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ORIGINAL RESEARCH

Unanticipated side cutting alters lower limb kinematic and kinetic variables in futsal athletes

Mohammad Aziminia[1], Ali Abbasi[1,2✉], Samira Sadat Sajjadi[1], Gholamhossein Nazemzadegan[2], and Mehdi Khaleghi Tazji[1]

[1]Department of Biomechanics and Sports Injuries, Faculty of Physical Education and Sports Sciences, Kharazmi University, Tehran; and [2]Department of Sport Sciences, Faculty of Education and Psychology, Shiraz University, Shiraz, Iran

Abstract

Background: Numerous studies have examined the risk of non-contact anterior cruciate ligament (ACL) injuries during fast sports activities involving cutting maneuvers. However, these studies often focus on isolated measurements. A critical factor influencing this risk is the anticipation of the cutting movement. **Objective:** This study aimed to compare the kinematic and kinetic variables of the lower limb during anticipated and unanticipated side cutting maneuvers in futsal athletes. **Methods:** Eighteen male futsal players participated in this study. The angle of the dominant lower limb joints, the peak vertical ground reaction force, rate of loading, and knee joint moment were calculated during the stance phase. **Results:** The results of the paired sample *t*-test showed that the hip joint range of motion (ROM) in the frontal plane was significantly reduced in the unanticipated compared to anticipated side cutting (p = .040). The frontal plane's mean ROM and peak knee joint valgus were significantly higher in the unanticipated conditions (p = .048, p = .031). In the sagittal plane, the ankle joint ROM during unanticipated side cutting was significantly reduced (p = .018). Knee joint moments were significantly greater for unanticipated side cutting in the transverse plane (p = .037). **Conclusions:** This study highlighted the role of ankle joint in absorbing the force and reducing the rate of loading and showed that the unanticipated side cutting altered the lower limb joint kinematics and kinetics which are associated with ACL risk factors.

Keywords: anterior cruciate ligament, kinematics, kinetics, knee, side cutting

Introduction

Sudden changes in body path such as side cutting maneuvers in fast sports activities have been considered from the point of view of creating the risk of injury. Side cutting maneuvers are movements performed in a closed kinetic chain by athletes in various team sports to reduce the speed of movement and change the direction of the center of mass of the whole body from a linear way to a side path. These maneuvers may be performed more than 100 times at various angles during a futsal or basketball game in response to a defender or carrying and stalking the ball (Zhou et al., 2023).

Studies have shown that performing cutting maneuvers during sports activities can show different responses in the kinematic and kinetic variables of the trunk and lower limb joints, which leads to severe irreparable injuries (Dos'Santos et al., 2019). One of the most common non-contact injuries in the knee joint among athletes is an anterior cruciate ligament tear, which can occur during a side cutting maneuver. Non-contact Anterior Cruciate Ligament (ACL) injuries account for 20% of knee injuries in team sports athletes (Boden et al., 2010). Sudden changes in body direction in fast sports activities such as side cutting maneuvers cause more risk compared to forward movements. To perform a cutting maneuver, athletes usually have to slow down in the forward direction, then shift their body to a new direction, and finally increase the movement acceleration in the new path (Zhou et al., 2023). Usually, the combination of damaging mechanisms in ACL tear occurs in the deceleration phase to change the direction of body movement (Shyu et al., 1994). In this situation, the most important mechanisms of ACL tear include the knee joint valgus, anterior displacement of the tibia relative to the femur, reduction of knee flexion, and external rotation of the tibia on the pronated ankle (Benjaminse et al., 2015). On the other hand, previous studies have shown that the risk of ACL tear in the deceleration phase during the side cutting maneuver increases with increasing valgus angle and knee adduction moment in the frontal plane, increasing the internal rotation moment in the transverse plane, and the peak ground reaction force (Shin et al., 2011).

Another important variable that is effective in recognition of the increased risk of ACL injury is the rate of loading (ROL). The ROL is considered as the peak force changes in the vertical plane per unit of time. It is possible that increasing the rate of force loading has a direct relationship with increasing the knee flexion moment and this factor can increase the risk of ACL injury (Dai et al., 2014).

