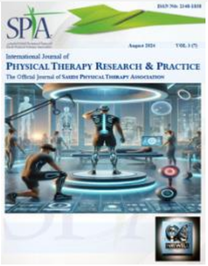

INTERNATIONAL JOURNAL OF
PHYSICAL THERAPY RESEARCH & PRACTICE

AN OFFICIAL JOURNAL OF SAUDI PHYSICAL THERAPY ASSOCIATION

Original Article

Biomechanical Demand during 90° and 135° Cutting Manoeuvres: Implications for Anterior Cruciate Ligament Injury

Ayman Alhammad[1], Lee Herrington[2], Paul Jones[2], Omar W Althomali[3*], Richard Jones[2]

[1] Department of Physiotherapy, College of Medical Rehabilitation Sciences, Taibah University, Almadinah Almunawarah, Saudi Arabia.
[2] Human Movement and Rehabilitation, School of Health and Society, University of Salford, Salford, UK.
[3] Department of Physiotherapy, College of Applied Medical Sciences, University of Ha'il, Ha'il, Saudi Arabia.

*Corresponding Authors: o.althomali@uoh.edu.sa

Article info

Received : Jul 30, 2024
Accepted : Aug 12, 2024
Published : Aug 30, 2024

To Cite: Alhammad, A., Herrington, L., Jones, P., W. Althomali, O., & Jones, R. Biomechanical Demand during 90° and 135° Cutting Manoeuvres: Implications for Anterior Cruciate Ligament Injury. International Journal of Physical Therapy Research &Amp; Practice, 3(7), 294–306. https://doi.org/10.62464/ijoprp.v3i7.43.

Abstract

Background: Anterior cruciate ligament (ACL) injuries in athletes have financial and health consequences and are considered career-threatening. The current study aimed to shed light on biomechanical differences between various change of direction (COD) manoeuvres. Understanding such differences is important, given their association with the incidence of non-contact ACL injuries. **Methods:** Thirty-six male recreational soccer players participated and performed 90° and 135° COD manoeuvres. For gait analysis, the Vicon system was used. The speed and shoe-surface interface were standardized in the COD manoeuvres. Paired sample t-tests were used to compare conditions. **Results:** A Greater peak external knee abduction moment (PEKAM) ($p<0.001$) and knee abduction angle at initial contact (IC) ($p<0.001$) in the 135° COD manoeuvre compared to the 90° COD manoeuvre were observed, highlighting the increased injury risk potential at greater COD angles. In addition, the hip sagittal plane range of motion (RoM) from IC to peak knee valgus angle was higher in the 135° COD manoeuvre than 90° COD manoeuvre ($p<0.001$). **Conclusion:** The results of the current study support the idea that ACL biomechanical risk factors are angle-dependent. A sharper cutting angle showed a higher risk of ACL injury due to the increase in the PEKAM and the knee abduction angle at initial contact. Therefore, players should be trained to reduce high PEKAM and the knee abduction angle by using different strategies.

Keywords: Abduction moment, Screening, Side-step, Kinematics, Kinetics, Cutting.

Introduction

A considerable portion of ACL injuries (70–89%) are non-contact injuries (Benis et al., 2018; Johnston et al., 2018; Montgomery et al., 2018). Interestingly, 60–70% of non-contact injuries occur while performing COD manoeuvres (Johnston et al., 2018; Montgomery et al., 2018). The effect of such injuries can be devastating for the player and the team due to the significant time away from the sport and the risk of significant comorbidities. Therefore, prevention of these injuries is paramount. In 2014, a study (systematic review and meta-analysis) highlighted that only 65% of non-professional athletes resumed to pre-injury levels and that nearly half (55%) returned to practice competitive sport after ACL injury (Ardern et al., 2014). Moreover, ACL injuries have been linked to developing knee osteoarthritis, with 80% of those affected showing signs of knee osteoarthritis within 5–15 years after the injury, especially if it was combined with meniscus injury (Neuman et al., 2008). ACL injuries have long- and short- term consequences (health, psychological and financial) and can be career threatening (Cumps et al., 2008; T. Hewett & Bates, 2017; Lohmander et al., 2007). Therefore, being able to identify those prone to ACL injuries can be considered a first step toward reducing the risk of such injuries (Fox et al., 2017; T. Hewett & Bates, 2017).

Change of direction (COD) manoeuvres is a critical component of many sport activities (Baptista et al., 2018; Bloomfield et al., 2007; Robinson et al., 2011). Previous studies showed that COD manoeuvres between 30 and 180° are associated with non-contact anterior cruciate ligament (ACL) injuries (Montgomery et al., 2018; Waldén et al., 2015). Performing COD manoeuvres requires deceleration before positioning the body to negotiate the directional change and then acceleration (Hase & Stein, 1999). Deceleration followed by acceleration with a rapid change in direction leads to lower limb (e.g., initial knee valgus and reduced knee flexion) and trunk postures (e.g., lateral trunk lean) changes that evoke large knee valgus moments, which pose a risk of non-contact ACL rupture (Grassi et al., 2017; Montgomery et al., 2018; Waldén et al., 2015).

To be able to prevent ACL injuries, an understanding of high-risk maneuvers from a mechanical perspective is important. Several studies have focused on the risk of ACL injuries at less sharp COD angles (i.e. 45°), although greater angles are likely to pose a greater risk of injury (Havens & Sigward, 2015a; Schreurs et al., 2017). Studies that compared ACL injuries at higher cutting angles (30° vs. 60° (Besier et al., 2001; Cochrane et al., 2010), 45° vs.110°(Sigward et al., 2015), 45° vs. 90° (Havens & Sigward, 2015a; Imwalle et al., 2009) and 45° vs. 180° (Cortes et al., 2011)) during COD manoeuvres have shown a higher risk (increase external knee abduction moment or knee internal rotation or knee valgus angle) of ACL injury at higher cutting angles. In another study that compared knee kinetics and kinematics data among athletes performing COD maneuvers at different angles (180°, 135°, 90° and 45°), the authors revealed a decrease in knee flexion angle at greater cutting angles (Schreurs et al., 2017). The latter is problematic, as the anterior tibial translation (ACL load) increases with an extended knee (Yu et al., 2006), which could lead to a higher risk of ACL injury (Markolf et al., 1995). The study also found that a higher valgus moment at greater angles increased the ACL load. Such studies help to improve current understanding of biomechanical risk factors in different COD manoeuvres. However, studies are needed to shed light on the role of hip joint mechanics in COD manoeuvres.

