



The influence of athletic background, lower limb dominance and cutting angle on the center of mass kinematics during a sidestep cutting task

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HIGHLIGHTS

- The cutting angle impacts the angular performance error during sidestep cutting maneuvers.
- The athlete's athletic background influenced the center of mass's kinematic patterns during sidestep cutting maneuvers;
- Even high level athletes decreased their speed significantly when changing directions at greater angles.

ABBREVIATIONS

ANOVA	Analysis of variance
GC	Group Control
GH	Group high-level
COM	Center of mass

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BACKGROUND: Successful performance in futsal depends on athletes' ability to change direction efficiently.

AIM: To investigate the effect of athletic background on COM kinematics during sidestep cutting maneuver performed at different cutting angles towards both sides.

METHOD: Eighteen futsal athletes participated, comprised of nine high-level training (Group high-level) and nine recreational (Group Control, GC). Twenty reflective markers were placed on the participant's trunk and upper and lower limbs. Participants performed acceleration at maximum speed and in a straight line for 10 meters, followed by a change of direction (30°, 60°, and 90°). The whole body's COM trajectory was identified using a body model for each trial. Differences in angular error and COM speed were evaluated with a three-way analysis of variance [Group (GH vs. GC) X Cutting angle (30° vs. 60° vs. 90°) X Side (dominant and non-dominant), with repeated measures for the last two factors].

RESULTS: The main results indicated that the angular error increased as the cutting angle increased. The high-level futsal athletes performed a cutting task for the dominant side with greater speed and higher angular errors than the control group. These findings provided important information for understanding the trajectory of the center of mass at different angles and velocities and the possible repercussions on body dynamics.

CONCLUSION: Athletic background affected the kinematic patterns of the center of mass during sidestep cutting maneuvers; when sidestep is performed with the dominant side, high-level futsal athletes changed direction faster with more significant angular error than recreational athletes.

KEYWORDS: Center-of-mass | Futsal | Sidestep cutting maneuver

INTRODUCTION

Futsal is a high-intensity intermittent team sport characterized by multifaceted motor tasks, successive high-speed sprints, change of directions, jumps, and landings¹. The athletes perform accelerations, abrupt decelerations, and sidestep-cutting maneuvers to diverse angles with a short recovery time between bouts^{2,3}. Therefore, movement control of the whole body during such direction changes, whether under planned or unanticipated conditions, arises from the interactions between individuals, tasks, and environments that require control strategies of the center of mass (COM) as a priority mechanism to change directions successfully. Also, efficiently reorienting the body's COM from a straight trajectory to a new course after the cutting maneuver is vital for a positive outcome⁴.

The risk of lower extremity injuries during athletic tasks has been associated with anatomical, hormonal, and neuromuscular aspects⁵⁻⁸. Additionally, the athletic background also seems to impact such risk, as elite athletes exhibit higher knee joint moments than non-elite athletes⁹. It has also been observed that higher movement competency could be expected from high-level athletes⁹ with more appropriate body segment placement and less injurious movement patterns. Barbado, Barbado et al.¹⁰ showed that athletic background

impacted trunk control during trunk perturbations and unstable sitting tasks, as well as superior trunk proprioceptive ability, postural control, and neuromuscular responses during seated balance tasks¹¹. However, it is still unclear whether athletic experience in futsal athletes can impact COM kinematics, especially during sidestep cutting maneuvers.

While different studies have related the sidestep cutting maneuver with knee injuries^{12–16}, it is known that lower limb kinematics is strongly related to COM displacement¹⁷. Additionally, the posterior position of the COM is also associated with an increase in braking impulse and better control of the whole body's forward momentum during running gait^{18,19} and likely during sidestep maneuvers. Therefore, a better understanding of the COM velocity and position during fast, dynamic tasks provides essential information regarding how individuals control stability during sports conditions. Similarly, the COM was more than two feet posterior to the base of support when landing in athletes who suffered ACL ruptures. Further, trunk²¹, hip¹⁵, and arms kinematics are associated with peak valgus knee moments during the sidestep-cutting maneuver²². Therefore, the ability to redirect the COM in a new direction has been reported as an essential strategy for preventing anterior cruciate ligament injuries¹⁴. For example, Donnelly, Lloyd et al.¹⁴ have found that optimizing whole-body kinematics towards the desired direction of travel reduces peak valgus knee moments during sidestep cutting maneuvers and decreases knee risk of injury. In addition, understanding the biomechanics underlying sidestep-cutting tasks are essential to inform clinicians when developing injury prevention programs²³.