✉ **Corresponding author:** Ali Abbasi, e-mail abbasi@khu.ac.ir, ORCID® record https://orcid.org/0000-0001-9733-6501

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The injury rate in competition is much higher than in training, with an athlete's exposure to an ACL injury being 1 to 5 times higher in competition than in training. The random nature of sports often reveals that athletes need unplanned scenarios that require unanticipated responses (Hanson et al., 2008). Side cutting maneuvers can be performed at different angles and in planned or unplanned conditions, depending on the competition demands and the external stimuli. In performing the anticipated skill, the person puts the trunk and lower limbs in a suitable position to create the desired amount of movement. However, if the athlete is forced to make an unanticipated side cutting maneuver in response to her opponent or teammate, the biomechanical variables of his/her trunk and lower limb joints may be changed for at least two reasons: doubts about choosing the correct movement and technique, and not having enough time to respond to the stimulus (Weir et al., 2019). Performing a cutting maneuver in an unanticipated condition requires quick and accurate reactions. In this situation, the time pressures associated with these dynamic movements may alter the biomechanical variables and increase the force loading in the joints, including the knee joint. For example, previous studies have shown that the knee valgus moment during the unanticipated cutting maneuver is twice as high as the anticipated one (Besier et al., 2001). In unanticipated conditions, the time factor may limit the ability of the nervous system to initiate movement and may be suppressed, which can affect the athlete's performance during the sports skill (Wyatt et al., 2019). Many studies have aimed to identify the risk factors of ACL injury in a controlled laboratory environment. However, most non-contact ACL injuries occur unexpectedly (Ford et al., 2005). Therefore, this study used the unexpected mode of side cutting maneuver to evaluate the selected kinematic and kinetic variables of the movement, as close to the competition as possible, and to identify the ACL injury factors more accurately. The hypothesis of the present study posits that kinematic and kinetic variables of the lower limb during anticipated and unanticipated side-cutting maneuvers differ in futsal athletes.

Methods

Participants

Eighteen healthy male futsal players from the National Futsal League (age 22.7 ± 2.2 years, body mass 71.4 ± 8.5 kg, body height 176.8 ± 4.3 cm, body mass index 21.7 ± 1.7 kg/m^2), all with a minimum of three years of experience in futsal, voluntarily participated in this study. According to previous studies, the sample size was estimated based on a priori power calculations to achieve an 80% statistical power with an alpha level of .05 (McLean et al., 2005; Weir et al., 2019). The inclusion criteria were an age range of 20 to 30 years, free of lower limb injuries and pains during the past 12 months, no history of surgery, and chronic musculoskeletal pain in the trunk and lower limbs. The lower limb dominance of all the participants was right, and it was identified by using the ball-kicking test (Weir et al., 2019; Zhou et al., 2023). This study was performed following the Helsinki Declaration. All participants signed an informed consent form, and the research protocol and details were approved by the Institutional Review Board of Kharazmi University. All experiments were performed in accordance with relevant guidelines and regulations.

Instrumentation

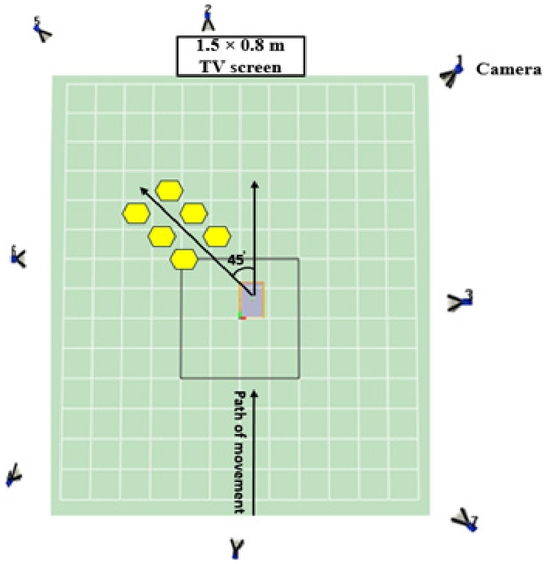
An 8-camera motion capture system (Raptor model, Motion Analysis, Rohnert Park, CA, USA) at 240 Hz and an AMTI force platform at 1000 Hz (Bertec, Columbus, OH, USA) were used to record the kinematic and kinetic data, respectively (Sujae et al., 2022). 14 mm reflective markers were used to make a 3D model of the lower limbs of the athletes. Thirty markers were placed on the upper body (acromion, C7, T2, T10), pelvis (iliac crests, anterior superior iliac spines, posterior superior iliac spines), lower limbs (greater trochanter, lateral and medial femoral epicondyles, four marker thigh clusters, medial and lateral malleoli, four marker shank cluster) and foot (heel, second toe tip, first and fifth metatarsal head, lateral and medial aspect of each foot), see Graci et al. (2012). All participants wore standardized shoes provided by the researcher.