In a study on university athletes that compared three COD tasks (45°, 90° and 180°) (Dos'Santos et al., 2021), among the three angles, the riskiest COD angle was 90° due to higher knee abduction and internal rotation moments, which contradict the findings of an earlier study (Schreurs et al., 2017). However, the study did not investigate the hip frontal plane moment under the three conditions. Such outcomes (hip flexion, abduction and internal rotation internal) are important, as previous studies found a correlation between these and knee frontal plane angle and moment (Havens & Sigward, 2015b; McLean et al., 2005; Sigward & Powers, 2006). Controlling the frontal and transverse planes of motion of the hip is important because these are linked to the knee valgus angle. Hip rotation may place a strain on the ligament working to control the knee and may be a predictor of knee valgus (Paterno et al., 2010). Landing with hip adduction and internal rotation has been found to be a risk factor for knee valgus (T. E. Hewett, Myer, Ford, Heidt, Colosimo, McLean, Van Den Bogert, et al., 2005). In addition, lower hip flexion angle while landing was found to be a predictor for ACL injury, and increasing knee and hip flexion was proposed to be a successful strategy in reducing the risk of ACL injury by reducing the ground reaction force (GRF) and external knee flexion moment (Leppänen et al., 2017).

Interestingly, velocity and angle are considered important factors affecting the biomechanics of COD and therefore the loading in the knee and technical execution of COD (Dos'Santos et al., 2018). The aforementioned studies on COD manoeuvres focused on a discrete point, such as peak value, which may lead to the omission of important information. Including the hip joint and analysing the data over multiple time points rather than the peak point could provide a better understanding of the manoeuvres performed and explain the cause of variation between existing studies. It could be that these differences lie before peaks or after. Understanding the implications of changing the angle on COD biomechanics is critical for researchers and practitioners. Therefore, the current study aimed to compare knee and hip biomechanical variables while performing 90° and 135° COD manoeuvres over multiple time points. We hypothesised that COD at greater angles would lead to increased knee joint loads.

Methods

This was a cross-sectional study and was approved by Salford University (ethical approval number: HSCR16-88).

Participants

To be enrolled in the study, participants had to meet the following criteria: aged between 18 and 35 years and a healthy recreational soccer player, defined as participating in soccer three times a week for a duration of 30 minutes on a regular basis in the last 6 months. In addition, all participants had to have regularly performed COD maneuvers in their sport and had to be free of lower limb injuries during the last 6 months. Injury was considered as any musculoskeletal injury or complaint that prevented the subject from participating in their regular exercise routine. The procedure of the study was explained to each participant before completing a consent form. Data on demographic characteristics and past medical history were then collected.

2.2 3D gait analysis

The Vicon system (Vicon-Bonita cameras, U.K.) with 10 cameras sampling at 250 Hz were used in the current study, which were synchronized with two force platforms (Kistler force plate Type 9286AA, Winterthur, Switzerland) sampling at 1,000 Hz. Motion and force data were acquired using version 2.6.1 of the Nexus program.

Before the participants arrived, the laboratory was checked, prepared and calibrated. The subjects wore shorts during the data collection to allow the placement of the markers on the skin. The Calibrated Anatomical System Technique (CAST) (Collins et al., 2009) was used, and the markers were placed on the posterior superior iliac spine, anterior superior iliac spine, greater tuberosity, iliac crest, medial and lateral condyle, medial and lateral malleolus, heel and first, second and fifth metatarsal head. All the subjects were provided with shoes of the same design to wear during the data collection to control for the shoe-surface interface. In addition, four casts with four markers in each one were placed in the anterior lateral direction of each shank and each thigh. After placing the markers and the casts on each subject, a static trial was undertaken to approximate the position of the casts to anatomical markers. Following this, some markers (iliac crest, greater tuberosity, medial and lateral condyle and medial and lateral malleolus) were removed prior to dynamic trials to allow better task performance.

Task performance

In each task, the participants were asked to run 5 meters (through timing cells at the start) towards the force platforms, where they performed a COD (90° or 135°) maneuver, planting the required limb on the force platform, before then sprinting 3 meters (through a second set of timing cells cutting toward the other leg) to complete the task. To do this, several cones were used to guide the participants and to ensure that all the participants performed the COD at the same angle. Before conducting the trials, each participant was given time to practice. The average speed to complete the 8-meter course was measured using a timing system (Brower Gate, TCI, USA). To successfully complete a trial, the participants needed to complete the trial in 4.2 ± 0.5 m/s. The current study speed was selected in approximately the middle of the speed range of the previous studies to allow comparison. Five successful trials were collected and defined as complete foot placement on the force plate, with no part of the foot on the edge of the force plate and achieving the required speed. A 30-second rest was given between each trial and the next one to reduce the fatigue effect on the participants. Data were collected from the preferred and non-preferred foot in a random order. The preferred foot was defined by asking the participants which foot they preferred to perform the maneuver and monitoring them in practice trials before the start of the trials.

Data processing

The markers were labelled using the Nexus program (version 2.6.1) in each trial and then exported as a Visual 3D file for further processing. Using the Visual 3D tool, a 6-degree freedom model was built, and the participant's dimorphemic characteristics (height and mass) were entered into the model. All kinetic data were normalized by mass. Kinematic data were interpolated and filled as a maximum as 10 frames. Force data were smoothed with a Butterworth low-pass filter, with a cut-off frequency of 25 Hz, and marker data were smoothed with a 12 Hz cut-off frequency (Roewer et al., 2012; Winter, 2009). The events were created as follows: initial contact (IC), followed by toe off. IC was made when the vertical GRF (VGRF) data ascended past 10 N. Toe off was defined when the VGRF descended past 10 N. The data were time normalized on 100% on the contact phase (stance phase). Other events were created as follows: peak VGRF (PVGRF), first 60 milliseconds of stance, peak external knee abduction moment (PEKAM) and peak knee valgus angle (PKVA).

The knee frontal plane angle and sagittal plane angle were analyzed as the following: peak angles (flexion, abduction) at initial contact and during the stance phase. Furthermore, Knee frontal and sagittal planes ROM was computed by subtracting the maximum from the minimum during the stance phase. The peaks of VGRF and EKAM during the stance phase were exported. Hip peak flexions, adduction, and internal rotation angles were extracted in five points: IC, PEKAM, PVGRF, PKVA, 60ms and PKFA. The hip frontal, sagittal and transverse planes ROM was calculated at five phases, IC to PEKAM, IC to PKVA, IC to PVGRF, IC to 60 milliseconds and IC to PKFA. These phases were selected because non-contact ACL injury can occur in the first 50% of the stance phase during the performance COD maneuvers were these phases located (T. E. Hewett, Myer, Ford, Heidt, Colosimo, McLean, van den Bogert, et al., 2005; Malinzak et al., 2001; McLean et al., 2005; Sigward & Powers, 2006; Yu et al., 2006). Moreover, there is insufficient evidence regarding the role of hip sagittal, frontal and transverse planes on the frontal plane knee variables (moment and angle). Our analysis which is not presented in the current study revealed no difference between the preferred leg and the non-preferred therefore the preferred leg was selected.

