Arendt, & Bershadsky, 2005; Boden, Dean, Feagin, & Garrett, 2000; Finestone, Milgrom, Evans, Yanovich, Constantine, & Moran, 2008; Hewett, Torg, & Boden, 2009; Krosshaug et al., 2007) with inadequate neuromuscular control of the lower limb during these manoeuvres considered a likely cause of injury (Dierks, Manal, Hamill, & Davis, 2008; Hewett et al., 2005; Myer, Ford, Foss et al., 2010; Souza & Powers, 2009). Decreased knee flexion and increased knee valgus, tibial rotation, hip abduction and internal rotation during landing and cutting manoeuvres are commonly seen during ACL injury episodes (Boden et al., 2000; Hewett et al., 2009; Koga et al., 2010; Krosshaug et al., 2007; Olsen, Myklebust, Engebretsen, & Bahr, 2004) and can increase strain placed on the ACL (Berns, Hull, & Patterson, 1992; Markolf, Burchfield, Shapiro, Shepard, Finerman, & Slauterbeck, 1995). However, only knee valgus angles, moments and differences between limbs during a drop jump task have been cited as a significant predictor of ACL injury (Hewett et al., 2005).

The same changes in lower limb posture can increase loads placed upon the PFJ with decreased knee flexion, increased hip internal rotation and increased knee valgus loads having been linked to development of patellofemoral pain syndrome (PFPS) (Boling, Padua, Marshall, Guskiewicz, Pyne, & Beutler, 2009; Lee, Anzel, Bennett, Pang, & Kim, 1994; Myer, Ford, Foss et al., 2010; Stefanshyn, Stergiou, Lun, Meeuwisse, & Worobets, 2006). The combination of these movements has been called dynamic knee
Recent evidence has shown that female collegiate basketball players (0.16 per 1000 exposures) suffer significantly greater non-contact ACL injury rates than female football players (0.13 per 1000 exposures) (Agel et al., 2005) which, considering the similar demands of both sports in terms of landing and changing direction, is unexpected. This was despite female footballers suffering significantly greater number of ACL injuries overall, and suggests that female basketball players may exhibit decreases in neuromuscular control which leaves them at greater risk of non-contact ACL injury. Differences in performance of screening tasks assessing lower limb neuromuscular control between the sports may provide some insight into why non-contact injury rates differ between the two sports. Despite this, there is limited literature where the performance of landing tasks among participants from football and basketball has been evaluated (Cowley, Ford, Myer, & Hewett, 2006). Cowley and colleagues (Cowley et al., 2006) found no difference in knee valgus angles and moments during bilateral drop jump and cutting tasks between football and basketball athletes. The authors did note significant asymmetry between limbs during the cutting task in all athletes and this requires further attention, as this asymmetry or limb dominance effect has been observed in limbs during the cutting task in all athletes and this requires further attention, as this asymmetry or limb dominance effect has been observed in all female athletes.

2. Materials and methods

2.1. Participants

Subjects included 52 national league division 2 female football players from 2 clubs and 41 national league division 1 basketball players from 3 clubs. Invitations were sent via e-mail to the coaches of each national league team in both sports to participate in pre-season testing; those who responded were eligible for inclusion in the study. All subjects were involved in the sports on a part-time basis and undertook training and competition a minimum of three times per week. All subjects had no history of ACL or other knee injury, no significant lower limb pathology (missing greater than 1 month of play) and had been injury free for at least 3 months prior to data collection. Written informed consent was obtained from all subjects, in the case of those between 16 and 18 years of age from a parent or guardian, and the project was approved by the University’s research and ethics committee.

2.2. Procedure

Markers were placed on the lower extremity of each subject as employed by Willson et al. (Willson et al., 2006). Markers were placed at the midpoint of the femoral condyles to approximate the centre of the knee joint, midpoint of the ankle malleoli for the centre of the ankle joint, and on the proximal thigh at the midpoint along a line from the anterior superior iliac spine to the knee marker (Fig. 1). Midpoints were determined using a standard tape measure and all markers were placed by the same experimenter. These markers were used in order for FPPA of the knee to be determined from digital images using Quintic software package (9.03 version 17), further information on this process can be found later in the method.

All subjects were asked to perform 2 common screening tasks: the single leg drop landing and bilateral drop jump. Each participant was given the opportunity to practice the tasks until they were comfortable, this was typically 1–2 practice trials. Subjects were then asked to perform 3 test trials for each task; the sequence of tasks was assigned in block order. Both legs were tested and analysed in each task.