Procedure

Each participant performed a 5-min warm-up before the test, which included running at 4 m/s on a treadmill and doing dynamic stretching movements, to prevent injury during the test. After preparing the participants, static and dynamic calibration of the camera motion capture system was performed. Then, the athletes performed the cutting maneuver at maximum speed with their dominant limb in two conditions of anticipated and unanticipated conditions at an angle of 45°. Cones placed at 35° and 55° from the original direction of progression were used to direct the subjects to cut at an angle of 45°. In the anticipated task, participants performed the required task at the predetermined place on the force plate that was in the middle of the pass (Figure 1).

In the unanticipated task, athletes were asked to perform a randomized set of run, run-stop, and side cutting tasks (Weir et al., 2019). Run and run-stop tasks were used for task randomization to limit the predictability of the unanticipated side cutting tasks and were not used formally in the analysis. To perform the task, colored symbols were considered as different stimuli and different responses were designed for each color. In this study, the green symbol (run), yellow symbol (run-stop), and red symbol (cutting maneuver) were considered, which were displayed on the television screen (1.5 × 0.8 m) at the end of the runway path (8 m) at a distance of 1.65 m. In the unanticipated task, the athletes performed the desired task at the maximum speed after covering a distance of 10 meters, at the closest distance from the force plate by identifying the color of the symbol. Participants completed five successful trials each of anticipated and unanticipated side cutting as defined by the following criteria: (1) the participant's foot remained within the borders of the force platform, (2) the participant remained within the pathway designated by the

Figure 1 Overview of the laboratory (arrangement of the motion analysis system, force plate, and movement path of side cutting maneuver)



cones. Participants were given nearly 60 s of rest between tasks to minimize any effects of fatigue (Wyatt et al., 2019).

Data analysis

Kinematic and ground reaction forces data were filtered using a fourth-order zero-lag low-pass Butterworth 14 Hz (Weir et al., 2019). The trajectories of markers were labeled by Cortex Software (Version 8.1.0.2017 64-bit; Motion Analysis, Rohnert Park, CA, USA). The time series was obtained from three cycles of both anticipated and unanticipated side cutting maneuvers. The stance phase was identified as the period from initial foot contact to toe-off, as determined by the force platform recordings (using the vertical ground reaction force from > 10 N to < 10 N). The stance phase was normalized by linearly interpolating the temporal data to 100 data points, each representing 1% of the phase. So that the first point of each cycle indicated the time of initial foot contact, and the 100th point indicated toe-off on the force plate.

To calculate the angles of the lower limb during anticipated and unanticipated side cutting maneuvers in the stance phase were used Euler's formula relationships (Robertson et al., 2014).

The vertical ground reaction force data were used in the stance phase to calculate kinetic variables, including peak ground reaction force (vGRF), ROL, and joint moment. Peak vertical force was defined as the highest force recorded in the Fz direction during side cutting maneuver for each person, then normalized to body weight (N). The ROL was calculated with the peak vertical force divided by the time to reach the peak vertical force (Hargrave et al., 2003).

Moreover, the knee joint moment during anticipated and unanticipated side cutting maneuvers was estimated in three directions. In the first step, the body mass and center of mass were calculated using anthropometric data. Then, after calculating the inertia moment of the shank and foot, the net joint force and the inertia moment of the knee, and ankle joints were calculated using the Newton-Euler equation (Robertson et al., 2014). All the calculations were done using MATLAB (Version R2015a; MathWorks, Natick, MA, USA).