Statistical analysis

The data were exported from Visual 3D into an Excel spreadsheet and then entered into the Statistical Package for Social Sciences software (SPSS), version 21. Data normality was investigated using the Shapiro–Wilk test and visually by histograms. All variables were normally distributed, and therefore a paired sample t-test was used to compare the same variable between two tasks, as the same participant performed both tasks (Edwards et al., 2012). To reduce type one error, Holm's correction's method, $\alpha = (0.05/[\text{number of comparisons} - \text{rank} + 1])$ was used. Standard deviation and mean were computed and presented for the five trials with the effect size using Cohen's d method (Thomas, Silverman, S. J., & Nelson, 2015). The interpretation of the effect size was as follows: small (0.2), moderate (0.5) and large (0.8) (Cohen, 1988).

Results

Thirty-six male recreational healthy soccer players participated in the study, with a mean age of 24.25 ±6.21 years, height of 1.72 ±0.06 meters, mass of 66.41 ±10.83 kg and body mass index of 19.28 kg/m^2 (2.89). The results revealed some statistical differences between the 90° and 135° maneuvers. PEKAM and knee valgus angle at IC were significantly higher in the 135° COD maneuver compared to the 90°COD maneuver (Table 2 and Fig. 2). In addition, hip flexion ROM from IC to PKFA showed a similar statistically significant trend, where the 135°COD had a higher value than the 90° COD maneuver (Table 1 and Fig. 3). Other outcomes did not show any significant difference between the two tasks (Tables 1, 2 and Figs. 1, 2, 3).

Table 1: Hip joint angle and ROM in frontal, sagittal and transverse planes in the 90° COD and 135° COD maneuvers.

Outcome	135° Mean±SD	90° Mean±SD	Adjusted P-value	Original P-value	Effect size
Sagittal plane angle (°) + Flexion					
Peak at IC	37.1 ± 8.2	39.7 ± 7.4	0.001	0.005	0.50
Peak at PEKAM	39.5 ± 8.6	41.4 ± 7.4	0.002	0.04	0.37
Peak at PVGRF	39.7 ± 8.5	42.3 ± 7.6	0.001	0.008	0.47
Peak at PKVA	42.8 ± 10.2	44.3 ± 8.7	0.003	0.20	0.22
Peak at 60 ms	43.7 ± 10.3	46.1 ± 8.4	0.002	0.04	0.35
Peak at PKFA	49.6 ± 12.5	47.7 ± 9.4	0.003	0.19	0.22
Sagittal plane RoM (°)					
From IC to PEKAM	2.4 ± 2.5	1.8 ± 1.8	0.002	0.06	0.22
From IC to PVGRF	2.6 ± 2.3	2.6 ± 2.4	0.017	0.86	0.02
From IC to PKVA	5.7 ± 5.7	4.7 ± 4.5	0.005	0.43	0.09
From IC to 60 ms	6.6 ± 4.9	6.4 ± 4.4	0.008	0.71	0.06
From IC to PKFA	12.6 ± 7.3	8.1 ± 5.4	0.001	**0.000***	0.81
Frontal plane angle (°) + Adduction					
Peak at IC	-21.9 ± 7.6	-20.5 ± 6.61	0.002	0.04	0.35
Peak at PEKAM	-20.8 ± 7.8	-19.4 ± 6.61	0.002	0.06	0.32
Peak at PVGRF	-20.8 ± 7.8	-19.2 ± 6.61	0.002	0.03	0.37
Peak at PKVA	-19.6 ± 8.2	-18 ± 6.83	0.002	0.05	0.34
Peak at 60 ms	-20.2 ± 7.9	-18.1 ± 6.89	0.001	0.005	0.50
Peak at PKFA	-17 ± 8	-15.9 ± 6.98	0.002	0.14	0.25
Frontal plane RoM (°)					
From IC to PEKAM	1.2 ± 1.4	1 ± 1.1	0.007	0.69	0.05
From IC to PVGRF	1.16 ± 1.5	1.24 ± 1.2	0.003	0.22	0.15
From IC to PKVA	2.3 ± 3.4	2.5 ± 2.3	0.004	0.29	0.12
From IC to 60 ms	1.7 ± 2.2	2.4 ± 2	0.001	0.02	0.27
From IC to PKFA	4.9 ± 4.9	4.5 ± 3.75	0.050	0.96	0.01
Transverse plane angle (°) + Internal rotation					
Peak at IC	7.82 ± 9.04	4.8 ± 9.2	0.001	0.005	0.50
Peak at PEKAM	0.1 ± 8.7	-0.7 ± 9	0.006	0.45	0.13
Peak at PVGRF	-0.2 ± 8.7	-1.4 ± 9	0.004	0.25	0.19
Peak at PKVA	-6.7 ± 11	-6.8 ± 10.7	0.025	0.95	0.01
Peak at 60 ms	-2.3 ± 9.4	-4.2 ±9	0.002	0.11	0.27

Peak at PKFA	-10 ± 9.2	-11 ± 9.6	0.004	0.30	0.18
Transverse plane RoM (°)					
From IC to PEKAM	-7.7 ± 6.3	-5.5 ± 4.2	0.001	0.03	0.26
From IC to PVGRF	-8 ± 6.4	-6.3 ± 4.5	0.002	0.05	0.23
From IC to PKVA	-14.6 ± 7.8	-11.7 ± 7.2	0.002	0.05	0.34
From IC to 60 ms	-10.1 ± 6.4	-9 ± 5.5	0.003	0.36	0.14
From IC to PKFA	-17.8 ± 7.3	-15.9 ± 6.4	0.002	0.08	0.21

***Significant**

Table 2: Knee joint angle in sagittal and frontal planes and PVGRF and PEKAM in the 90° COD and 135° COD maneuvers.

