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Enhancing Performance & Preventing Injuries in Team Sport Players

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Jump landing characteristics predict lower extremity injuries in indoor team sports

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The aim of this study is to investigate the predictive value of landing stability and technique to get insight in risk factors for ankle and knee injuries in indoor team sport players. Seventy-five male and female basketball, volleyball or korfball players were screened by measuring landing stability after a single leg jump-landing and landing technique during a repeated counter movement jump by detailed 3-dimensional kinematics and kinetics. During the season 11 acute ankle injuries were reported along with 6 acute and 7 overuse knee injuries by the teams' physical therapist. Logistic regression analysis showed less landing stability in forward and diagonal jump direction (OR 1.01 – 1.10, $p \leq 0.05$) in players who sustained an acute ankle injury. Furthermore landing technique with a greater ankle dorsiflexion moment increased the risk for acute ankle injury (OR 2.16, $p \leq 0.05$). A smaller knee flexion moment and greater vertical ground reaction force increased the risk of an overuse knee injury (OR 0.29 and 1.13 respectively, $p \leq 0.05$). Less one-legged landing stability and suboptimal landing technique was shown in players sustaining an acute ankle and overuse knee injury compared to healthy players. Determining both landing stability and technique may further guide injury prevention programs.

Keywords: overuse, acute, knee, ankle, stability, biomechanics

INTRODUCTION

In team sports like basketball, volleyball and korfball the loads at the lower extremities are high due to the repeated jumps, sudden accelerations, decelerations and directional changes [23,36,38]. On average, a basketball player performs 70 jumps in a game and volleyball players jump approximately 60 times during one hour of game play [29,32]. In these sports lower extremity injuries account for up to 60% of all injuries [3,16]. Ankle and knee injuries are the most common [3,16,20]. Studies up until now mainly investigated acute injury risk factors, although overuse injuries account for about 14% of the injuries [30,51].

Currently, 45-86% of the acute ankle and knee injuries in basketball and volleyball occur after landing from a jump [5,6,34]. For ankle injuries landing stability is used to determine risk factors. A higher variation in postural sway when standing on one leg was shown to be a risk factor for an ankle injury [33,44]. In these studies postural sway was determined in a static condition, while the conditions in which players get injured are dynamic [19]. Landing stability measured with the dynamic postural stability index (DPSI) shows to be more accurate and reliable compared to static measurements [21,48,49], making this a potentially more valid method for landing stability. Furthermore, the DPSI is able to distinguish between copers and non-copers with ankle instability after an ankle injury [46]. However this tool has not been used prospectively to examine ankle injury risk.

In jump landing 50% of the acute knee injuries result from landing on another person's foot and the other 50% from suboptimal landing [5,6,34]. This indicates the importance of a proper landing technique. Suboptimal landing technique increases the load on the lower extremities. For example as a result of increased vertical ground reaction force (vGRF), knee valgus moment, less joint flexion and less joint range of motion (RoM) resulting in a stiff landing strategy [1,9,10,27,37]. On the contrary, an optimal landing technique involves soft landing with active muscular control, where energy absorption is more efficient, reducing the load at the lower extremities [1,31]. To get insight in landing technique, the drop vertical jump [8,11] and the tuck jump [27,35] are regularly analyzed. In a prospective study, female players that sustained an anterior cruciate ligament (ACL) injury showed suboptimal lower extremity biomechanics in terms of more knee valgus and peak vGRF when landing from a drop vertical jump [27]. In addition, players developing an overuse knee injury showed smaller knee extension moments and less ankle and knee flexion angles during jump landing [7,11]. Therefore, players with suboptimal jump landing technique have greater risk for acute as well as for overuse knee injuries [7,11,27]. Aforementioned studies focusing on landing technique all included one single jump without repetition. A recent report proposed a protocol with repeated jumping to assess landing technique [35], being more sport-specific. Unfortunately this is also not yet prospectively examined.

When landing, ankle stability is important as well. Up to 45% of landings in volleyball are one-legged with actions like blocking in which landing stability is assumed to be critical [42]. Although research on the role of stability in jump landing is limited, landing patterns are indeed suboptimal, i.e. less knee flexion and less ankle dorsiflexion, in players with chronic ankle instability (CAI) in comparison to without CAI [24,41]. In addition, in jump landing a smaller ankle RoM is associated with suboptimal landing technique [10,24,41]. These studies indicate similarities in ankle and knee injury risk factors, and the role of stability in landing technique.