An in-depth look at whole-body dynamics through COM measurements can provide a valuable understanding of the control mechanisms employed successfully to perform the sidestep-cutting maneuver²⁴. Previous studies reported increased lower extremity loading and increased muscle demands as the cutting angle increased, including shear forces, hip internal rotation, and knee valgus position contributing to knee valgus loading during cutting performed to smaller (45 degrees) and larger (110 degrees) angles¹⁶. These two aspects suggest the greater demand that must be controlled and the greater risk of injury if body segments are not placed correctly to absorb the ground reaction force to redirect the COM, so investigations with different cutting angles are warranted.

This study aimed to investigate the influence of athletic background, lower limb dominance, and cutting angle in COM kinematics during the sidestep cutting maneuver. In contrast to recreational futsal athletes, we hypothesized that professional athletes with greater sport-specific athletic experience would perform the sidestep cutting maneuver at a greater performance level observed by analyzing whole-body's COM variables. Moreover, we also hypothesized that the non-dominant limb would impact the kinematic patterns of the center of mass during the sidestep-cutting task.

METHODS

Subjects

Eighteen futsal athletes, comprised of nine high-level training (Group High-level, GH; 23.6 ± 2.34 years; 73.4 ± 3.60 kg; 8.6 ± 0.70 hours of practice/week) and nine recreational (Group Control, GC; 21.8 ± 2.66 years; 70.4 ± 7.81 kg; 0.77 ± 7.66 hours of practice/week) athletes without a history of lower limb injuries in the past six months, participated in this study. All athletes were at the beginning of the competitive season during data collection. The local Research Ethics Committee approved the study, and all participants provided written informed consent.

Table 1. Mean and standard deviation (±) of age, body weight, and hours of practice/week.

	Groups	
	GH	GC
Age (years)	23.6 ± 2.34	21.8 ± 2.66
Body weight (Kg)	73.4 ± 3.60	70.4 ± 7.81
Practice/week (hours)	8.66 ± 0.70	0.77 ± 0.66

Experimental procedures

Three-dimensional motion data were collected during the sidestep cutting maneuvers with a motion capture system with eight infrared cameras Optitrack™ Prime 17W (Natural Point Inc. – USA) positioned at approximately 30° from each other starting at 15°, 45°, and 75°, and the last camera positioned further away at 120° (Figure 1). The cameras tracked passive retroreflective markers (sampled at 250 Hz) attached to the following anatomical landmarks: both anterior superior iliac spines, first sacral vertebra, prominence of the greater trochanter, lateral and medial epicondyle of the femur, head of the fibula, lateral aspect of the calcaneal tuberosity, lateral and medial malleolus, first and fifth metatarsal heads⁸ (Figure 2).

Participants performed the cutting maneuver on a futsal court and wore their commonly used futsal practice shoes. All participants completed 18 trials: three trials per cutting angle (30°, 60°, and 90° from the runway's long axis), each performed with the dominant and non-dominant side planted on the ground for the opposite sidestep cutting maneuvers. Lower limb dominance was

determined by asking participants which leg they used to kick the ball for a distance ²⁵. They were instructed to perform the experimental tasks as fast as possible and simulate their movements performed during practice. At the beginning of each anticipated trial, the athletes were informed how they would perform the maneuver, considering the limit of the three trials for each condition.

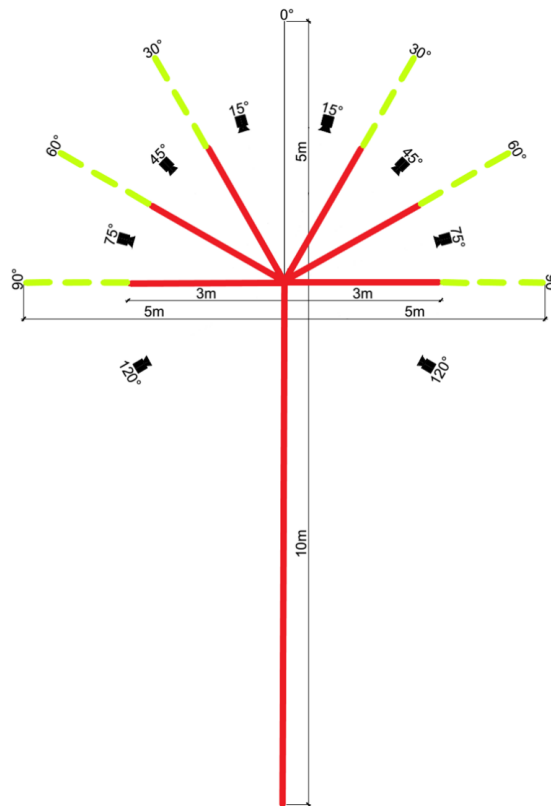


Figure 1. Arrangement of cameras in the data collection.