Outcome	**135°**	**90°**	**Adjusted P-value**	**Original P-value**	**Effect size**
	Mean ± SD	**Mean ± SD**			
Frontal plane angle (°) + Adduction					
Peak at IC	-0.48 ± 4.26	1.9 ± 3.9	**0.001**	**0.001**	1.09
Peak during the stance phase	-5.87 ± 5.78	-4.2 ± 5	0.001	0.005	0.50
RoM during the stance phase	-5.39 ± 4.07	-6.1 ± 3.8	0.003	0.20	0.22
Sagittal plane angle (°) + Flexion					
Peak at IC	18.9 ± 5	17.9 ± 6.3	0.002	0.13	0.26
Peak during the stance phase	63.0 ± 8.8	61.6 ± 8.1	0.005	0.32	0.17
RoM during the stance phase	44.2 ± 7.9	43.7 ± 7.1	0.010	0.74	0.06
Kinetics					
PVGRF (Body weight)	2.16 ± 0.35	2.15 ± 0.31	0.002	0.76	0.05
PEKAM (Nm/kg)	2.34 ± 1.11	1.23 ± 0.57	0.005	**0.000***	1.04

*** Significant**

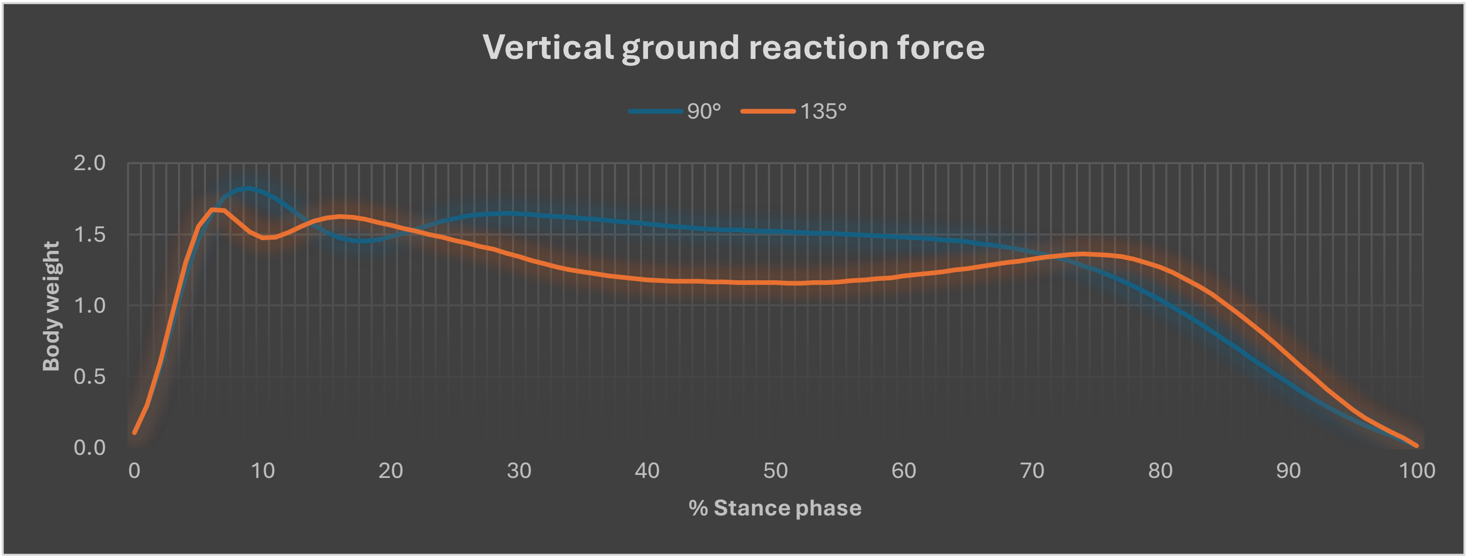

Figure 1: VGRF in the 90° COD and 135° COD maneuvers.

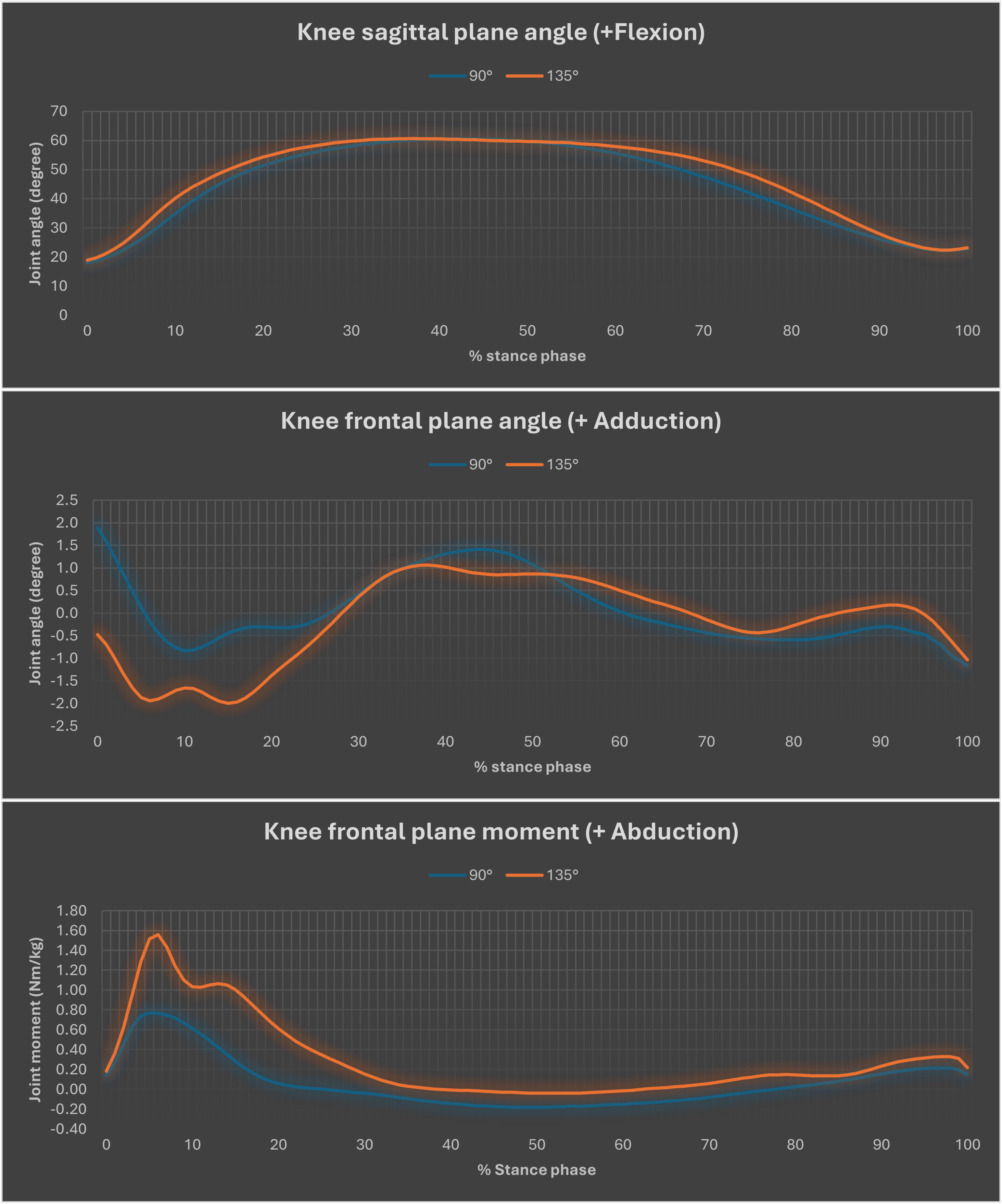

Figure 2: Knee sagittal and frontal plane motion and moment in the 90° COD and 135° COD maneuvers.