Up until now there have been no studies that analyzed both landing technique and landing stability in a prospective study design. In addition, landing technique was mainly analyzed from a single jump and not during repeated jumping. Mainly acute injury risk is investigated, while also overuse injury occurrences appear to be important. Both landing technique and ankle stability may give more insight in risk factors for sustaining ankle and knee injuries. Therefore the aim of this study is to investigate the predictive value of dynamic stability and repeated jump landing to get more insight in risk factors for ankle and knee injuries in indoor team sport players.

METHODS

Subjects

A total of 75 (male n=49, female n=26) elite or sub-elite level basketball, volleyball or korfball players participated in this study (age 21.9 ± 3.5 yr, body mass 82.5 ± 14.3 kg, length 187.6 ± 11.5 cm, BMI 23.3 ± 2.6 kg·m^2). All players signed an informed consent after being fully informed about the study. Institutional approval was received from the medical ethical committee of the University Medical Center Groningen, the Netherlands conform the declaration of Helsinki and in accordance with the ethical standards of the IJSM [26]. This study is part of a larger monitoring study, known as the Groningen Monitoring Athletic Performance Study (Groningen MAPS).

Procedures

Prior to testing, general anthropometrics were measured. At the start of the season all players first performed a single leg jump landing (SLJ) followed by a repeated counter movement jump (rCMJ) to measure landing stability and technique, respectively. These tests were performed at the SportsFieldLab Groningen of the Hanze University of Applied Sciences, School of Sportstudies, Groningen,The

Netherlands. At time of testing, players had no current injury, wore no ankle or knee brace and were free of injury for at least 2 months. Before jumping the players performed a 5-minute warm-up on a cycle ergometer (Excalibur Sport, Lode B.V., Groningen, The Netherlands) where they kept the pedal frequency between 80 and 90 RPM at a power of 70 to 100 watts. After the warm-up, players maximal reaching height was determined and they performed 3 maximal jumps from stance of which the highest jump was taken as the maximal jump height. The maximal vertical jump height was determined by taking the difference between maximal jump height and maximal reaching height. During the season injuries were registered according to the recommendations of Fuller et al. [22]. At the end of the season the predictive value of baseline measurements for ankle and knee injury occurrence was determined.

Instrumentation

Kinematic data were collected using an 8-camera motion analysis system at 200 Hz (Vicon Motion Analysis System Inc., Oxford, UK). The motion analysis system was calibrated prior to each session according to guidelines from the manufacturer. For the collection of the ground reaction force data two force plates (Bertec, Corporation, Columbus, OH) collecting data at 1000 Hz were used. Twenty-one reflective markers of 14 mm in diameter were placed according to the Vicon Plug-in-Gait marker set and model to generate the kinematic and kinetic data. In addition, trunk markers were added to the sternum, clavicle, C7, T10 and right scapula. All subjects wore spandex shorts and shirts (for females) and their own athletic shoes during the test session.

Landing stability- Single Leg Jump-Landing

To determine landing stability the SLJ protocol was used as described by Wikstrom et al. [48]. Players jumped from diagonal (45°), lateral (180°) and forward (90°) direction to the center of the force plate, which was placed at 70cm distance from the start of the jump (Figure 1). Players were instructed to jump to a rope, placed at 50% of their maximal vertical jump height, before landing on one leg. In contrast to the protocol of Wikstrom et al. [48] players landed on the leg most nearby the force plate since this is more specific for ball team sports players [42]. The player practiced until a successful jump met the following criteria; jumping up with hands at the height of the rope, landing on one leg, and keeping balance for three seconds with hands on the hips. A trial was discarded if balance was kept with touching or leaning on the other leg or the ground. After practicing (mean number of practice trials: forward 1.57 ± 0.79, diagonal 1.69 ± 0.97, lateral 1.57 ± 0.75), three successful jumps were counted. If the jump did not meet the before mentioned criteria the trial was discarded and repeated.

The method of Wikstrom et al. [47] was used to calculate medial/lateral stability index (MLSI), anterior/posterior stability index (APSI), vertical stability index (VSI) and an overall DPSI. Each dynamic stability index (DSI) was calculated as an average of landing on the left and right leg from one jump direction; diagonal, lateral or forward, where a higher stability index represents less stability.