Figure 2. Participant standing in the anatomical position with the marker set utilized in this study.

Data Analysis

Marker trajectories were reconstructed and labeled using the software Motive® Optitrack software v.1.9 (64 bit) (NaturalPoint, Inc.), labeled, filtered with a low-pass fourth-order Butterworth filter with a 10-Hz cut-off frequency, and exported as a .c3d format. A static model, composed of feet, legs, thighs, pelvis, trunk, and upper arms, was created individually for each participant using the software Visual 3D (C-motion, Inc., Rockville, MD) with the reference system defined by x -, y -, and z -axis, where the z -axis represented the vertical direction (positive indicating upwards), the y -axis represented the anteroposterior direction (positive indicating anterior of the participant), and x -axis was defined as the cross product of y by z (positive meaning right side).

The whole body's COM trajectory was identified for each trial using a body model explicitly created for the marker placement protocol. COM trajectory was exported as .txt files and analyzed with the software Matlab® (MathWorks® Inc. Natick, Massachusetts, EUA).

The COM variables of interest were calculated between the last toe-off before the sidestep-cutting maneuver and the first foot strike after the maneuver (initial ground contact detected visually during the labelling process in Motive software). Therefore, the COM speed and COM cutting maneuver angles were calculated within this period. Lastly, the angular error was calculated by the product between the foot-strike angle and the proposed angle (30°, 60°, and 90°), calculating the actual COM speed and angular trajectory.