Statistical analysis

The Shapiro-Wilk test was used to check the normality of data. The paired *t*-tests were used to compare parameters between the two conditions of anticipated and unanticipated side cutting maneuvers. Cohen's *d* effect sizes (Cohen, 1988) were calculated and considered as small (0.2), moderate (0.5), and large (0.8). Statistical analyses were conducted in IBM SPSS Statistics (Version 27; IBM, Armonk, NY, USA) at a significance level of $p = .05$.

Results

The results of the Shapiro-Wilk test indicated that the variables had normal distribution ($p > .05$). The hip joint range of motion (ROM) in the frontal plane ($p = .040$, $d = 0.72$) and the ankle joint ROM in the sagittal plane ($p = .018$, $d = -0.31$) were significantly reduced in the unanticipated compared to the anticipated side cutting maneuver (Table 1). The mean ROM ($p = .048$, $d = 0.61$) and the peak knee joint valgus ($p = .031$, $d = 0.56$) in the frontal plane were significantly higher in the unanticipated condition than anticipated (Tables 1 and 2). No significant difference was found in the ROM and peak angles in other joints (Tables 1 and 2).

In the transverse plane, knee joint moments were significantly greater in unanticipated side cutting compared with anticipated side cutting ($p = .037$, $d = 0.82$; Table 3). No significant differences were observed in knee joint moments in the sagittal and frontal planes and in peak vGRF and ROL between anticipated and unanticipated side cutting maneuvers (Table 3). The results of hip, knee, and ankle joint kinematics and knee joint moments in three movement planes were presented in Figures 2 and 3, respectively.

Table 1 Means and standards deviation of the range of motion (in degrees)

Joint/Plane	Condition		p
	Anticipated	Unanticipated	
Hip			
Sagittal	47.94 ± 13.16	46.36 ± 11.04	.645
Frontal	23.60 ± 8.58	16.15 ± 8.42	.040
Knee			
Sagittal	39.63 ± 11.38	37.24 ± 8.20	.273
Frontal	8.70 ± 3.49	10.81 ± 4.79	.048
Ankle			
Sagittal	47.63 ± 5.55	44.07 ± 4.92	.018
Frontal	10.18 ± 7.76	8.94 ± 5.39	.588

Table 2 Means and standard deviations of peak joint angles

Angle (degrees)	Condition		p
	Anticipated	Unanticipated	
Hip flexion	41.54 ± 10.41	41.24 ± 7.55	.904
Hip abduction	21.60 ± 10.99	24.67 ± 11.41	.272
Knee flexion	47.81 ± 11.39	48.41 ± 8.22	.745
Knee valgus	8.46 ± 3.12	10.54 ± 4.61	.031
Ankle dorsi flexion	14.55 ± 4.58	13.65 ± 5.66	.442
Ankle inversion	7.72 ± 2.70	7.08 ± 3.55	.440

Table 3 Means and standard deviations of kinetic variables

Variable	Condition		p
	Anticipated	Unanticipated	
Peak vGRF ($N \cdot BW^{-1}$)	2.852 ± 0.493	2.828 ± 0.595	.870
ROL ($N \cdot BW^{-1} \cdot ms^{-1}$)	145.84 ± 114.81	137.09 ± 118.93	.814
Knee moment ($N \cdot m \cdot kg^{-1}$)			
Sagittal plane	2.410 ± 0.959	2.136 ± 1.283	.400
Frontal plane	–4.611 ± 1.701	–4.868 ± 1.900	.393
Transverse plane	1.305 ±0.751	1.978 ± 1.162	.037

Note. vGRF = vertical ground reaction force; BW = body weight; ROL = rate of loading.