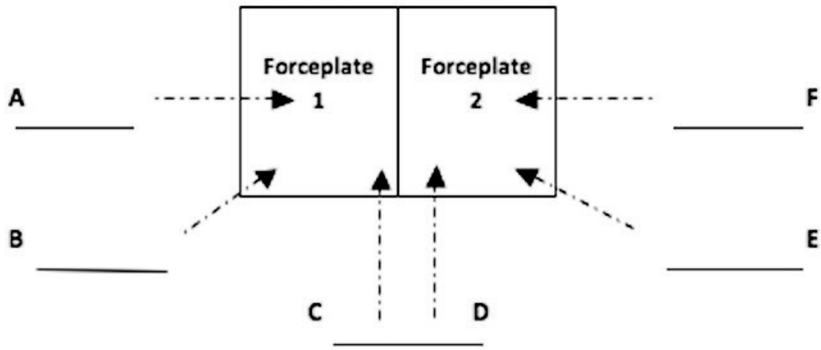

Figure 1. Starting positions single leg jump landing test modified from Wikstrom et al. [48]. All positions were placed 70 cm from the center of the force plate. Jumps on force plate 1 were landed on the right leg (A,B,C) and jumps on force plate 2 were landed on the left leg (D,E,F) both on the center of the force plate.

Landing technique – Repeated Counter Movement Jump

To examine landing technique, players performed a rCMJ, which consisted of 10 series of three maximal CMJs, with a rest period of 20 seconds between series. Trials of three consecutive jumps were practiced until successful landing on the force plates (mean number of practice trials: 1.18 ± 0.43).

Injury registration

Players completed an injury history questionnaire at baseline, which included questions about the location, severity and type of previous injuries over a whole lifetime for severe injuries resulting in time-loss of a month or longer. During the season injuries were reported by the team's physical therapist. The reporting system was based on the recommendations by Fuller et al. [22]. An injury was defined as "any physical complaint sustained by a player that results from a match of training, irrespective of the need for medical attention or time loss from sports activities" [22]. In this study only the medical attention injuries were registered by the physical therapist. An acute injury was defined as "an injury resulting from a specific, identifiable event" [22]. The definition of an overuse injury was "an injury caused by repeated micro-trauma without a single, identifiable event responsible for the injury" [22].

Statistical analysis

Customized software using Matlab 6.1 (The MathWorks Inc., Natick, MA) was used to calculate the DSI and hip, knee and ankle joint kinematics and kinetics at the time of peak vGRF. Force plate and kinetic data were filtered using a fourth-order zero-lag Butterworth low-pass filter at 10 Hz.

For all outcome variables of the SLJ and rCMJ means and standard deviations were calculated. The outcome variables for landing stability from the SLJ were MLSI, APSI, VSI and DPSI. The outcome variables for landing technique of the rCMJ were peak vGRF($N \cdot kg^{-1}$) sagittal hip, knee and ankle angles (°) and moments ($Nm \cdot kg^{-1}$), RoM (°) and frontal knee moments ($Nm \cdot kg^{-1}$). RoM is expressed as the value at peak vGRF minus the value at initial contact. The moments are expressed as external moments. The values were calculated for the dominant leg, which was determined by asking the players which leg they prefer kicking a ball with [11,18,39]. Since there were no significant differences found in any of the kinematic and kinetic variables (p >0.05) between the 10 series of three jumps, the average of the 10 series of three jumps was taken for kinematic and kinetic variables.

Since no overuse ankle injuries were reported, the injuries were divided in ankle and knee (acute and overuse) injuries. The acute and overuse medical attention injuries were used for analysis in this study. To determine the differences between players with and without an ankle injury an independent t-test was used for each variable. To compare variables between players with an acute, an overuse or no knee injury an one-way ANOVA was used, with a Bonferroni post-hoc test. Cohen's d effect sizes (ES) were calculated to determine the magnitude of the differences between groups. Magnitude of the ES was interpreted as small (d <0.2), moderate ($0.2 \leq d < 0.8$) or large ($d \geq 0.8$) [13].