2.2.1. Drop jump (DJ) task

Subjests stood with feet shoulder width apart on a 28 cm high step and were instructed to lean forward and drop from the step as vertically as possible, in an attempt to standardize landing height. Subjects were required to land at a mark 30 cm from the step and immediately perform a maximal vertical jump, finally landing back on the mark. There were no set instructions regarding arm movement, only for the subjects to perform the jump naturally. The initial landing from the step was used for analysis purposes (Herrington & Munro, 2010).

2.2.2. Single leg landing (SLL) task

Subjects dropped from a 28 cm step, again leaning forward and dropping as vertically as possible. Subjects were asked to take a unilateral stance on the contralateral limb and to step forward to drop onto the mark with the test limb ensuring the contralateral leg makes no contact with any other surface and balance is held for a minimum of 3 s (Herrington & Munro, 2010).

2.2.3. FPPA

A digital video camera (Sony Handycam DCR-HC37) was placed at a height of 50 cm, 3 m anterior to the subjects landing target. FPPA of the knee was measured as the angle subtended between the line from the markers on the proximal thigh to the knee joint and the line from the knee joint to the ankle, and was measured at the frame which corresponded with the point of maximum knee flexion (Willson et al., 2006), as shown in Fig. 1. Point of maximum knee flexion was determined as the lowest point of the movement. Each angle was digitised manually by the same experimenter using the Quintic software package. Positive FPPA values reflected knee valgus (Hewett et al., 2005) and women frequently demonstrate postures which contribute to dynamic knee valgus more than men and this is widely regarded as one of the primary reasons for the disparity in injury rates (Ferber, Davis, & Williams, 2003; Ford, Myer, & Hewett, 2003; Hewett, Myer, & Ford, 2004; Hewett et al., 2005; Zeller, McCrory, Kibler, & Uhl, 2003).

FPPA of the knee was measured as the angle subtended between the line from the anterior superior iliac spine to the knee and the line from the knee joint to the ankle, and was measured at the point corresponding with the frame of maximum knee flexion (Williams, 2006), as shown in Fig. 1. Point of maximum knee flexion was determined as the lowest point of the movement. Each angle was digitised manually by the same experimenter using the Quintic software package. Positive FPPA values reflected knee valgus (Hewett et al., 2005) and women frequently demonstrate postures which contribute to dynamic knee valgus more than men and this is widely regarded as one of the primary reasons for the disparity in injury rates (Ferber, Davis, & Williams, 2003; Ford, Myer, & Hewett, 2003; Hewett, Myer, & Ford, 2004; Hewett et al., 2005; Zeller, McCrory, Kibler, & Uhl, 2003).

The use of two-dimensional (2D) video analysis of dynamic knee valgus in the form of frontal plane projection angle (FPPA) has been suggested for identification of individuals suspected to be at high-risk of ACL or PFJ joint injury (Hewett et al., 2005; Willson & Davis, 2008). 2D FPPA has previously been shown to relate to three-dimensional (3D) measures of joint kinematics (Hewett et al., 2005; Willson & Davis, 2008) and to identify differences in dynamic knee valgus between men and women (Willson, Ireland, & Davis, 2006). PFPS patients and healthy controls (Willson & Davis, 2008) and basketball and volleyball players (Herrington, 2011). 2D FPPA may be useful in clinical and sports-team environments where 3D motion analysis is too-expensive, complex and time-consuming for use (Myer et al., 2011). If a simpler assessment tool which can be used in the field such as 2D FPPA can show differences in dynamic knee valgus between sports where injury rates differ, it may help to gain insight into why these injury rates vary and also screen for potential ACL and PFJ injury risk on a more widespread basis.

The aims of our study were 1) to evaluate whether FPPA differs between bilateral and unilateral landing tasks in female athletes; 2) to evaluate whether FPPA during landing tasks differs between females who participate in football and basketball and 3) to assess whether asymmetry between left and right limbs existed in these athletes. We hypothesise that; all athletes will demonstrate increased FPPA during unilateral landing tasks than bilateral landing tasks, female basketball players will exhibit increased FPPA during bilateral and unilateral landing tasks compared to female football players, and side-to-side differences in FPPA would exist in all female athletes.

2. Materials and methods

2.1. Participants

Subjects included 52 national league division 2 female football players from 2 clubs and 41 national league division 1 basketball
valgus, excursion of the knee towards the midline of the body so the knee marker was medial to a line between the ankle and thigh markers. Negative FPPA values reflected knee varus. The average FPPA from 3 trials was used for analysis. Between-session reliability of this method has been established using intraclass correlation coefficients and range from 0.72 to 0.91 (Munro, Herrington, & Carolan, 2012).