Figure 2 Means and standard deviations of hip flexion/extension (A), abduction/adduction (B), knee flexion/extension (C), valgus/varus (D), ankle plantar/dorsi flexion (E), and inversion/eversion (F) angles during anticipated and unanticipated side cutting

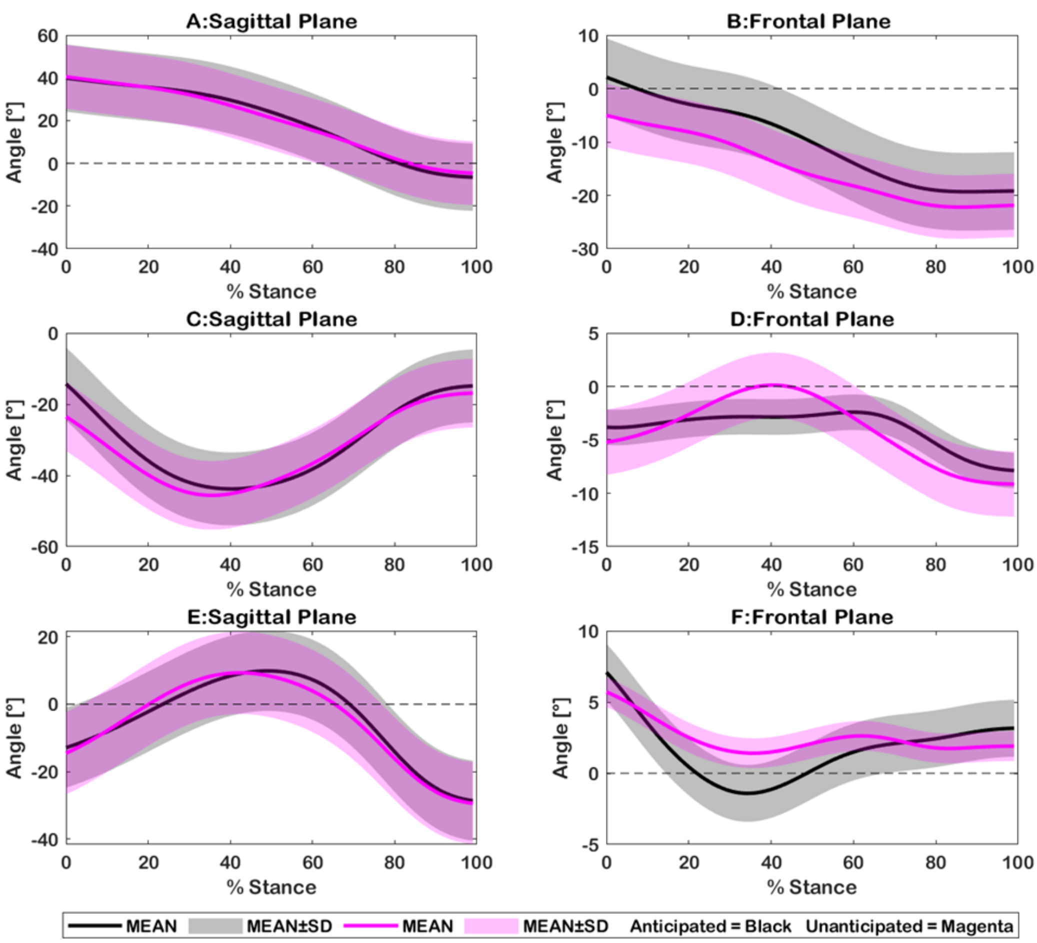
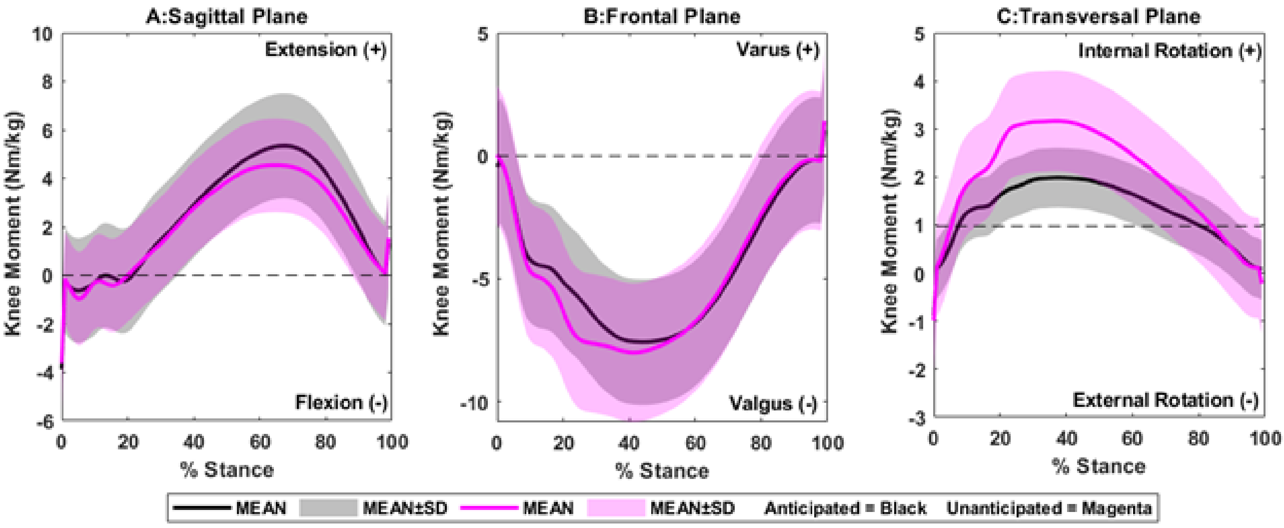