To determine the predictive value of the dependent variables for both ankle and knee injuries, binomial and multinomial logistic regression was used. The dependent variables were the injuries during the season; an ankle injury, acute knee injury or overuse knee injury. Ankle injuries were predicted with binomial logistic regression because there were only two groups defined: with and without an ankle injury. For knee injuries multinomial logistic regression was used for three groups: no injury, acute injury and overuse injury. Odds ratios (OR) and 95% confidence intervals (95%CIs) were calculated for ankle and knee injuries. IBM SPSS Statistics 20 for Windows was used for all data analysis. The level of statistical significance was set at $p \leq 0.05$ a priori.

RESULTS

During the season 11 (14.7%) players sustained an acute ankle injury and no overuse ankle injuries were registered. Thirteen (17.3%) players had a knee injury; 6 acute and 7 overuse.

Landing stability - SLJ

Unstable landing increased ankle injury risk. Forward VSI and DPSI and diagonal APSI, VSI and DPSI were significantly higher at baseline, with large ES (ES=0.8 – 1.0), for players sustaining an ankle injury during the season ($p \leq 0.05$, Table 1). The binomial logistic regression showed that a higher DSI, representing instability, in the forward and diagonal jump direction increased the risk of an ankle injury ($p \leq 0.05$).

Landing technique - rCMJ

Landing technique after repeated jumping (rCMJ) was prospectively related to acute ankle injuries. A landing technique with a greater ankle dorsiflexion moment was shown in players sustaining an acute ankle injury ($p \leq 0.05$, ES=0.7,Table 2). Binomial regression showed a greater ankle dorsiflexion moment increased the risk of an ankle injury ($p \leq 0.05$).

Besides, landing technique during repeated jumps (rCMJ) was also prospectively related to overuse knee injuries. A landing with a smaller knee flexion moment and greater vGRF was shown in players sustaining an overuse knee injury ($p \leq 0.05$, ES=0.3 and ES=0.9 respectively, Table 3). Multinomial regression showed that a smaller knee flexion moment and a greater vGRF increased the risk of an overuse knee injury ($p \leq 0.05$).

Table 1. Descriptives (mean±SD), Cohen's effect size (ES) and Binomial Logistic Regression analysis for the dynamic postural stability score of the Single Leg Jump (SLJ). Odds Ratio (OR) and 95% Confidence Intervals (CI) for **acute ankle injuries**.

	No injury (N=64)			**Ankle injury** (N=11)					
	Mean	±	**SD**	**Mean**	±	**SD**	**ES**	**OR**	**CI 95%**
Forward MLSI	0.03	±	0.01	0.04	±	0.01	-1.0		
Forward APSI	0.10	±	0.01	0.10	±	0.01	0.0		
Forward VSI	0.34	±	0.05	0.38	±	0.06*[a]	-0.8	1.01*	1.00-1.03
Forward DPSI	0.35	±	0.05	0.39	±	0.06*[a]	-0.8	1.02*	1.00-1.03
Diagonal MLSI	0.08	±	0.01	0.08	±	0.01	0.0		
Diagonal APSI	0.07	±	0.01	0.08	±	0.01*[a]	-1.0	1.10*	1.02-1.19
Diagonal VSI	0.33	±	0.05	0.37	±	0.05*[a]	-0.8	1.02*	1.00-1.04
Diagonal DPSI	0.35	±	0.05	0.39	±	0.05*[a]	-0.8	1.02*	1.00-1.04
Lateral MLSI	0.10	±	0.01	0.10	±	0.01	0.0		
Lateral APSI	0.05	±	0.01	0.06	±	0.02	-0.8		
Lateral VSI	0.32	±	0.05	0.34	±	0.06	-0.4		
Lateral DPSI	0.20	±	0.04	0.22	±	0.04	-0.5		

*p ≤0.05, a; values significantly different from players with no injury; MLSI = Medial/Lateral Stability Index, APSI = Anterior/Posterior Stability Index; VSI = Vertical Stability Index; DPSI = Dynamic Postural Stability Index

Table 2. Descriptives (mean ± SD), Cohen's effect size (ES) and Binomial Logistic Regression analysis for the dominant leg kinematic and kinetic variables of the repeated Counter Movement Jump (rCMJ). Odds Ratio (OR) and 95% Confidence Intervals (CI) for **acute ankle injuries**.

