

Exploring the impact of sidestep cutting maneuvers at different angles on biomechanical parameters

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Abstract:

This study aimed to evaluate kinetic and kinematic parameters during planned and unplanned sidestep cutting maneuvers performed at cutting angles of 45° and 90°. Twelve collegiate soccer players performed six successful trials for each task (three at a 45° angle and three at a 90° angle). Kinematic and kinetic data were recorded using ten optoelectronic cameras and a force plate, operating at sampling rates of 250 and 1000 Hz, respectively. A two-way repeated measures ANOVA was used to analyze the effects of task and angle. The findings revealed that the cutting angle significantly influenced ground reaction forces (GRFs) and lower limb joint kinematics at initial contact (IC) and maximum vertical GRF (max vGRF), while no significant differences were observed between the planned and unplanned tasks. Regarding kinetic parameters, 90° cutting maneuvers elicited higher lateral and vertical forces at IC and generated a greater posterior force at max vGRF compared to 45° cutting maneuvers. For kinematic parameters, 90° cutting maneuvers exhibited greater hip abduction angles at IC and more pronounced hip joint moments in flexion, abduction, and external rotation at IC and max vGRF. These factors can contribute to a higher knee flexion angle, greater knee abduction, and internal rotation moments at IC. Conversely, 45° cutting maneuvers produced greater knee flexion moments and inversion angles, resulting in improved force distribution. To optimize performance while minimizing injury risk, coaches should incorporate drills encompassing various cutting angles into their training programs. This will prepare athletes for the various cutting scenarios encountered during gameplay.

Keywords: change of direction, kinetics and kinematics parameters, cutting angles, injury risk

Introduction

Change of direction (COD) ability refers to an athlete's capacity to rapidly decelerate (eccentric action) and accelerate (concentric action) in a new direction while running or sprinting (Young et al., 2015). This planned and multidirectional action is a crucial physical quality in many team sports (Sheppard & Young, 2006; Paul et al., 2016; Chaabene, 2017). COD maneuvers can be performed using various techniques, primarily categorized as sidestep and crossover cutting maneuvers (Dos'Santos et al., 2019). Notably, in invasion sports such as soccer, rugby, and basketball, CODs are often performed in response to external stimuli, such as an opponent's actions or the movement of the ball. Consequently, agility is defined as a COD performed in response to a stimulus (Sheppard & Young, 2006; Young et al., 2015; Paul et al., 2016). Research performed in laboratory settings generally uses different terminology. For instance, the COD task is often referred to as a "cutting maneuver," and maneuvers are classified as unplanned (i.e., unanticipated) or planned (i.e., anticipated) based on the presence or absence of a visual stimulus (Brown et al., 2014).

Cutting angle and approach velocity are two crucial factors influencing the performance of cutting maneuvers and are associated with injury risk, particularly non-contact anterior cruciate ligament (ACL) injuries. Sharper and faster cutting maneuvers can generate excessive mechanical loads, creating a "performance-injury conflict" (Dos'Santos et al., 2018). To mitigate injury risk, an "angle-velocity trade-off" is necessary, involving a reduction in cutting angle when approach velocity is high (Dos'Santos et al., 2018). Variations in technical execution associated with cutting angle have been observed in young rugby players (Condello et al., 2013) and collegiate soccer players (Condello et al., 2016). These findings demonstrate the existence of more rounded or sharper executions of sidestep cutting maneuvers. From an injury prevention perspective, sharper cutting angles, such as 90°, 135°, and 180°, have been associated with a higher risk of ACL injuries owing to the excessive knee valgus moment they induce compared to 45° maneuvers (Schreurs et al., 2017). Additionally, as the cutting angle increases, greater ground reaction forces (GRF) are produced in a shorter duration, imposing a higher external load on the knee joint (Marques et al., 2020). Similarly, knee valgus moments were found to be greater during a 110° cutting maneuver compared to a maneuver with a smaller angle (45°) (Sigward et al., 2015). However, video analysis of elite soccer players revealed a higher prevalence of cutting maneuvers with angles ranging from 0° to 90° (Bloomfield et al., 2007). Comparisons

between 45° and 90° cutting maneuvers in experienced high-level soccer players have demonstrated several differences at initial contact (IC) for joint (i.e., ankle, knee, and hip) kinematic parameters in the sagittal plane during deceleration and in the frontal plane during redirection (Havens & Sigward, 2015a). Similarly, faster completion times were predictive of 45° and 90° cutting maneuvers in different ways, with sagittal plane mechanisms primarily predictive of faster 45° cutting maneuvers and frontal plane mechanisms primarily predictive of faster 90° cutting maneuvers (Havens & Sigward, 2015b).

The demands of a cutting maneuver are further amplified when comparing unplanned and planned conditions (Brown et al., 2014). Unplanned sidestep-cutting maneuvers may impose a greater external load on the knee joint and increase injury risk owing to the limited time available for postural adjustments before the action (Besier et al., 2001; Marques et al., 2020). Staynor and coworkers (2018) investigated trunk muscle activation between unplanned and planned sidestep cutting maneuvers, suggesting that trunk muscles may be unable to adequately control frontal-plane trunk positioning during the penultimate flight phase, potentially contributing to a higher risk of ACL injuries. Additionally, Wyatt et al. (2019) demonstrated that athletes exhibited an increased range of center of mass displacement in the anterior–posterior and vertical directions during unplanned sidestep cutting maneuvers. Concurrent manipulation of cutting angles and conditions (unplanned versus planned) may provide new insights into the adaptations of kinetic and kinematic parameters associated with injury risk in soccer players. Accordingly, this study aimed to evaluate kinetic and kinematic parameters during planned and unplanned sidestep cutting maneuvers performed at 45° and 90° cutting angles. We hypothesized that knee internal rotation and knee valgus angle would be greater in unplanned compared to planned sidestep cutting maneuvers and greater in 90° compared to 45° cutting maneuvers.