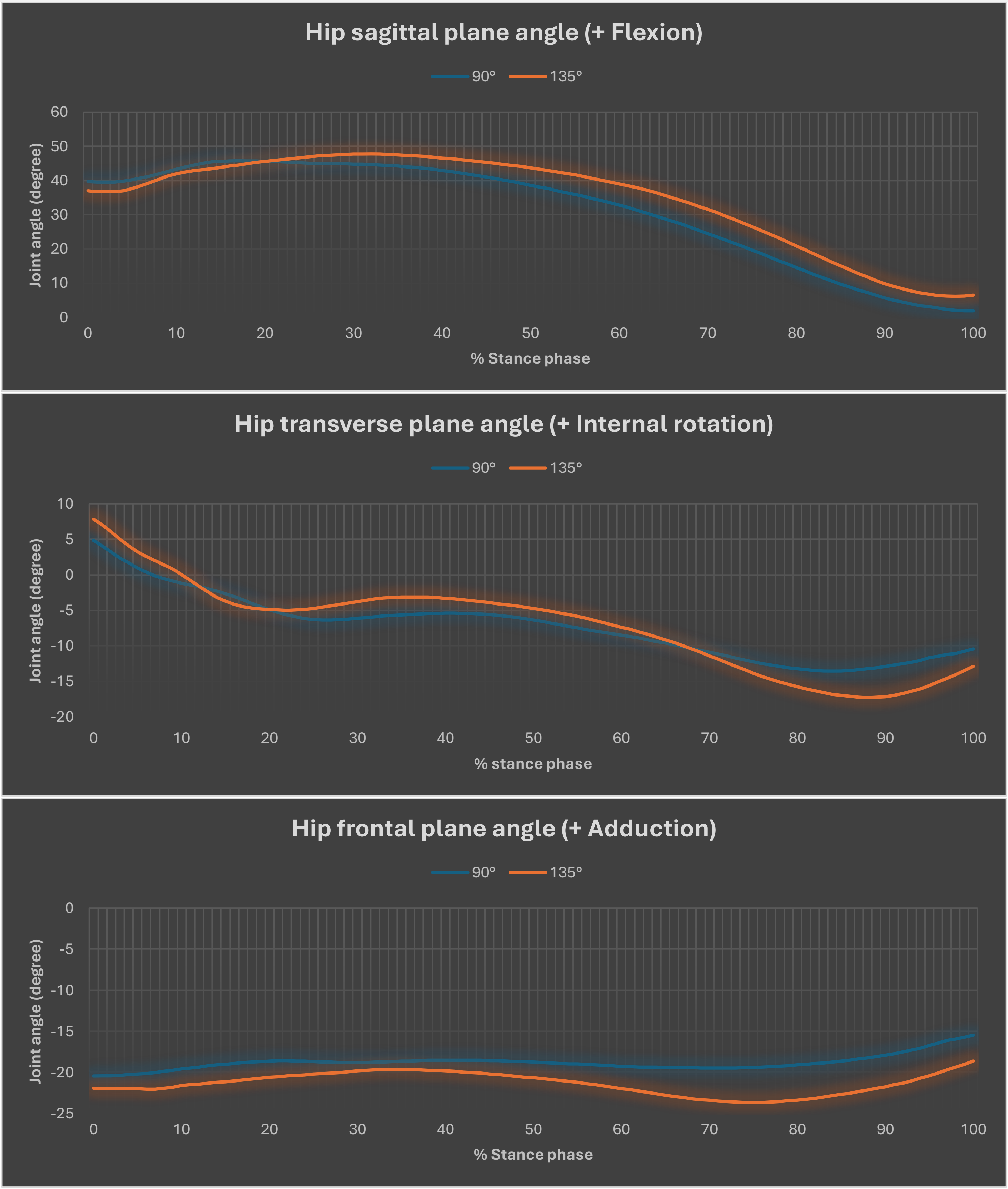

Figure 3: Hip motion in the sagittal plane, transverse plane and frontal plane in the 90° COD and 135° COD maneuvers.

Discussion

The purpose of the current study was to investigate biomechanical differences between 90° and 135° COD manoeuvres, with a specific focus on ACL injury biomechanical risk varibales. The data of the current study suggest that there are some biomechanical differences between both manoeuvres. The results showed significantly higher values for PEKAM, knee valgus angle at IC and hip sagittal plane RoM from IC in the 135° COD manoeuvre as compared to the 90° COD manoeuvre. Several researchers have explored knee and hip biomechanical differences at different angles (45° to 90° and 45° to 110°) in COD manoeuvres (Sigward et al., 2015) and knee biomechanical at 135° and 90° COD manoeuvres (Schreurs et al., 2017). However, the present study is unique, as it investigated knee and hip biomechanical differences at different intervals during the stance phase, something that has not been studied previously. Interestingly, the PEKAM in the 135° COD manoeuvre was nearly twice as high as that in the 90° COD manoeuvre. There are two potential explanations for the increase in the PEKAM during the 135° manoeuvre. The first is the significant increase in knee valgus angle in the 135° COD manoeuvre compared to the 90° COD manoeuvre. The second is that the GRF passes more laterally to the knee joint in 135° COD manoeuvre compared to the 90° COD manoeuvre. Several possible factors could have caused the latter, such as shifting the centre of mass with the trunk, lateral rotation of the knee or shifting the centre of pressure more to the lateral side of the foot. Our findings are similar to those of a previous study, which reported a 2.4 times greater value for the PEKAM in a 110° COD manoeuvre in comparison to a 45° COD manoeuvre (Sigward et al., 2015). The increase in the PEKAM is cause for concern, as a greater PEKAM has been found to be associated with an increased risk of ACL injury (T. E. Hewett, Myer, Ford, Heidt, Colosimo, McLean, van den Bogert, et al., 2005; Jones et al., 2015; Kristianslund et al., 2014; Sigward et al., 2015) and ACL strain (Markolf et al., 1990, 1995). The results of the current study are in agreement with those of earlier studies, which found that sharper COD angles were associated with higher PEKAMs (Havens & Sigward, 2015b; Schreurs et al., 2017; Sigward et al., 2015).