Figure 3 Means and standard deviations of knee flexion/extension (A), valgus/varus (B), and internal/external rotation (C) moments during anticipated and unanticipated side cutting



Discussion

The aim of the present study was to compare the kinematic and kinetic variables of the lower limb during anticipated and unanticipated side cutting maneuvers in futsal athletes. The results of the present study showed a significant decrease in the ROM of the hip joint in the frontal plane during the unanticipated side cutting maneuver compared to the anticipated one in the stance phase. The hip joint is crucial for transferring body weight from the pelvis to the leg, as it has both stability and high mobility (Levangie & Norkin, 2011). Therefore, changes in its kinematic variables, including reducing its ROM, can cause changes in the distal parts of the lower limb.

The valgus angle of the knee joint in the frontal plane, which is a major risk factor for ACL rupture, can be influenced by the hip joint's unfavorable kinematics, which is seen during unanticipated maneuvers. The hip joint's movements in the frontal plane affect the knee valgus, which is a major risk factor for ACL rupture. A reduced ROM of the hip joint in this plane can impair the optimal load distribution in the knee joint in the same plane and increase the risk of ACL tear (Ford et al., 2005). Previous studies have shown the relationship between the movements of the hip and knee joint, and that an increase in the hip abduction angle can cause the knee joint to move inward in the frontal plane, leading to non-contact knee injuries (Imwalle et al., 2009). However, in this study, the hip abduction angle during the unanticipated side cutting maneuver increased compared to the anticipated one, but the difference was not statistically significant.

The unanticipated side cutting maneuver increased the ROM and the peak valgus angle of the knee joint significantly compared to the anticipated one in the stance phase. This may be due to the unpredictability and the time constraint of adjusting the posture properly before performing the sport maneuver. Sports movements usually occur in multiple planes of motion, and ACL injury may not result from a single plane. A combination of dynamic valgus, transverse rotation, and hyperextension of the knee joint during sports maneuvers can create excessive anterior shear force on the ACL and alter the force distribution on the upper surface of the tibia, which increases the risk of ACL injury and arthritis (Agostinone et al., 2021).

Montgomery et al. (2018) reported that 80% of the anterior cruciate ligament rupture mechanisms in professional rugby athletes occurred with increased knee valgus angle and the resulting stress, which was consistent with the findings of the present study. Sudden and unplanned decisions during sports skills may impair the ability of an athlete to predict and execute a suitable technique to deal with external forces on the knee. This may expose the ACL ligament is more force and load, which increases the risk of injury. Therefore, this finding supports the hypothesis that unpredictability alters the knee joint kinematics (Mache et al., 2013).