Materials and methods

Participants

The sample size for this study was determined using G*Power software (Faul et al., 2007), which performed a priori power analysis for analysis of variance with an effect size of 0.84, a significance level of 0.05, a power of 0.95, and a two-sided alternative (Dos'Santos et al., 2021). The power analysis indicated that the study required a minimum sample size of 12 subjects to identify a minimal detectable difference threshold. Accordingly, twelve collegiate soccer players (age: 20.92 ± 1.03 years; weight: 70.33 ± 8.45 kg; height: 176.67 ± 5.07 cm) with at least 5 years of playing experience (Ye et al., 2022) voluntarily participated in this study. To be eligible, participants were required to engage in at least three training sessions per week, each lasting for a minimum of one hour, in addition to competitive matches. Exclusion criteria included severe lower extremity injuries or surgeries in the past six months, as well as a history of musculoskeletal or ACL injuries. All participants were informed about the testing procedures and provided informed consent by signing a form approved by the Committee on Human Rights Related to Human Experimentation at Mahidol University (MU-CIRB 2023/075.0805).

Procedure/Test protocol/Skill test trial/Masurement/Instruments

Forty-four reflective markers were placed on the participant's body based on anatomical landmarks defined by the Liverpool John Moores University Lower Limb and Trunk (LLT) model, which includes the thorax, pelvis, thighs, shanks, and feet (Vanrenterghem et al., 2010). The LLT model, with functional hip and knee joints, is based on a 6DOF model to define the location of hip and knee joint motion. Ten optoelectronic cameras (Raptor-E, Motion Analysis Corporation, Santa Rosa, CA, USA) captured kinematics at a sampling rate of 250 Hz. A force plate (Kistler Instrument AG, Switzerland) collected kinetic data at a sampling rate of 1000 Hz, identifying ground contact and the stance phase during the sidestep cutting maneuvers.



Figure 1 Attachment of 44 reflective markers to bony landmarks following the LLT biomechanical model (Vanrenterghem et al., 2010)

The preferred leg was determined by asking players which leg they primarily used to kick a ball (Condello et al., 2016). Before the experimental trials, all participants were instructed to initiate their run

from a starting point 10 m from the force plate. Upon reaching the force plate, they were to perform the cutting maneuvers by pushing off with their preferred foot, following the angle displayed on a television screen. An alleyway marked on the ground guided the sidestep cutting maneuvers, with cutting angles set at 45° and 90°. Participants were instructed to accurately follow the displayed cutting angles by positioning their non-preferred leg in the alleyway, ensuring accurate execution (Hanson et al., 2008). During planned sidestep cutting tasks, participants received visual cues on a screen indicating the angle they were to cut before each trial. In unplanned sidestep-cutting trials, symbols representing 45° and 90° angles appeared 2 m before the force plate (Beaulieu et al., 2009).

Participants started with a 15-min warm-up comprising jogging followed by dynamic stretching, squats, frontal and lateral lunges, submaximal jumps (in vertical, frontal, and horizontal directions), short accelerations, directional changes, and submaximal trials of the tests. Each participant was required to complete 6 successful trials (3 at a 45° angle and 3 at a 90° angle) in each task (planned and unplanned), with a 30-s rest period between each trial and in a randomized order. A successful trial was defined as participants performing a correct cut and COD at a velocity exceeding 4 m/s, measured by timing gates (TIMING PRO, TestYou, Krakow, Poland) placed at the starting point and 2 m before the force plate.

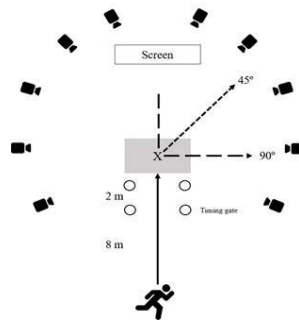


Figure 2 Laboratory setup

Data processing and analysis

Kinematic data were processed using a zero-lag, fourth-order Butterworth low-pass filter with a cutoff frequency of 10 Hz. IC was defined as the point at which the vertical component of the GRF exceeded 20 N. The analysis focused on two specific events: IC and the maximal vertical GRFs (max vGRFs) (Nagano et al., 2011; Jeong et al., 2021). GRF and joint moment were normalized to each participant's body mass. Each trial was analyzed at the IC and max vGRFs events for the three components of GRF and the lower extremity kinematics, including hip, knee, and ankle angles, as well as joint moments. Hip and knee flexion, adduction, and internal rotation angles and moments, as well as ankle dorsiflexion, eversion, and adduction angles, were calibrated to be positive. Additionally, the vertical, lateral, and anterior GRF values were all adjusted to be positive. For statistical analysis, the values from the three trials for each task and angle were averaged (Wyatt et al., 2019).

Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (IBM Corp., Version 23.0, Armonk, NY, USA). Statistical significance was set at $p < 0.05$. All results are presented as mean $\pm$ SD. The Shapiro–Wilk test was used to assess the normal distribution of the data, which confirmed its normality for all kinetic and kinematic parameters. A two-way repeated measures ANOVA was used to examine the effects of task (planned vs. unplanned) and angle (45° vs. 90°). Effects size for the main effects were calculated as partial eta squared (η_p^2) and interpreted as follows: small (0.01–0.06), medium ($0.06 < \eta_p^2 < 0.14$), and large (>0.14). For significant interactions, pairwise comparisons (t-tests) with Bonferroni adjustments were performed. Cohen's d was calculated for each comparison and interpreted as follows: trivial (<0.19), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), very large (2.0–4.0), and extremely large (>4.0).

Results

A significant main effect of angle (45° and 90°) was observed at IC for the mediolateral and vertical components of GRF ($p < 0.05$) and at max vGRF for the anteroposterior component of GRF ($p < 0.05$) (Table 1). The 90° cutting maneuvers generated greater lateral (-0.24 ± 0.22 N/kg, $p < 0.01$; $d = 1.01$) and vertical (1.39 ± 0.98 N/kg, $p < 0.01$; $d = -0.66$) GRFs compared to the 45° maneuvers (mediolateral: 0.02 ± 0.12 N/kg; vertical: planned 0.91 ± 0.60 N/kg) at IC. At max vGRF, a greater posterior GRF was found for the 90° cutting maneuvers (-8.09 ± 3.52 N/kg, $p < 0.01$; $d = 0.97$) compared to the 45° maneuvers (-5.19 ± 3.34 N/kg).

Table 1. Kinetic data for the three ground reaction force (GRF) components at initial contact (IC) and maximum vertical GRF (vGRF) during sidestep cutting maneuvers for planned and unplanned tasks at 45° and 90°. Data are presented as mean (SD).

Variable	Task and angle condition				Angle effect		Task effect		Interaction effect	
	Planned 45°	Planned 90°	Unplanned 45°	Unplanned 90°	P value	Effect size	P value	Effect size	P value	Effect size
At IC										
Anteroposterior GRF (N/kg)	-0.41 (0.33)	-0.40 (0.42)	-0.39 (0.36)	-0.47 (0.44)	0.65	0.01	0.87	0	0.49	0.02
Mediolateral GRF (N/kg)	0.00 (0.08)	-0.21 (0.19)	0.04 (0.14)	-0.28 (0.25)	<0.01	0.53	0.78	0	0.28	0.03
Vertical GRF (N/kg)	0.91 (0.57)	1.32 (0.83)	0.92 (0.66)	1.47 (1.14)	<0.01	0.32	0.79	0	0.66	0.01
At maximum vGRF										
Anteroposterior GRF (N/kg)	-5.16 (3.39)	-7.50 (3.11)	-5.23 (3.44)	-8.68 (3.93)	<0.01	0.51	0.63	0.01	0.38	0.04
Mediolateral GRF (N/kg)	5.02 (1.59)	5.48 (1.70)	5.42 (1.37)	5.22 (1.32)	0.54	0.02	0.91	0	0.14	0.09
Vertical GRF (N/kg)	25.03 (4.28)	23.6 (5.08)	24.41 (4.06)	23.47 (5.57)	0.18	0.08	0.83	0	0.78	0

Bold font indicates statistical significance. Effect sizes are reported as partial eta squared (η_p^2).

A significant main effect of angle was observed for the hip adduction angle at IC ($p < 0.01$, $\eta_p^2 = 0.839$) (Figure 3). The 90° cutting maneuvers resulted in a greater abduction angle ($-16.90^\circ \pm 6.75^\circ$, $p < 0.01$; $d = 2.23$) compared to 45° maneuvers ($-5.52^\circ \pm 5.43^\circ$). Additionally, a significant main effect of angle emerged for knee flexion angle at IC ($p < 0.01$; $\eta_p^2 = 0.273$). The 45° cutting maneuvers exhibited a greater flexion angle ($20.23^\circ \pm 5.13^\circ$, $p < 0.01$; $d = -0.60$) compared to 90° maneuvers ($22.26^\circ \pm 6.96^\circ$). Furthermore, a significant main effect of angle emerged for ankle joint angles at IC (dorsiflexion angle: $p < 0.01$, $\eta_p^2 = 0.567$; inversion angle: $p < 0.01$, $\eta_p^2 = 0.386$). Greater dorsiflexion ($22.87^\circ \pm 9.87^\circ$, $p < 0.01$; $d = 1.10$) was observed for the 90° cutting maneuvers compared to 45° maneuvers ($32.75^\circ \pm 10.49^\circ$), while a greater inversion angle ($-14.32^\circ \pm 5.61^\circ$, $p < 0.01$; $d = -0.77$) emerged for the 45° cutting maneuvers compared to 90° maneuvers ($-12.46^\circ \pm 5.80^\circ$).