In the current study, the value of PEKAM was 2.34 Nm/kg while performing the COD at a 135° angle. Although a direct comparison cannot be made between studies due to different experimental set-ups, this result is consistent with that of a previous study, which reported a 2.5 Nm/kg in PEKAM while performing a COD at a 105° angle (Marshall et al., 2015). In the 90° COD manoeuver in the present study, the average PEKAM was 1.23 Nm/kg, which is consistent with that of a study by Jones, who reported a value of 1.26 Nm/kg while performing a COD at a 90° angle (Jones et al., 2015).

In contrast to the findings of the present study, a study conducted in 2017 found a similar value for PEKAM when comparing 45° to 90° and 135° to 180° COD manoeuvres (Schreurs et al., 2017). The discord in the findings may be explained by the use of different approach speeds at the different angles, which has been identified as a key factor affecting biomechanical variables (Dos'Santos et al., 2018). Standardization of the speed when comparing different relative tasks is important. Previous studies showed that increasing the speed led to a change in kinetics and kinematics of the lower limb (Nedergaard et al., 2014; Vanrenterghem et al., 2012). The majority of investigators have emphasized the importance of standardized speed (Colby et al., 2000; Kadaba et al., 1989; Pollard et al., 2004; Queen et al., 2006).

In terms of the knee valgus angle, higher values were recorded during IC when performing the 135° compared to the 90° COD manoeuvre. This raises a concern, as higher valgus increases the risk of developing ACL injuries (Grassi et al., 2017; Johnston et al., 2018; Koga et al., 2010; Montgomery et al., 2018; Waldén et al., 2015). A similar finding was made in a previous study, with the authors reporting a greater valgus angle during COD maneuvers at sharper angles (Sigward et al., 2015). The current study demonstrated that the value of the knee valgus angle during IC was -0.5° (varus) during the 90° COD and 1.9° (valgus) during the 135° COD. A study conducted in 2015 reported a value of -1° for the valgus angle during a 90° COD maneuver. Sex-related differences may explain the difference in the findings. The current study included only male athletes, whereas the study by Jones included female soccer players (Jones et al., 2015).

Previous studies revealed significant differences between knee and hip internal rotation angles when comparing 45° COD manoeuvres to 90° COD manoeuvres (Havens & Sigward, 2015b; Imwalle et al., 2009). The current study detected no difference in hip kinematic data, except an increase in hip sagittal plan RoM in the COD at a 135° angle compared to the COD at a 90° angle (from IC to PKFA). This may indicate that performing shaper COD manoeuvre increase in the sagittal plane RoM to reduce knee loading. The hip transverse plane RoM and external rotation recorded while performing the COD maneuver suggest the contribution of the joint to the rotation to the new direction. During executing COD maneuver, the participant contacted the ground with hip abduction, followed by adduction to an abduction position (Grassi et al., 2017; Johnston et al., 2018; Koga et al., 2010; Montgomery et al., 2018; Waldén et al., 2015).

Although, the current study helps to enhance our knowledge of biomechanical differences between two (90° and 135°) COD manoeuvres, the findings should be interpreted with caution. The experiment in the current study was conducted in a laboratory setting, which may not represent real-life situations where other variables may affect mechanics. In addition, the current study compared only the preferred limb between tasks. Moreover, the approach speed could not be calculated due to the short capture volume. It is possible that the subject adjusted their speed during foot contact, which may have affected the result. Finally, the current study included only male soccer players wearing standardized shoes, which reduce the generalizability of the data to elite players, females or other shoe types.

Conclusions

We conclude that different COD angles involve different knee or/and hip kinetics and kinematics. The main finding of the current study is that a sharper cutting angle (135°) poses a greater risk of injury than a less sharp angle (90°), as demonstrated by a higher PEKAM and initial contact knee abduction angle in the 135° COD manoeuvre compared to the 90° COD manoeuvre. These variables should be targeted by coaches to reduce the risk of injury when performing COD maneuvers. Several methods can be used to reduce a high knee external abduction moment and abduction angle. These include controlling the trunk and hip frontal plane movement and hip transverse plane rotation. Intermittingly, the hip sagittal plane RoM from IC to PKFA was higher during the performing sharper cutting angle. This may indicate that the participants increased their hip sagittal plane RoM to reduce knee loading.

Acknowledgments:

We appreciate the participants who devoted their time and contributed invaluably to our study.

Conflict of interest: The authors declare no conflicts of interest.

Funding: The authors report no funding.

Reference

Ardern, C. L., Taylor, N. F., Feller, J. A., & Webster, K. E. (2014). Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. British Journal of Sports Medicine, 48(21), 1543–1552. https://doi.org/10.1136/bjsports-2013-093398

Baptista, I., Johansen, D., Seabra, A., & Pettersen, S. (2018). Position specific player load during match-play in a professional football club. PLOS ONE, 13, e0198115. https://doi.org/10.1371/journal.pone.0198115

Benis, R., LA Torre, A., & Bonato, M. (2018). Anterior cruciate ligament injury profile in female elite Italian basketball league. The Journal of Sports Medicine and Physical Fitness, 58(3), 280–286. https://doi.org/10.23736/S0022-4707.16.06663-9

Besier, T. F., Lloyd, D. G., Cochrane, J. L., & Ackland, T. R. (2001). External loading of the knee joint during running and cutting maneuvers. Medicine and Science in Sports and Exercise, 33(7), 1168–1175. https://doi.org/10.1097/00005768-200107000-00014

Bloomfield, J., Polman, R., & O'Donoghue, P. (2007). Physical Demands of Different Positions in FA Premier League Soccer. Journal of Sports Science & Medicine, 6(1), 63–70. https://pubmed.ncbi.nlm.nih.gov/24149226

Cochrane, J. L., Lloyd, D. G., Besier, T. F., Elliott, B. C., Doyle, T. L. A., & Ackland, T. R. (2010). Training affects knee kinematics and kinetics in cutting maneuvers in sport. Medicine and Science in Sports and Exercise, 42(8), 1535–1544. https://doi.org/10.1249/MSS.0b013e3181d03ba0

Cohen, J. (1988). Statistical Power Analysis for the Behavioural Science (2nd Edition). In Statistical Power Anaylsis for the Behavioral Sciences.