2.3. Statistical analyses

Corruption of the basketball video files meant that for the left leg of the drop jump task only 40 athletes were analysed and 37 were analysed for single leg. Means and SD's were calculated for all FPPA measures (dependent variable). The data was found to be normally distributed. 2 × 2 × 2 fixed factorial ANOVA (Factors/ independent variables: task, sport and limb) was used to assess main and interaction effects. T-tests with Bonferroni correction were carried out post-hoc, where any significant differences were found. P-value was set a-priori as \( p = 0.05 \), corrected \( p \)-value was set as \( p < 0.013 \). Effect sizes were determined using the Cohen \( d \) method (Thomas, Nelson, & Silverman, 2005), which defines 0.2, 0.5 and 0.8 as small, medium and large, respectively. Power analysis was conducted where significant differences were found between interaction effects (Faul, Erdfelder, Lang, & Buchner, 2007).

3. Results

Table 1 outlines the participant demographics. Basketball players were significantly older (\( p = 0.003 \)), taller (\( p < 0.001 \)) and heavier (\( p < 0.001 \)) than football players. However, there was no differences in body mass index (BMI) between football and basketball players (\( p = 0.504 \)). Means and standard deviations for FPPA values during the SLL and DJ tasks for all athletes are shown in Table 2. Factorial ANOVA showed significant main effect for task only (\( p < 0.001 \)), no main effects were observed between limbs (\( p = 0.166 \)) or sport (\( p = 0.17 \)). Interaction effects were shown between sport and task (\( p = 0.003 \)). No interaction effects between sport and limb (\( p = 0.133 \)) or task and limb (\( p = 0.994 \)).

Table 3 outlines the results of post-hoc t-tests. Dependent t-tests showed that SLL FPPA values were higher than DJ in both football (\( p < 0.001 \), ES = 0.52, power 0.98) and basketball (\( p < 0.001 \), ES = 0.98, power 0.99). Independent t-tests also showed that basketball players exhibited significantly greater FPPA values than football players during the SLL task (\( p < 0.001 \), ES = 0.63, power 0.84) but no differences were found in the DJ task (\( p = 0.328 \), ES = 0.20).

4. Discussion

Previous research has suggested that a relationship exists between poor neuromuscular control and ACL and PFJ injury.

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Table 1

<table>
<thead>
<tr>
<th></th>
<th>Basketball</th>
<th>Soccer</th>
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<tbody>
<tr>
<td>Age (years)*</td>
<td>21.9 ± 3.7</td>
<td>19.3 ± 4</td>
</tr>
<tr>
<td>Height (m)*</td>
<td>1.71 ± 0.6</td>
<td>1.61 ± 0.6</td>
</tr>
<tr>
<td>Weight (kg)*</td>
<td>69.3 ± 11.1</td>
<td>60 ± 8.5</td>
</tr>
<tr>
<td>BMI</td>
<td>23.6 ± 2.9</td>
<td>23.1 ± 5.8</td>
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*significant difference at \( p < 0.05 \).

Table 2

<table>
<thead>
<tr>
<th></th>
<th>Basketball</th>
<th>Soccer</th>
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</thead>
<tbody>
<tr>
<td>Single leg landing (°)</td>
<td>Drop jump (°)</td>
<td>Single leg landing (°)</td>
</tr>
<tr>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Mean</td>
<td>9.67</td>
<td>9.85</td>
</tr>
<tr>
<td>SD</td>
<td>5.35</td>
<td>5.67</td>
</tr>
</tbody>
</table>

* main effect of task significant for both sports.

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Fig. 1. Frontal plane projection angle during (a) drop jump and (b) single leg landing tasks.
(Boling et al., 2009; Dierks et al., 2008; Hewett et al., 2005; Myer, Ford, Foss et al., 2010; Souza & Powers, 2009) and that females who participate in basketball are at greater risk of non-contact ACL injury than those who play football (Agel et al., 2005). Our study aimed to assess whether differences in landing strategies were present between females who play football and basketball, whether these athletes exhibit greater FPPA during unilateral tasks compared to bilateral and whether any differences existed between left and right limbs.