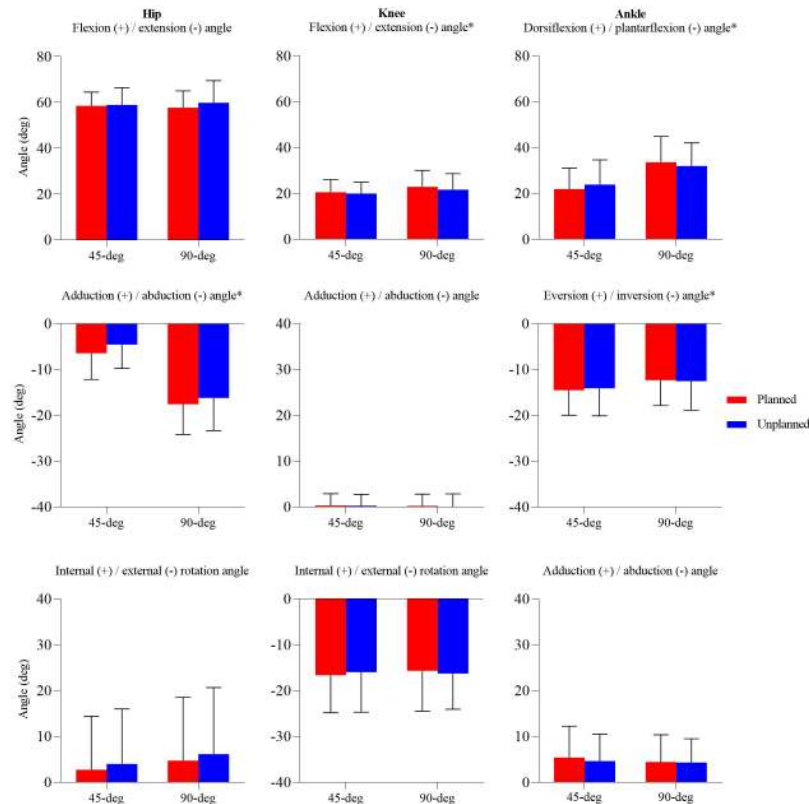


Figure 3 Joint angles in the sagittal (left column), frontal (center column), and transverse (right column) planes for 45° and 90° tasks during planned (red) and unplanned (blue) maneuvers at initial contact.

*Indicates a significant main effect of angle ($p < 0.05$).

A significant main effect of angle was observed for the hip flexion moment ($p < 0.01$, $\eta_p^2 = 0.283$), adduction moment ($p < 0.01$, $\eta_p^2 = 0.765$), and internal rotation moment ($p < 0.01$, $\eta_p^2 = 0.682$) at IC (Figure 4). The 90° cutting maneuvers resulted in a greater hip flexion moment (0.82 ± 0.36 Nm/kg, $p < 0.01$; $d = 0.60$), abduction moment (-0.69 ± 0.33 Nm/kg, $p < 0.01$; $d = -1.75$), and external rotation moment (-0.34 ± 0.16 Nm/kg, $p < 0.01$; $d = -1.43$) compared to 45° maneuvers (flexion moment: 0.64 ± 0.22 Nm/kg; abduction moment: -0.24 ± 0.19 Nm/kg; external rotation moment: -0.13 ± 0.13 Nm/kg). Additionally, a significant main effect of angle emerged for knee flexion moment ($p < 0.01$, $\eta_p^2 = 0.269$), abduction moment ($p < 0.01$, $\eta_p^2 = 0.791$), and internal rotation moment ($p < 0.01$, $\eta_p^2 = 0.663$) at IC.

The 90° cutting maneuvers resulted in a greater abduction moment (-0.39 ± 0.14 Nm/kg, $p < 0.01$; $d = -1.87$) and internal rotation moment (0.15 ± 0.08 Nm/kg, $p < 0.01$; $d = 1.40$) compared to the 45° maneuvers (abduction moment: -0.13 ± 0.09 Nm/kg; internal rotation moment: 0.06 ± 0.04 Nm/kg). In contrast, the 45° cutting maneuvers demonstrated a greater knee flexion moment (0.19 ± 0.20 Nm/kg, $p < 0.01$; $d = 0.59$) compared to 90° maneuvers (0.06 ± 0.23 Nm/kg). A significant main effect of angle was observed for all ankle joint moments at IC (dorsiflexion moment: $p < 0.01$, $\eta_p^2 = 0.435$; adduction moment: $p < 0.01$, $\eta_p^2 = 0.271$; inversion moment: $p < 0.01$, $\eta_p^2 = 0.631$). Greater dorsiflexion moment (0.23 ± 0.17 Nm/kg, $p < 0.01$; $d = 0.83$) and eversion moment (-0.04 ± 0.03 Nm/kg, $p < 0.01$; $d = -1.27$) at IC emerged for the 90° cutting maneuvers compared to the 45° maneuvers (dorsiflexion moment: 0.12 ± 0.14 Nm/kg; eversion: 0.00 ± 0.02 Nm/kg), while a greater adduction moment emerged for the 45° cutting maneuvers (0.05 ± 0.04 Nm/kg, $p < 0.01$; $d = -0.60$) compared to 90° maneuvers (0.02 ± 0.06 Nm/kg).