	No Injury (N=64)			Ankle injury (N=11)					
	Mean	±	SD	Mean	±	SD	ES	OR	CI 95%
Hip Flexion Angle (°)	25.43	±	10.64	27.45	±	10.5	-0.2		
Knee Flexion Angle (°)	-53.86	±	9.86	-53.08	±	10.5	-0.1		
Ankle Dorsiflexion Angle (°)	12.19	±	5.96	10.13	±	6.12	0.3		
Hip RoM (°)	10.11	±	11.16	9.53	±	13.04	0.1		
Knee RoM (°)	-32.44	±	7.17	-31.62	±	4.97	-0.1		
Ankle RoM (°)	42.99	±	7.42	41.16	±	6.93	0.2		
Knee Flexion Moment (Nm·kg^{-1})	-1.23	±	0.96	-1.45	±	0.65	0.2		
Ankle Dorsiflexion Moment (Nm·kg^{-1})	2.40	±	0.81	3.04	±	1.10*a	-0.7	2.16*	1.06 - 4.40
Varus-Valgus Moment (Nm·kg^{-1})	-0.01	±	0.36	0.03	±	0.38	-0.1		
vGRF (Nm·kg^{-1})	21.70	±	6.84	23.61	±	6.02	-0.3		

*$p \leq 0.05$, RoM = range of motion, vGRF = vertical Ground Reaction Force, a; values significantly different from players with no ankle injury

Table 3. Descriptives (mean ± SD), Cohen's effect size (ES) and Multinomial Logistic Regression analysis for the dominant leg kinematic and kinetic variables of the repeated Counter Movement Jump (rCMJ). Odds Ratio (OR) and 95% Confidence Intervals (CI) for **knee injuries**.

	No Injury (N=62)			Acute Knee injury (N=6)				Overuse Knee Injury (N=7)					
	Mean	**±**	**SD**	**Mean**	**±**	**SD**	**ES**	**Mean**	**±**	**SD**	**ES**	**OR**	**CI 95%**
Hip Flexion Angle (°)	25.53	±	10.42	29.82	±	16.50	-0.4	23.93	±	5.35	0.2		
Knee Flexion Angle (°)	-53.41	±	9.64	-57.54	±	8.17	0.4	-53.32	±	8.83	0.0		
Ankle Dorsiflexion Angle (°)	11.79	±	5.67	13.65	±	2.98	-0.3	11.10	±	10.09	0.1		
Hip RoM (°)	9.87	±	10.96	10.69	±	17.91	-0.1	10.73	±	10.02	-0.1		
Knee RoM (°)	-32.44	±	6.83	-32.89	±	6.68	0.1	-30.74	±	8.12	-0.2		
Ankle RoM (°)	43.21	±	7.48	40.31	±	5.54	0.4	40.43	±	7.44	0.4		
Knee Flexion Moment (Nm·kg^{-1})	-1.21	±	0.91	-0.97	±	1.18	-0.3	-0.94	±	0.33*a	-0.3	0.29*	0.09 - 0.97
Ankle Dorsiflexion Moment (Nm·kg^{-1})	2.45	±	0.90	2.42	±	0.91	0.0	2.92	±	0.75	-0.5		
Varus-Valgus Moment (Nm·kg^{-1})	-0.01	±	0.38	0.09	±	0.27	-0.3	-0.08	±	0.24	0.2		
vGRF (Nm·kg^{-1})	21.65	±	6.65	18.94	±	1.67	0.4	27.49	±	7.62*b	-0.9	1.13*	1.01 - 1.27

*$p \leq 0.05$, RoM = range of motion, vGRF = vertical Ground Reaction Force, a; values significantly different from players with no knee injury, b; values significantly different from players with no or an acute knee injury.

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DISCUSSION

This study aimed to investigate the predictive value of landing stability and technique to get more insight in risk factors for sustaining ankle and knee injuries in indoor team sport players. Out of the 75 players 14.7% sustained an ankle injury, which is comparable to other studies [28,33] 17.3% of the players. This is lower compared to other more epidemiological type of studies [3,16]. However, comparison of injury rates is limited by differences in study population and design. The results for the predictive value of landing stability and technique showed that less landing stability is predictive for sustaining acute ankle injuries. A different landing technique, in comparison to healthy players, from a rCMJ was shown in players with both acute ankle and overuse knee injuries.