Colby, S., Francisco, A., Yu, B., Kirkendall, D., Finch, M., & Garrett, W. J. (2000). Electromyographic and kinematic analysis of cutting maneuvers. Implications for anterior cruciate ligament injury. The American Journal of Sports Medicine, 28(2), 234–240. https://doi.org/10.1177/03635465000280021501

Collins, T. D., Ghoussayni, S. N., Ewins, D. J., & Kent, J. A. (2009). A six degrees-of-freedom marker set for gait analysis: repeatability and comparison with a modified Helen Hayes set. Gait & Posture, 30(2), 173–180. https://doi.org/10.1016/j.gaitpost.2009.04.004

Cortes, N., Onate, J., & Van Lunen, B. (2011). Pivot task increases knee frontal plane loading compared with sidestep and drop-jump. Journal of Sports Sciences, 29(1), 83–92. https://doi.org/10.1080/02640414.2010.523087

Cumps, E., Verhagen, E., Annemans, L., & Meeusen, R. (2008). Injury rate and socioeconomic costs resulting from sports injuries in Flanders: data derived from sports insurance statistics 2003. British Journal of Sports Medicine, 42(9), 767–772. https://doi.org/10.1136/bjsm.2007.037937

Dos'Santos, T., Thomas, C., Comfort, P., & Jones, P. A. (2018). The Effect of Angle and Velocity on Change of Direction Biomechanics: An Angle-Velocity Trade-Off. In Sports Medicine. https://doi.org/10.1007/s40279-018-0968-3

Dos'Santos, T., Thomas, C., & Jones, P. A. (2021). The effect of angle on change of direction biomechanics: Comparison and inter-task relationships. Journal of Sports Sciences. https://doi.org/10.1080/02640414.2021.1948258

Edwards, S., Steele, J. R., Cook, J. L., Purdam, C. R., & McGhee, D. E. (2012). Lower limb movement symmetry cannot be assumed when investigating the stop-jump landing. Medicine and Science in Sports and Exercise. https://doi.org/10.1249/MSS.0b013e31824299c3

Fox, A. S., Bonacci, J., McLean, S. G., & Saunders, N. (2017). Efficacy of ACL injury risk screening methods in identifying high-risk landing patterns during a sport-specific task. Scandinavian Journal of Medicine & Science in Sports, 27(5), 525–534. https://doi.org/10.1111/sms.12715

Grassi, A., Smiley, S. P., Roberti di Sarsina, T., Signorelli, C., Marcheggiani Muccioli, G. M., Bondi, A., Romagnoli, M., Agostini, A., & Zaffagnini, S. (2017). Mechanisms and situations of anterior cruciate ligament injuries in professional male soccer players: a YouTube-based video analysis. European Journal of Orthopaedic Surgery & Traumatology : Orthopedie Traumatologie, 27(7), 967–981. https://doi.org/10.1007/s00590-017-1905-0

Hase, K., & Stein, R. B. (1999). Turning strategies during human walking. Journal of Neurophysiology, 81(6), 2914–2922. https://doi.org/10.1152/jn.1999.81.6.2914

Havens, K. L., & Sigward, S. M. (2015a). Cutting mechanics: relation to performance and anterior cruciate ligament injury risk. Medicine and Science in Sports and Exercise, 47(4), 818–824. https://doi.org/10.1249/MSS.0000000000000470

Havens, K. L., & Sigward, S. M. (2015b). Joint and segmental mechanics differ between cutting maneuvers in skilled athletes. Gait & Posture, 41(1), 33–38. https://doi.org/10.1016/j.gaitpost.2014.08.005

Hewett, T., & Bates, N. (2017). Preventive Biomechanics: A Paradigm Shift With a Translational Approach to Injury Prevention. The American Journal of Sports Medicine, 45, 036354651668608. https://doi.org/10.1177/0363546516686080

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Colosimo, A. J., McLean, S. G., Van Den Bogert, A. J., Paterno, M. V., & Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. American Journal of Sports Medicine. https://doi.org/10.1177/0363546504269591

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S. J., Colosimo, A. J., McLean, S. G., van den Bogert, A. J., Paterno, M. V, & Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. The American Journal of Sports Medicine, 33(4), 492–501. https://doi.org/10.1177/0363546504269591

Imwalle, L., Myer, G., Ford, K., & Hewett, T. (2009). Relationship Between Hip and Knee Kinematics In Athletic Women During Cutting Maneuvers: A Possible Link to Noncontact Anterior Cruciate Ligament Injury and Prevention. Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 23(8), 2223–2230. https://doi.org/10.1519/JSC.0b013e3181bc1a02

Johnston, J. T., Mandelbaum, B. R., Schub, D., Rodeo, S. A., Matava, M. J., Silvers-Granelli, H. J., Cole, B. J., ElAttrache, N. S., McAdams, T. R., & Brophy, R. H. (2018). Video Analysis of Anterior Cruciate Ligament Tears in Professional American Football Athletes. The American Journal of Sports Medicine, 46(4), 862–868. https://doi.org/10.1177/0363546518756328

Jones, P. A., Herrington, L. C., & Graham-Smith, P. (2015). Technique determinants of knee joint loads during cutting in female soccer players. Human Movement Science, 42, 203–211. https://doi.org/https://doi.org/10.1016/j.humov.2015.05.004

Kadaba, M. P., Ramakrishnan, H. K., Wootten, M. E., Gainey, J., Gorton, G., & Cochran, G. V. B. (1989). Repeatability of kinematic, kinetic, and electromyographic data in normal adult gait. Journal of Orthopaedic Research, 7(6), 849–860. https://doi.org/10.1002/jor.1100070611

Koga, H., Nakamae, A., Shima, Y., Iwasa, J., Myklebust, G., Engebretsen, L., Bahr, R., & Krosshaug, T. (2010). 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, 38(11), 2218–2225. https://doi.org/10.1177/0363546510373570

Kristianslund, E., Faul, O., Bahr, R., Myklebust, G., & Krosshaug, T. (2014). Sidestep cutting technique and knee abduction loading: implications for ACL prevention exercises. British Journal of Sports Medicine, 48(9), 779–783. https://doi.org/10.1136/bjsports-2012-091370

Leppänen, M., Pasanen, K., Krosshaug, T., Kannus, P., Vasankari, T., Kujala, U. M., Bahr, R., Perttunen, J., & Parkkari, J. (2017). Sagittal Plane Hip, Knee, and Ankle Biomechanics and the Risk of Anterior Cruciate Ligament Injury: A Prospective Study. Orthopaedic Journal of Sports Medicine, 5(12), 2325967117745487. https://doi.org/10.1177/2325967117745487