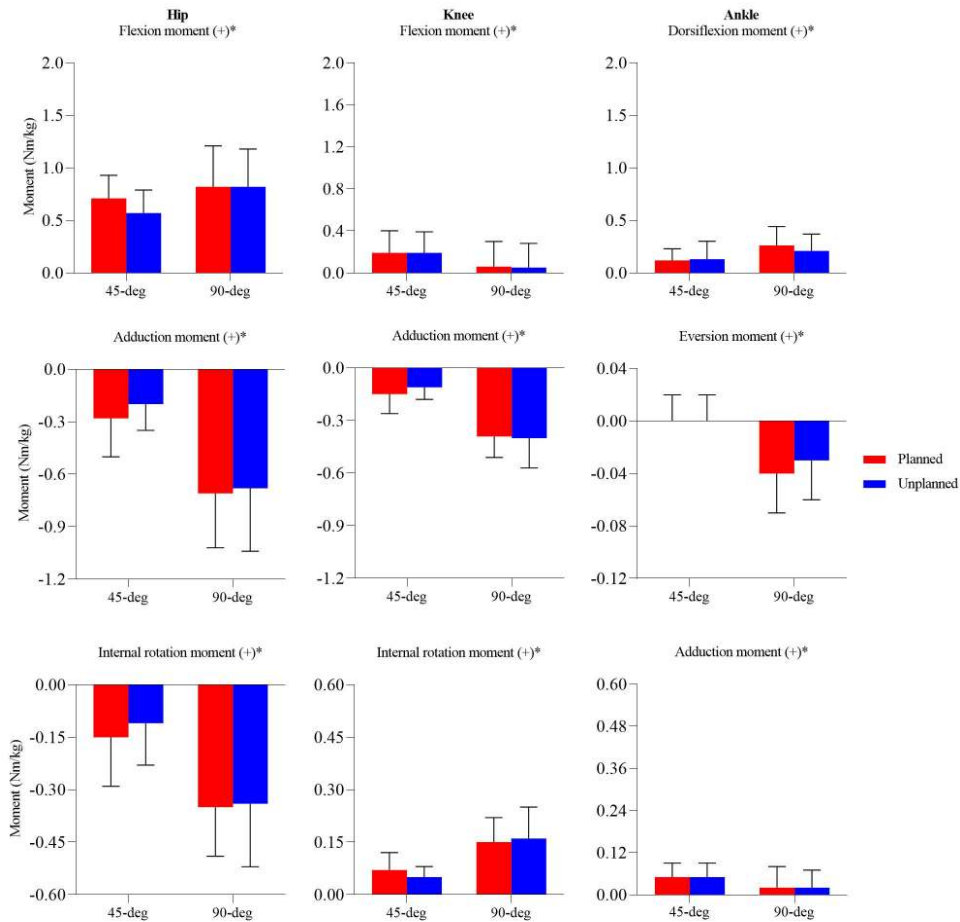


Figure 4 Joint moments in the sagittal (left column), frontal (center column), and transverse (right column) planes for 45° and 90° tasks during planned (red) and unplanned (blue) maneuvers at initial contact.

*Indicates a significant main effect of angle ($p < 0.05$).

A significant main effect of angle was observed for hip flexion ($p < 0.01$, $\eta_p^2 = 0.291$) and adduction ($p < 0.01$, $\eta_p^2 = 0.866$) angle at max vGRF (Figure 5). The 90° cutting maneuvers resulted in greater flexion ($60.46^\circ \pm 7.84^\circ$, $p < 0.01$; $d = -0.60$) and abduction angle ($-18.34^\circ \pm 6.58^\circ$, $p < 0.01$; $d = 2.49$) compared to

the 45° maneuvers (flexion angle: $57.07^\circ \pm 7.41^\circ$; abduction angle: $-6.11^\circ \pm 5.82^\circ$). Additionally, a significant main effect of angle emerged for ankle joint angles at max vGRF (dorsiflexion angle: $p < 0.01$, $\eta_p^2 = 0.663$; inversion angle: $p < 0.05$, $\eta_p^2 = 0.194$). Lower dorsiflexion ($19.14^\circ \pm 7.85^\circ$, $p < 0.01$; $d = 1.34$) was observed for the 45° cutting maneuvers compared to ankle dorsiflexion at 90° ($27.56^\circ \pm 7.16^\circ$), while a greater inversion angle ($-13.25^\circ \pm 5.29^\circ$, $p < 0.05$; $d = -0.47$) was revealed for the 45° cutting maneuvers compared to inversion at 90° ($-12.11^\circ \pm 5.94^\circ$).