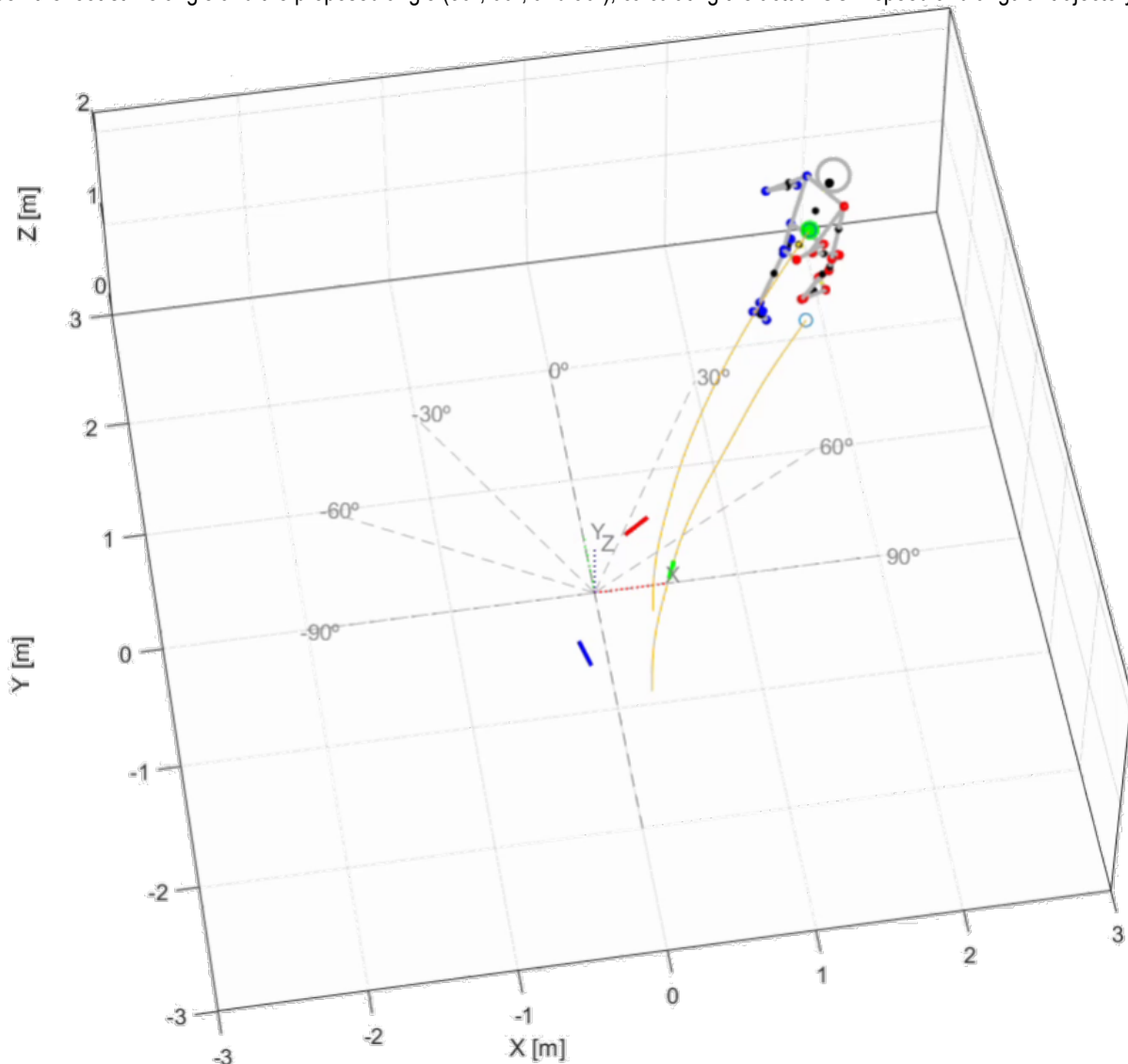


Figure 3. Illustration of a 30° sidestep cutting maneuver. The green lines represent the trajectory of the COM. The last foot contact before changing direction is represented in blue, and the first contact is represented in red.

For each group, data from the three trials per condition (i.e., cutting angle and side) were average per participant. All data presented homogeneity of variance, homoscedasticity, and sphericity. We used separate three-way analysis of variance (ANOVA) [Group (GH vs. GC) X Cutting angle (30° vs. 60° vs. 90°) X Side (dominant and non-dominant)], with repeated measures for the last two factors] to identify differences in angular error and COM speed. When applicable, we used Bonferroni's post-hoc test. The standardized magnitude of any significant difference was determined by calculating effect sizes (Cohen's *d*). The level of significance was set at $p < 0.05$. All statistical analyzes were performed with SPSS 20 (IBM Corp, Armonk, NY, USA) and JAMOVI software (Version 2.3, the jamovi Project 2022).

RESULTS

Regarding COM speed, the cutting angle had a significant main effect ($F_{2,32}=117.59$, $p < 0.001$). The COM speed was higher at 30° than at 60° (Cohen's $d=1.01$, CI: 0.68, 1.39, $p < 0.001$) and 90° cutting angle (Cohen's $d=3.79$, CI: 3.13, 4.67, $p < 0.001$). Also, the COM speed was higher at 60° compared to the 90° cutting angle (Cohen's $d=2.23$, CI: 1.74, 2.85, $p < 0.001$; Table 2). Furthermore, there was a significant interaction between group and side ($F_{1,16}=5.24$, $p=0.036$). The GH showed a higher COM speed than the GC when the cutting maneuver was performed on the dominant side (Cohen's $d= 0.57$, CI: 0.04, 1.16, $p = 0.015$; Figure 4).

Regarding angular error, there was a significant main effect of cutting angle ($F_{2,32}=48.03$, $p < 0.001$). The angular error was higher at 60° (Cohen's $d=2.83$, CI: 2.23, 3.60, $p < 0.001$) and 90° (Cohen's $d=2.24$, CI: 1.69, 2.92, $p < 0.001$) compared to the 30° cutting angle (Table 2). Moreover, there was a significant interaction between group and side ($F_{1,16}=8.78$, $p=0.009$). The GC showed lower angular error than the GH when the cutting maneuver was performed on the dominant side (Cohen's $d= -0.54$, CI: -1.12, 0.00, $p = 0.015$; Figure 4). Also, the GC presented lower angular error on the dominant side than their non-dominant side (Cohen's $d= -0.54$, CI: -0.90, -0.22, $p = 0.015$).

Table 2. Descriptive analysis of Angular Error and Center of Mass (COM) speed.