Lohmander, L. S., Englund, P. M., Dahl, L. L., & Roos, E. M. (2007). The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. The American Journal of Sports Medicine, 35(10), 1756–1769. https://doi.org/10.1177/0363546507307396

Malinzak, R. A., Colby, S. M., Kirkendall, D. T., Yu, B., & Garrett, W. E. (2001). A comparison of knee joint motion patterns between men and women in selected athletic tasks. Clinical Biomechanics (Bristol, Avon), 16(5), 438–445. https://doi.org/10.1016/s0268-0033(01)00019-5

Markolf, K. L., Burchfield, D. M., Shapiro, M. M., Shepard, M. F., Finerman, G. A., & Slauterbeck, J. L. (1995). Combined knee loading states that generate high anterior cruciate ligament forces. Journal of Orthopaedic Research : Official Publication of the Orthopaedic Research Society, 13(6), 930–935. https://doi.org/10.1002/jor.1100130618

Markolf, K. L., Gorek, J. F., Kabo, J. M., & Shapiro, M. S. (1990). Direct measurement of resultant forces in the anterior cruciate ligament. An in vitro study performed with a new experimental technique. The Journal of Bone and Joint Surgery. American Volume, 72(4), 557–567.

Marshall, B., Franklyn-Miller, A., Moran, K., King, E., Richter, C., Gore, S., Strike, S., & Falvey, É. (2015). Biomechanical symmetry in elite rugby union players during dynamic tasks: an investigation using discrete and continuous data analysis techniques. BMC Sports Science, Medicine & Rehabilitation, 7, 13. https://doi.org/10.1186/s13102-015-0006-9

McLean, S. G., Huang, X., & van den Bogert, A. J. (2005). Association between lower extremity posture at contact and peak knee valgus moment during sidestepping: implications for ACL injury. Clinical Biomechanics (Bristol, Avon), 20(8), 863–870. https://doi.org/10.1016/j.clinbiomech.2005.05.007

Montgomery, C., Blackburn, J., Withers, D., Tierney, G., Moran, C., & Simms, C. (2018). Mechanisms of ACL injury in professional rugby union: a systematic video analysis of 36 cases. British Journal of Sports Medicine, 52(15), 994–1001. https://doi.org/10.1136/bjsports-2016-096425

Nedergaard, N. J., Kersting, U., & Lake, M. (2014). Using accelerometry to quantify deceleration during a high-intensity soccer turning manoeuvre. Journal of Sports Sciences, 32(20), 1897–1905. https://doi.org/10.1080/02640414.2014.965190

Neuman, P., Englund, M., Kostogiannis, I., Fridén, T., Roos, H., & Dahlberg, L. E. (2008). Prevalence of tibiofemoral osteoarthritis 15 years after nonoperative treatment of anterior cruciate ligament injury: a prospective cohort study. The American Journal of Sports Medicine, 36(9), 1717–1725. https://doi.org/10.1177/0363546508316770

Paterno, M. V, Schmitt, L. C., Ford, K. R., Rauh, M. J., Myer, G. D., Huang, B., & Hewett, T. E. (2010). Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. The American Journal of Sports Medicine, 38(10), 1968–1978. https://doi.org/10.1177/0363546510376053

Pollard, C. D., Davis, I. M., & Hamill, J. (2004). Influence of gender on hip and knee mechanics during a randomly cued cutting maneuver. Clinical Biomechanics (Bristol, Avon), 19(10), 1022–1031. https://doi.org/10.1016/j.clinbiomech.2004.07.007

Queen, R. M., Gross, M. T., & Liu, H. Y. (2006). Repeatability of lower extremity kinetics and kinematics for standardized and self-selected running speeds. Gait and Posture, 23(3), 282–287. https://doi.org/10.1016/j.gaitpost.2005.03.007

Robinson, G., O'Donoghue, P., & Wooster, B. (2011). Path changes in the movement of English Premier League soccer players. The Journal of Sports Medicine and Physical Fitness, 51(2), 220–226.

Roewer, B. D., Ford, K. R., Myer, G. D., & Hewett, T. E. (2012). The "impact" of force filtering cut-off frequency on the peak knee abduction moment during landing: Artefact or "artifiction." British Journal of Sports Medicine, 48(6), 464–468. https://doi.org/10.1136/bjsports-2012-091398

Schreurs, M. J., Benjaminse, A., & Lemmink, K. A. P. M. (2017). Sharper angle, higher risk? The effect of cutting angle on knee mechanics in invasion sport athletes. Journal of Biomechanics, 63, 144–150. https://doi.org/10.1016/j.jbiomech.2017.08.019

Sigward, S. M., Cesar, G. M., & Havens, K. L. (2015). Predictors of Frontal Plane Knee Moments During Side-Step Cutting to 45 and 110 Degrees in Men and Women: Implications for Anterior Cruciate Ligament Injury. Clinical Journal of Sport Medicine : Official Journal of the Canadian Academy of Sport Medicine, 25(6), 529–534. https://doi.org/10.1097/JSM.0000000000000155

Sigward, S. M., & Powers, C. M. (2006). The influence of gender on knee kinematics, kinetics and muscle activation patterns during side-step cutting. Clinical Biomechanics (Bristol, Avon), 21(1), 41–48. https://doi.org/10.1016/j.clinbiomech.2005.08.001

Thomas, Silverman, S. J., & Nelson, J. K. (2015). Research Methods in Physical Activity (7th Editio). Human Kinetics, Inc.

Vanrenterghem, J., Venables, E., Pataky, T., & Robinson, M. A. (2012). The effect of running speed on knee mechanical loading in females during side cutting. Journal of Biomechanics, 45(14), 2444–2449. https://doi.org/10.1016/j.jbiomech.2012.06.029

Waldén, M., Krosshaug, T., Bjørneboe, J., Andersen, T., Faul, O., & Hägglund, M. (2015). Three distinct mechanisms predominate in noncontact anterior cruciate ligament injuries in male professional football players: A systematic video analysis of 39 cases. British Journal of Sports Medicine, 49. https://doi.org/10.1136/bjsports-2014-094573

Winter, D. a. (2009). Biomechanics and motor control of human gait. In Motor Control. https://doi.org/10.1002/9780470549148

Yu, B., Lin, C.-F., & Garrett, W. E. (2006). Lower extremity biomechanics during the landing of a stop-jump task. Clinical Biomechanics (Bristol, Avon), 21(3), 297–305. https://doi.org/10.1016/j.clinbiomech.2005.11.003