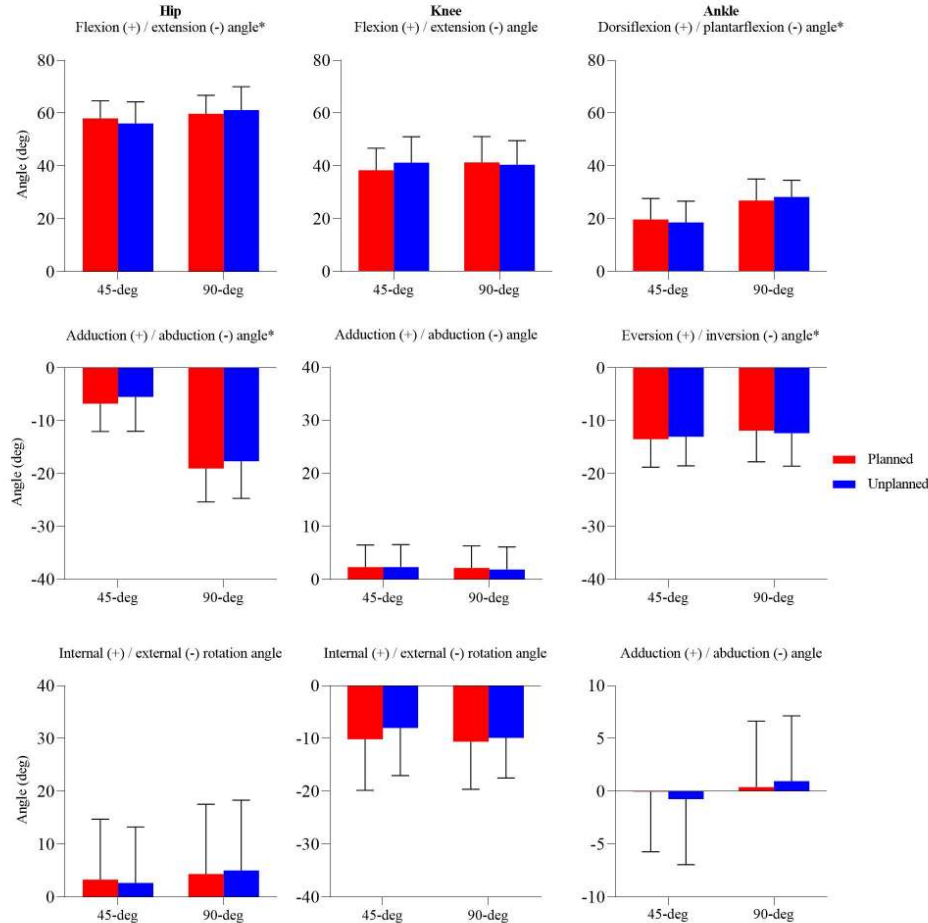


Figure 5 Joint angles in the sagittal (left column), frontal (center column), and transverse (right column) planes for 45° and 90° tasks during planned (red) and unplanned (blue) maneuvers at maximum vertical ground reaction force. *Indicates a significant main effect of angle ($p < 0.05$).

A significant main effect of angle was observed for flexion moment ($p < 0.01$, $\eta_p^2 = 0.427$), abduction moment ($p < 0.01$, $\eta_p^2 = 0.895$), and internal rotation moment ($p < 0.01$, $\eta_p^2 = 0.680$) at max vGRF (Figure 6). The 90° cutting maneuvers resulted in greater flexion moment (1.80 ± 0.41 Nm/kg, $p < 0.01$; $d = 0.83$), abduction moment (-1.04 ± 0.45 Nm/kg, $p < 0.01$; $d = -2.82$), and external rotation moment (-0.13 ± 0.31 Nm/kg, $p < 0.01$; $d = -1.42$) compared to the 45° maneuvers (flexion moment: 1.38 ± 0.57 Nm/kg; abduction moment: 0.00 ± 0.42 Nm/kg; internal rotation moment: 0.23 ± 0.27 Nm/kg).

Additionally, a significant main effect of angle emerged for knee flexion moment ($p < 0.01$, $\eta_p^2 = 0.449$), abduction moment ($p < 0.01$, $\eta_p^2 = 0.713$), and internal rotation moment ($p < 0.01$, $\eta_p^2 = 0.705$) at max vGRF. The 45° cutting maneuvers demonstrated a greater flexion (1.68 ± 0.55 Nm/kg, $p < 0.01$; $d = 0.85$) and adduction (0.14 ± 0.36 Nm/kg, $p < 0.01$; $d = -1.53$) moment compared to the 90° maneuvers (flexion moment: 1.23 ± 0.46 Nm/kg; abduction moment: -0.37 ± 0.34 Nm/kg). Conversely, the 90° cutting maneuvers resulted in a greater knee internal rotation moment (0.24 ± 0.15 Nm/kg, $p < 0.01$; $d = 1.50$) compared to the 45° maneuvers (0.00 ± 0.14 Nm/kg). A main effect of angle was observed for ankle eversion moment at max vGRF ($p < 0.01$, $\eta_p^2 = 0.607$), with greater values for the 45° cutting maneuvers (0.11 ± 0.09 Nm/kg, $p < 0.01$; $d = -1.22$) compared to 90° maneuvers (-0.01 ± 0.11 Nm/kg). A significant interaction between angle and task emerged for ankle dorsiflexion moment at max vGRF ($p < 0.05$, $\eta_p^2 = 0.234$). However, post-hoc analysis did not reveal any significant differences.