			Mean	Standard Deviation
COM speed (m/s)				
High-level	30° ^{*A}	D	5.30	0.52
		ND	5.14	0.58
	60° ^{*B}	D	4.62	0.52
		ND	4.32	0.72
	90°	D	2.85	0.42
		ND	2.89	0.42
Control	30° ^{*A}	D	4.83	0.94
		ND	4.87	0.92
	60° ^{*B}	D	3.15	1.06
		ND	3.84	0.94
	90°	D	2.26	0.36
		ND	2.17	0.26
Angular Error (°)				
High-level	30°	D	6.30	5.06
		ND	5.90	3.96
	60° ^{*C}	D	29.60	9.11
		ND	28.20	8.02
	90° ^{*C}	D	29.90	11.90
		ND	30.90	12.60
Control	30°	D ^{*D}	5.12	4.78
		ND	9.17	3.67
	60° ^{*C}	D ^{*D}	20.20	9.98
		ND	27.00	4.13
	90° ^{*C}	D ^{*D}	20.20	6.50
		ND	27.90	14.70

Notes: COM: Center of mass; * $p < 0.05$; ^A COM speed at 30° was higher than at 60° and 90°; ^B COM speed at 60° was higher than at 90°; ^C Angular error was higher at 60° and 90° than at 30°; ^D GC showed a lower angular error on the dominant side than their non-dominant side (independently of the cut angle).

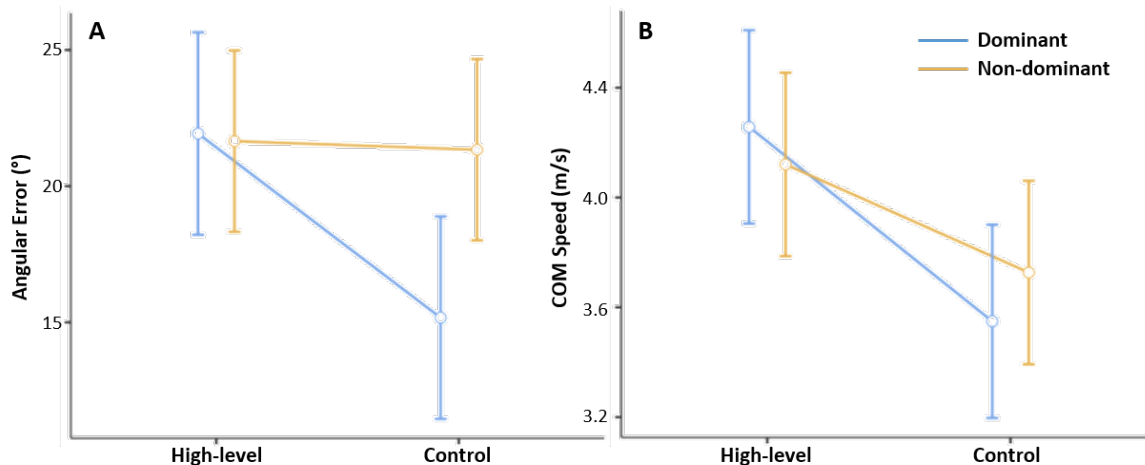


Figure 4. Interaction between group and side on Angular Error (A) and COM Speed (B). The blue and yellow lines represent the Dominant and Non-Dominant sides, respectively. Note: * $p < 0.05$; COM: Center of Mass.

DISCUSSION

The capacity to efficiently change direction is critical to achieving success in multidirectional sports, such as futsal, soccer, and handball^{26,27}. Therefore, understanding the biomechanical parameters of the sidestep cutting maneuver provides the underpinnings of training techniques for performance improvement as well as injury prevention via screening of the methods used to perform this motor task²⁸. This study investigated the influence of athletic background and cutting angle on the center of mass kinematics during the sidestep cutting maneuver. Our main finding demonstrated more angular errors during the change of direction with greater cutting demands (i.e., a greater angle of direction change). Additionally, recreational and high-level training athletes slowed their speed when greater cutting angles were performed. These findings provided important information for understanding the trajectory of the center of mass at different angles and speeds and the possible repercussions on body dynamics, thus helping to build a more robust theoretical framework of studies.

It is known that the angle and speed of the sidestep cutting maneuver are critical factors that directly impact knee joint load²⁹ and whole-body kinematics^{30–32}. Also, numerous biomechanical investigations have been conducted to elucidate the inherent doubts about changes in direction at specific angles, motivated mainly by the fact that changes in direction are the primary mechanism in the genesis of anterior cruciate ligament injuries²⁸. Further, previous studies have shown that, regardless of the cutting angle, the actual trajectory of the change of direction performed by the participants was not the same as requested, even though the participants were instructed to change direction following the demarcation lines on the ground^{33–36}. Our findings show a significant effect of cutting angle on angular error, with the average error increasing with the proposed angle. However, a direct comparison of our findings with other studies is difficult given the differences in methodological approach across the literature. For example, the environment in which data collection is performed (laboratory vs. futsal courts) likely impacts motor behavior; also, the approach speed is a variable not often controlled, which we demonstrated that it can impact COM position during cutting maneuvers.