Our study showed that in addition to forward jump landing stability was mainly affected in the diagonal jump direction of players that sustained an acute ankle injury during the season. Therefore, the forward and diagonal DSI (ES=0.8-1.0) can detect higher risk for ankle injuries. This is in accordance with the ankle inversion motion, which involves a diagonal movement across anatomical planes with ankle plantar flexion and supination [4]. The lateral jump of the SLJ might not have been a replication of the purely lateral directions on the field when receiving an ankle sprain as our movement includes landing from a certain height as well. Still, the used protocol involves different jump directions, which has shown to be more valid in comparison to just forward jumping for injury prevention [48]. Supporting our findings, individuals with functionally unstable ankles show to be unstable in forward jump direction [45].

In addition to less landing stability, players sustaining an ankle injury also showed a greater ankle dorsiflexion moment landing from a rCMJ which increased the risk of sustaining an acute ankle injury. Studies focusing on risk factors for ankle injuries show that less dorsiflexion RoM increases the risk for acute ankle injuries [15,25,41,50]. Despite of being non-significant, our descriptive data showed indeed less ankle dorsiflexion and RoM in players sustaining an acute ankle injury compared to players with no injury (ES=0.2-0.3). In combination with a trend of greater vGRF (ES=0.3), this may play a role in the significantly increased ankle dorsiflexion moment resulting in stiffer ankle motion and higher loads at the ankle. Studies relating double legged landing technique to ankle injuries are limited. Our results reinforce the importance of more research in this area to guide prevention programs.

Our results for landing technique showed a smaller knee flexion moment and greater vGRF in players sustaining an overuse knee injury during the following season. Prospective research on overuse knee injuries is limited, however in line with our results players with a previous jumpers knee, show a landing technique with smaller flexion angles in all joints, smaller knee flexion moment and greater vGRF [7,8]. Our study also showed that players sustaining an overuse knee injury have non-significant smaller hip, knee and ankle flexion angles, which in combination with the significantly greater vGRF increases the load at the joints. However, in case of overuse injuries it should be taken into consideration that these do not specifically occur from a one time high load at the joints. These types of injuries are mainly a result of a specific movement repeated numerous times creating the same load at the joints over and over again [12,14]. Especially when this movement is performed in combination with a poor landing technique this might build up the load at the joints resulting in an overuse injury. Demonstrating again the importance of landing technique in sports with frequent jumping.

This is the first study looking closely at both DSI and landing technique to get more clear insight in the risk factors for sustaining ankle and knee injuries. In addition, we differentiated between acute and overuse knee injuries to assess risk factors separately. This resulted in rCMJ landing technique being predictive for acute ankle and overuse knee injuries. Furthermore, we incorporated a repeated jump landing protocol that is more sport specific and makes it a more stable measure for landing technique. To get insight in the risk factors for acute and overuse injuries a comprehensive biomechanical protocol was used, consisting of two different jumps at baseline and a detailed prospective injury follow-up across the season. This also resulted in a smaller number of included players compared to other cohort studies. However, one of the unique aspects of this study is the inclusion of elite and sub-elite players, all participating in jump-sports, increasing generalizability of the results. The players in this study were both male and female. However, it is known that females are more vulnerable to acute ankle as well as knee injuries [2,17,43]. Unfortunately due to the relatively small sample size the results of this study could not be presented separately for males and females. Future research should look further into differences between sexes for landing stability and technique. It can be advised to include unanticipated landing from diagonal directions in injury prevention and warming-up programs, based on our results in combination with previous findings on ankle injury mechanism. Future prospective studies should include both landing stability and technique (kinetics and kinematics) relating these to injury occurrence over the season, including all types of lower extremity injuries.

It can be concluded that less one-legged landing stability from a forward and diagonal jump and a greater ankle dorsiflexion moment during two-legged repeated jump landing can indicate increased risk of an ankle injury. A landing technique with a smaller knee flexion moment and greater vGRF can indicate increased risk of an overuse knee injury.

PRACTICAL APPLICATIONS

This study may lead to better and more precise screening at the start of the season for ankle and knee injuries by testing both landing stability and technique. This may guide prevention programs, which should focus on include unanticipated landing from diagonal directions for landing stability and on landing technique in terms of knee position and joint flexion. In these prevention programs the use of feedback seems to be important [40].

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