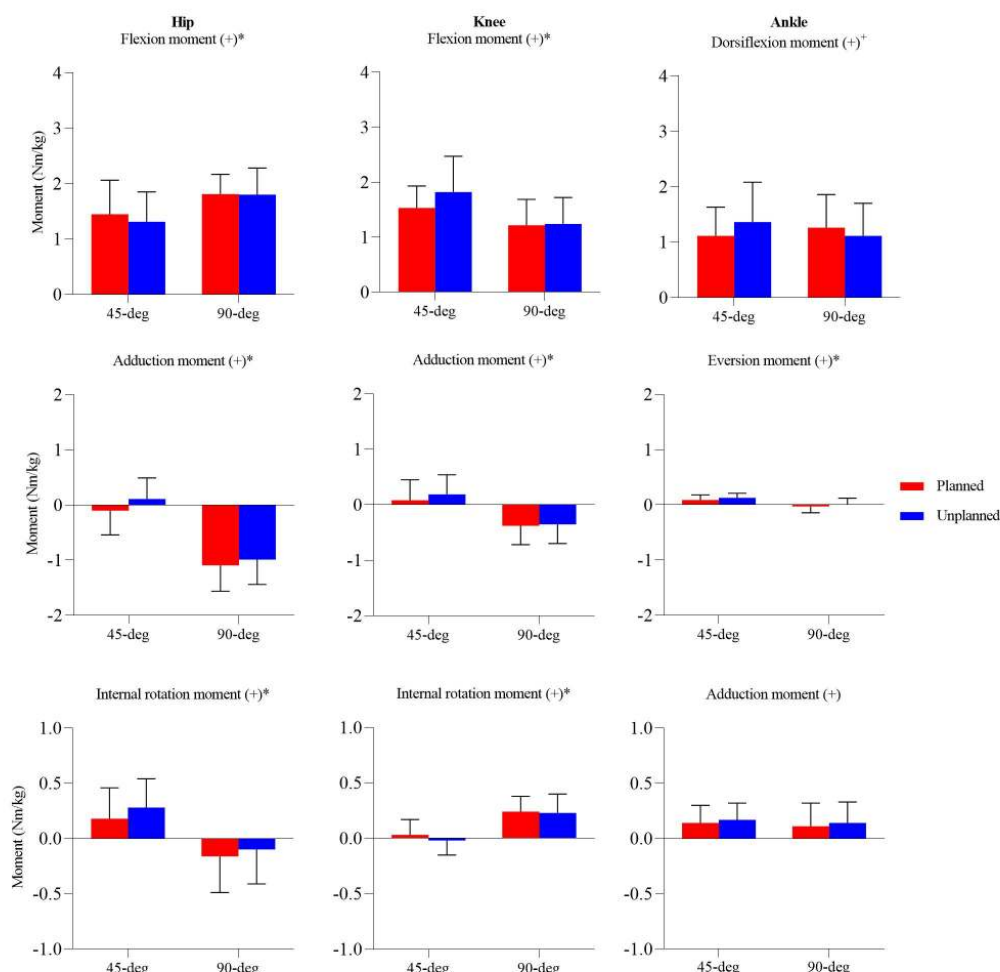


Figure 6 Joint moments in the sagittal (left column), frontal (center column), and transverse (right column) planes for 45° and 90° cutting maneuvers during planned (red) and unplanned (blue) tasks at maximum vertical ground reaction force. *Indicates a significant main effect of angle; +Indicates a significant interaction effect between angle and task.

Discussion

This study compared the responses of kinetic and kinematic parameters between planned and unplanned sidestep cutting maneuvers performed at 45° and 90° cutting angles. The findings revealed differences between the two cutting angles for several lower extremity kinetic and kinematic parameters at the two selected events, IC and max vGRF, while no differences emerged between planned and unplanned maneuvers.

Analysis of the kinetic parameters revealed differences in the mediolateral and vertical components of GRF at IC. The greater lateral GRF observed during the sidestep cutting maneuvers at 90° compared to maneuvers at 45° aligns with previous findings and supports the notion that greater lateral GRF during sidestep cutting maneuvers at sharper angles poses a higher injury risk (Sigward et al., 2015; Marques et al., 2020). Similarly, greater values for vertical GRF were found during sidestep cutting maneuvers at 90° compared to maneuvers at 45°. Comparable results were reported during sidestep cutting maneuvers at 110° compared to maneuvers at 45° (Sigward et al., 2015). The increased GRF components at IC during sharper angles may be attributed to the greater force necessary for body redirection. During sidestep cutting maneuvers at 90° versus 45°, the event max vGRF responses revealed high posterior GRF values. This posterior GRF influences the shear force and is recognized as a predictor of knee valgus moments, with higher forces correlating with greater moments. Furthermore, high knee valgus moments have been linked to an increased risk of ACL injury during sidestep cutting (Sigward et al., 2015). Hence, our findings corroborate the evidence suggesting that greater posterior and vertical GRFs during sharper angles contribute to a heightened risk of ACL injury.

This study performed an in-depth examination of kinematic parameters at the hip, knee, and ankle joints. Analysis of hip kinematics at IC revealed a greater hip abduction angle during sidestep cutting maneuvers at 90° compared to maneuvers at 45°, consistent with previous research comparing 110° and 45° cutting maneuvers (Sigward et al., 2015). The authors posited that a larger hip abduction angle is necessary for body redirection during higher-angle cutting maneuvers. Furthermore, hip abduction strength may be associated with ACL injury risk because lower hip abduction strength can increase knee load during sidestep cutting (Imwalle et al., 2009; Hewett & Myer, 2011). This study also found greater hip flexion, abduction, and external rotation moments at IC during sidestep cutting maneuvers at 90° compared to maneuvers at 45°. The increased hip adduction and internal rotation at a greater angle may result in a higher load on the knee during sidestep cutting (Imwalle et al., 2009). Hip adduction can be influenced by trunk motion, specifically lateral trunk movement. This trunk motion can directly increase knee abduction loading and lead to an increased hip adduction moment to maintain an upright stance and dissipate lower extremity force (Hewett & Myer, 2011). Previous research has demonstrated that increased hip internal rotation and hip adduction can predict greater knee valgus moments during sidestep cutting maneuvers at 45° and 110° (Imwalle et al., 2009; Sigward et al., 2015). These findings underscore the relationship between hip and knee kinematics during sidestep cutting at sharper angles.