The results supported our first hypothesis and showed that all athletes exhibited higher FPPA values during the SLL task than the DJ task. This is likely due to the increased demand to decelerate landing forces during the SLL task. Ground reaction forces exhibited by individuals during DJ and SLL tasks are often similar (Pappas, Hagins, Sheikhzadeh, Nordin, & Rose, 2007) effectively meaning that forces experienced by the limbs are doubled during a unilateral task. Our findings are in agreement with those of Pappas et al. (Pappas et al., 2007) who found that male and female recreational athletes demonstrated increased knee valgus during a unilateral landing compared to bilateral landing. Pappas and colleagues (Pappas et al., 2007) also noted that during unilateral landings the subjects tended to exhibit greater total hip adduction excursion of 17° compared to only 2.7° during bilateral landing. It is likely that FPPA in these athletes would have been greater during the unilateral task and therefore would confirm our findings. In contrast, Herrington (Herrington, 2011) found that basketball players exhibited increased FPPA during a DJ task than SLL. The SLL values in our study and the Herrington study are very similar, whereas the DJ values in the Herrington study were approximately 15–20° greater. This is surprising considering a similar population of division 1 female basketball players were studied and may be a result of the lower participant numbers and being from a single team in the Herrington (Herrington, 2011) study with our results being more representative of the elite female basketball population. Unilateral landings are more common ACL injury mechanisms than bilateral landings across female sports (Faude, Junge, Kindermann, & Dvorak, 2005; Myklebust, Maehlum, Holm, & Bahr, 1998; Powell & Barber-Foss, 2000). However, only neuromuscular control during bilateral drop jumps has been prospectively investigated and linked to ACL and PEl injury (Boling et al., 2009; Hewett et al., 2005; Myer, Ford, Foss et al., 2010) and therefore the potential for unilateral landing tasks to predict potential ACL and PEl injury risk should be prospectively investigated as they may be more sensitive to future injury risk.

Due to female basketball players suffering a greater number of non-contact ACL injuries than their football counterparts (Agel et al., 2005) we hypothesised that female basketball players would exhibit greater FPPA than football players during all landing tasks. This hypothesis was partially supported: basketball players had greater FPPA values than football players during the SLL task but not during the DJ task. The difference in FPPA for the DJ between basketball and soccer was within standard error of measurement (SEM) values previously reported, whereas those for the SLL task were greater than SEM values previously noted (Munro et al., 2012). As mentioned earlier, most ACL injuries in basketball and football occur during unilateral tasks so that no differences were apparent during the bilateral DJ task is not surprising. The fact that the basketball players exhibited greater FPPA during the SLL task may explain in part why they suffer significantly more ACL injuries than their football counterparts. Female basketball and basketball athletes have been shown to demonstrate similar knee valgus loads during bilateral DJ and landing and cutting tasks (Cowley et al., 2006). Whilst the cutting task was aimed at replicating ACL injury mechanism, it was still bilateral in nature and may not have been sufficiently different to the DJ task to show any differences between sports. Furthermore, Cowley et al. (Cowley et al., 2006) only observed changes in knee valgus load, which means that frontal plane motion at the hip and transverse motion at the hip and knee, which play a part in increasing ACL and PEl loads, are not accounted for and they may further explain the differences in injury rates observed between the sports and also the increased FPPA demonstrated by basketball players in the unilateral task in the current study.

Our final hypothesis stated that asymmetry may be present between left and right limbs as asymmetry has been suggested as an important factor for determining injury risk and differences in neuromuscular control between limbs has been shown (Cowley et al., 2006; Ford et al., 2003; Herrington, 2011; Hewett et al., 2005). Research has tended to focus on differences between dominant and non-dominant limbs or simply tested the dominant limb (Barber-Westin, Galloway, Noyes, Corbett, & Walsh, 2005; Borotikar, Newcomer, Koppes, & McLean, 2008; Brown, Palmieri-Smith, & McLean, 2009; Cowley et al., 2006; Ford et al., 2003; Hewett et al., 2004; Pollard, Sigward, & Powers, 2010). However there is no evidence that limb dominance affects injury rates (Faude et al., 2005; Hewett et al., 2005; Le Gall, Carling, & Reilly, 2008) and differences in neuromuscular control observed between limbs are inconsistent (Barber-Westin et al., 2005; Borotikar et al., 2008; Brown et al., 2009; Ford et al., 2003; Hewett et al., 2004). Limb dominance is commonly assessed by asking with which foot an athlete preferentially kicks a ball (Hewett et al., 2005). While this method may be applicable to kicking sports such as football, it may not be suitable for sports which are dominated by jumping and landing movements such as basketball, where the preferred take-off or landing leg may be more applicable. Our focus was on left and right limbs and our results showed no main affect of limb or interaction affects between limb and task or sport on FPPA. The difference between left and right limbs in each task was within SEM values (Munro et al., 2012), further supporting these findings. This contrasts with previous research by Herrington (Herrington, 2011), who found basketball players to have significantly higher FPPA on their right leg during a DJ task but no differences in the SLL task. Additionally, Cowley et al. (Cowley et al., 2006) found that valgus moments were on the dominant limb during cutting. Further prospective research is needed to ascertain whether limb dominance or left to right asymmetry truly exists and the potential affects on ACL injury risk.