The present study's findings showed a significant difference in the reduction of the ankle joint ROM in the sagittal plane in the unanticipated side cutting maneuver compared to the anticipated condition. Changes in ankle joint ROM during sports maneuvers increase the possibility of lower limb injury. The risk of ankle joint injury is higher in tasks that require deceleration and sudden changes in body direction (Daneshjoo et al., 2015). On the other hand, the limitation in the ankle joint ROM, especially the reduced dorsiflexion, restricts the forward movement of the knee joint. This increases the knee joint motion in the frontal plane and doubles the pressure on the ACL. Moreover, a decreased ankle dorsiflexion following decreased knee joint flexion leads to applying more force on the knee joint, which will increase the risk of ACL injury (Hewett et al., 2006). The ankle joint, as the most distal part of the lower limb, plays an essential role in transmitting force to the proximal joints and supporting body weight during standing, walking, and performing sports skills. Since the joints of the lower limb act as an interconnected system, so biomechanical changes in this segment can alter the force-loading direction in other joints and have negative effects (Holder et al., 2020).

No significant differences were seen in the knee moments variables in the sagittal and frontal planes between the anticipated and unanticipated side cutting maneuvers, but the transverse plane showed a significant increase in the unanticipated condition compared to the anticipated one. Studies have shown a significant relationship between the maximum knee moment and the kinematics of the lower limb joints, which can increase the injury risk for athletes. For example, McLean et al. (2005) reported that athletes who had increased knee valgus and consequently higher knee moment in the frontal plane during cutting and landing maneuvers were more likely to suffer from non-contact ACL injuries. The knee valgus moment during side cutting maneuver at a 45-degree angle is related to the lower limb joint angles and the ground reaction force at the initial contact time (Sigward & Powers, 2007). Performing the sport skill in multiple planes of motion increases the internal rotation and abduction of the hip joint and knee valgus, which in turn increases the knee valgus moment and the ACL tear risk (Hewett et al., 2005). In this study, the knee joint moments in the frontal and sagittal planes did not differ significantly among the conditions studied, but the athlete's kinematic variables in the unanticipated condition were different from the anticipated one. This implies that the unanticipated side cutting maneuver might increase the force exported on the knee joint by the athlete. Shin et al. (2011) showed that the combination of the knee valgus moment and the knee internal rotation moment exerted more force on the ACL ligament than each of them alone. This finding was consistent with the present study and suggested that this condition occurred more frequently in competition situations than in laboratory analyses.

This study found no significant differences in ROL and peak vGRF between predicted and unpredicted side cutting maneuvers. The ROL depends on two factors: the peak vGRF and the time to reach that peak during the initial contact of the foot with the ground, which indicates the amount of stress on the body's biological tissues such as ligaments, bones, and muscles. Controlling the force absorption when the foot hits the ground during dynamic activities is a way to prevent impact-related injuries, and the ankle joint movements play a crucial role in absorbing the impact (Hargrave et al., 2003). A higher ROL reduces shock absorption, which implies high stress to the lower limbs in a short time. Increasing the ankle joint ROM spreads the force over a longer range and time, which enhances shock absorption and decreases loading speed (Neely, 1998). Given the reduced ankle joint ROM in this study during the unanticipated side cutting maneuver, this factor may increase the impact forces and the loading speed on the lower limb joints.

Limitations

This study provided some valuable insights into the lower limb joints kinematics and kinetics during anticipated and unanticipated side cutting, but it had several limitations. First, it only included male futsal players. Since female athletes have a higher ACL injury risk in similar activities than men, future studies should investigate the gender effect. Second, it used only visual cues to make the skill unpredictable and limit the reaction time. Studies show that the reaction time depends on the stimulus type. Future studies should use auditory stimuli or combined cues to create unpredictability. Third, it did not consider other factors that may affect kinematic and kinetic variables, such as fatigue, diet, and psychological factors. Finally, to better identify the ACL injury risk factors during sports skills, future studies should measure the lower limb muscle activity.

Conclusions

This study found that the injury risk factors of ACL in the anticipated and unanticipated side cutting maneuvers were different. The unanticipated condition increased the knee valgus, decreased the hip and ankle ROM, and increased the knee moments in the frontal and transverse planes. The ankle joint, as the last segment in the closed kinetic chain, had a greater impact on the ROL and ground reaction force absorption. Therefore, this study suggested that futsal coaches and players should consider the unpredictability of the environment, design dynamic exercises, and implement unforeseen skills in their training protocols to better adapt to the competition conditions. This would help them correct their desired technique, increase their awareness of potential risks, and reduce lower limb injuries.

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Conflict of interest

The authors report no conflict of interest.

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