Knee kinematics exhibited differences at IC for knee flexion, with greater values during sidestep cutting maneuvers at 90° compared to maneuvers at 45°. This finding differs from previous studies (Schreurs et al., 2017; Havens & Sigward, 2015a) that reported lower knee flexion angles during sidestep cutting maneuvers at 90° compared to 45°. The authors suggested that reduced knee flexion angles and low quadriceps force production could impact the load on the ACL. Conversely, Nagano and coworkers (2011) posited that knee flexion during sidestep cutting was necessary to decrease the excursion of internal tibial rotation and mitigate ACL injury risk. While the current study's findings on knee flexion angles differ from those of Schreurs et al. (2017), the results for knee flexion moments align. Greater knee flexion moments were observed during sidestep cutting maneuvers at 45° compared to maneuvers at 90° at both IC and max vGRF. This indicates that athletes decelerated when changing direction at a sharper angle, which in turn affected the knee moment (Schreurs et al., 2017). Notably, Yu and coworkers (2007) suggested that knee moment was not a mechanism that directly led to ACL injury. The current study observed greater knee abduction and internal rotation moments during sidestep cutting maneuvers at 90° compared to maneuvers at 45° at both IC and max vGRF. These findings suggest a potentially higher risk of ACL injury during 90° sidestep cutting, as supported by previous research (Dos'Santos et al., 2018).

To our knowledge, few studies have investigated ankle kinematics during sidestep cutting maneuvers at varying angles. This study revealed lower dorsiflexion and greater inversion during sidestep cutting maneuvers at 45° compared to maneuvers at 90° at both IC and max vGRF. These observations may be attributed to compensatory mechanisms, where reduced ankle dorsiflexion at a sharper cutting angle is associated with adjustments in knee and hip kinematics. Assessing a distinct movement pattern, Taylor and coworkers (2022) investigated the range of motion (ROM) of ankle dorsiflexion during a landing action. Their findings suggest that a limited ankle dorsiflexion ROM can amplify frontal plane knee motion during landing, leading to compensatory movements such as knee abduction and hip adduction. Consequently, ankle dorsiflexion ROM may play a crucial role in preventing ACL injuries (Fong et al., 2011).

The ankle joint moments demonstrated substantial differences, with greater dorsiflexion, inversion, and abduction during sidestep cutting maneuvers at 90° compared to maneuvers at 45° at IC. Simpson and coworkers (2020) investigated sidestep cutting in individuals with chronic ankle instability and observed a decrease in ankle eversion moment compared to a control group without instability. This finding aligns with the observation that performing a more pronounced cutting maneuver with a greater angle can induce movement changes in the ankle joint that resemble those seen in individuals with chronic ankle instability. These changes in ankle joint movement can subsequently impact the knee, adhering to the principle of the kinetic chain. This study revealed that ankle abduction was greater during sidestep cutting maneuvers at 45° compared to maneuvers at 90° at both IC and max vGRF. Consequently, athletes must exert a greater force to change direction by increasing lateral GRF when performing sharper cuttings (Nagano et al., 2011; Sigward et al., 2015).

Overall, kinetic and kinematic factors are interrelated, influencing performance and injury risk at different cutting angles. Notably, this study did not identify differences between planned and unplanned sidestep cutting maneuvers. However, previous research suggests that knee valgus angle, knee valgus moment, and knee external rotation are more pronounced during unplanned movements (Besier et al., 2001; Marques et al., 2020). These findings indicate that athletes may have limited time to adjust their posture adequately before executing unexpected cutting maneuvers. However, this study was unable to corroborate the influence of an unpredictable task on kinetic and kinematic parameters. It is possible that participants adapted quickly to the unpredictable tasks after the initial trials, thereby mitigating variability in their responses. Additionally, familiarity with the task may have obscured any potential differences.

This study has some limitations that should be acknowledged and can guide future research endeavors. First, the relatively small sample size of collegiate soccer players may limit the generalizability of the findings to a broader population. Second, the study was performed in a controlled laboratory setting, which may not fully capture the complex and unpredictable conditions of real-game situations, potentially affecting the ecological validity of the conclusions. Additionally, while the study compares cutting angles of 45° and 90°, it may not comprehensively address the entire range of angles that are commonly encountered in practical situations. For practical implications, training should incorporate drills that cover various cutting angles to prepare athletes comprehensively for different in-game scenarios. Furthermore, training should simulate both planned and unplanned sidestep cutting maneuvers to enhance performance and reduce injury risk.

Conclusions

This study demonstrates that variations in sidestep cutting angles significantly influence GRFs and lower limb joint kinematics. Specifically, cutting maneuvers at a 90° angle generated greater lateral and vertical forces at initial foot contact and produced a higher posterior force at the peak of vertical GRF compared to cutting maneuvers at a 45° angle. These findings are attributed to increased hip joint loading, evidenced by higher hip abduction angles at IC. Furthermore, there were increased hip joint moments in flexion, abduction, and external rotation at IC and max vGRF. These factors contribute to a greater knee flexion angle, as well as increased knee abduction and internal rotation moments at IC. Additionally, greater knee flexion moments and inversion angles were observed during cutting maneuvers at a 45° angle, leading to improved force distribution. Practically, coaches should diversify the exercise structure in training programs to expose players to various cutting angles, reducing the risk of injuries related to GRFs and joint loads. Athletes should also focus on strengthening the stability of the hip, knee, and ankle to better manage the increased stress from 90° cutting maneuvers. Training programs should aim for a balanced combination of cutting angles to optimize performance while prioritizing joint safety and minimizing injury risk.

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Conflicts of interest

The authors declare no conflict of interest.

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