There may be other factors which affect non-contact ACL injury rates between the two sports. We observed that the basketball players in this study were older, taller and heavier than the football players. Basketball players tend to be taller and heavier due to the nature of the two sports and it is not something we attempted to control. It is currently unclear what affect height and weight have on ACL injury rates and lower limb neuromuscular control. Increased tibia length and body mass have recently been linked to increased knee valgus moments during a drop jump (Myer, Ford, Khoury, Succeop, & Hewett, 2010). However, they were part of a prediction model which

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### Table 3

Frontal plane projection angle means and standard deviations (SD) during single leg landing and drop jump tasks.

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<thead>
<tr>
<th></th>
<th>Basketball</th>
<th>Soccer</th>
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<tbody>
<tr>
<td></td>
<td>Single leg landing (°)</td>
<td>Drop jump (°)</td>
</tr>
<tr>
<td>Mean</td>
<td>9.79&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.57</td>
</tr>
<tr>
<td>SD</td>
<td>5.49</td>
<td>9.75</td>
</tr>
</tbody>
</table>

<sup>a</sup> SLL sig greater than DJ in both sports.

<sup>b</sup> SLL sig greater in basketball than soccer.
also included several other variables (knee valgus motion, knee flexion ROM and quadriceps to hamstrings strength ratio) and the model was unable to predict all cases of high knee valgus moments. In addition, previous work by Herrington (2011) established differences between volleyball and basketball players in 2D FPPA during D) and SLL tasks, despite the athletes being of similar height and weight. This suggests the differences seen are due to the demands of the sports and not a product or height or weight. BMI, which is a product of height and weight, has previously been suggested as a risk factor for non-contact ACL injury (Uhorchak, Scoville, Williams, Arciero, St Pierre, & Taylor, 2003) and despite basketball players in this study being taller and heavier than football players there were no differences in BMI between the sports. Furthermore, Beutler and colleagues (Beutler, de la Motte, Marshall, Padua, & Boden, 2009) found that anthropometric factors, including BMI did not predict landing movement patterns. Despite the different ages seen between the two sports, we do not believe this would have affected our results. All athletes tested were over 16 years of age and would therefore be classed as late or postpubertal by which time any changes in landing strategies normally seen during maturation would already have taken place (Ford, Shapiro, Myer, Van den Bogert, & Hewett, 2010; Hewett et al., 2004). As a result we do not feel that the differences in age or anthropometrics in the current study would affect dynamic knee valgus values observed.

In this study 2D FPPA was able to detect differences in landing strategies between female football and basketball players which were greater than SEM values previously reported (Munro et al., 2012). 2D FPPA has also been shown to correlate to 3D measures of hip adduction, knee valgus and external rotation (Hewett et al., 2005; Willson & Davis, 2008) albeit the nature of 2D analysis means that it is less sensitive to subtle joint movements such as knee valgus and is influenced by movements at the hip and ankle. That being said, 2D FPPA incorporates hip, knee and ankle frontal and transverse plane movements, all of which have been shown to affect the loads upon the ACL and PFJ relate to mechanism of ACL injury more so than knee valgus alone (Berns et al., 1992; Hewett et al., 2009; Krosshaug et al., 2007; Tiberio, 1987). As a result, 2D analysis may be useful for screening for high-risk athletes.

Our study has several limitations. Firstly, while 2D FPPA has been shown to correlate to 3D variables and therefore may help to identify high-risk athletes this link has yet to be confirmed. Secondly, the results on the elite athletes in this study may not apply to recreational or younger athletes with different levels of training and experience.

5. Conclusion

The fact that basketball players demonstrated greater FPPA than football players in the unilateral landing task may reflect the higher injury rate in this sport. Athletes from both sports exhibited greater FPPA during unilaterally landing tasks and this should be taken into account when designing interventions for these athletes. Performance during unilaterally landing tasks should be prospectively evaluated as an injury risk prediction tool as it may be more sensitive than bilateral landing tasks previously suggested. Injury prevention programs should include unilateral jumping, landing and decelerating techniques and consider the mechanisms of injury in each sport.

Conflict of interest

None declared.

Ethical approval

All participants gave written informed consent to participate and the research was approved by the University of Salford Research and Ethics Committee.

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References