Having reported participants running at different angles than our established angles of cutting maneuvers^{27,29}, our work was the first to elucidate the mechanisms underlying the deviation from the expected angle during the completion of the cutting task. The change of direction to 60° performed was accomplished at 56°³³. Even at a less demanding cutting angle of 45°, the sidestep maneuver was performed at 34.9°, 29.4°, 23.8°, and 17.5° when the approach speed was 2 m/s, 3 m/s, 4 m/s, and 5 m/s, respectively³⁵. Moreover, according to Supej et al.,³⁷ who studied the angles of 30°, 60°, 90°, 120°, 150° and 180° at two different velocities, reported the following angles at a speed of 2.7 m/s 7.5°, 10.7°, 15.0°, 16.2°, 9.6° and 1.5°. In contrast, at a speed of 4.1 m/s, the angles were 6.9°, 12.7°, 14.6°, 7.0°, 8.3°, 3.2°, respectively. These findings are consistent with the outcomes of our study. The angle-speed trade-off during the change of direction decreases as the change angles increase³⁵, influenced by the kinetic differences in the joints and segments during the deceleration and reacceleration phases at different angles³¹. On the other hand, more significant biomechanical changes are observed (lower limb and whole-body postures and consequent load on the knee joint) with an increase in the sidestep cutting^{31,33}. Regarding the differences found in limb dominance, it is possible that the technique chosen as the experimental task, the sidestep cutting maneuver in which the change of direction is performed towards the contralateral side of the planted foot, influenced the outcome.

The literature also reports that those who can perform sidestep tasks at higher levels can also accomplish other athletic tasks at higher performance levels^{38,39}. The primary interaction between groups observed in our study also highlights the differences in performance between those with sport-specific experience and recreational athletes. The fact that greater exposure to hours of training and the skillful motor needs inherent to the sport may allow professional athletes to use more effective strategies to accomplish changes in direction. These studies were carried out with speeds ranging from 3m/s to 7m/s and at maximum speed^{35,40-43}. As reported in our research, Schreurs et al.⁴⁴ and Rouissi et al.⁴⁵ also demonstrated significant reductions in task execution speed as the angle of change of direction increased (45°, 90°, 135°, and 180°) and consequent increase in completion time^{44,45}. In terms of speed, several studies have been conducted to elucidate the implications of different rates on changes in direction, given that speed is a critical element that significantly influences other biomechanical variables.

The physical improvements inherent to the training include improvements in the deceleration performed by the penultimate contact before the change of direction, facilitating more effective direction changes at higher speeds^{40,42}. At the same time, Jones et al.⁴⁶ indicate that minimizing the decline in entry and exit speed in a shift in direction would be the most suitable for superior performance. Furthermore, the results showed that greater deceleration capacity is eccentrically more robust and thus reduces the time of contact with the ground during direction changes⁴⁶. Therefore, combining more effective deceleration and reduced ground contact time explains the shorter completion times of turn-turn tasks at smaller angles³⁰.

Notable biomechanical manifestations occur during sidestep cutting maneuvers performed at increased speeds^{35,47}, such as the increased loads to the knee joint, represented by the increase in valgus stress and peak moment in knee abduction. On the other hand, directional changes at reduced speeds decrease these loads but compromise the performance of the change of direction task, explaining a conflict between performance and injury. Therefore, a balance between these conditions is necessary. Consequently, research should be done on modalities of more effective training to optimize performance in changes of direction while minimizing loads on the knee joint²⁸.

There are a few limitations to this investigation. First, this study was performed in a court environment but used visual stimuli to dictate directional changes. Although we aimed to use an ecological approach with the experimental task, future studies should be conducted with actual individuals as opponents. In addition, although we achieved statistically significant findings, our study had a small sample size. Furthermore, previous biomechanical investigations with team sports showed a consistent low number of participants (e.g., four and eighteen)^{48,49}. We strongly suggest that future investigations with futsal athletes performing sidestep-cutting tasks increase the number of athletes to elucidate our non-significant findings regarding the impact of cutting angles on COM kinematics.

CONCLUSION

Recreational and high-level training futsal athletes exhibited different center of mass kinematic patterns during sidestep cutting maneuvers. When the sidestep was performed with the dominant side, high-level futsal athletes changed direction at a faster but with more significant angular error compared to recreational athletes. Furthermore, both groups exhibited angular errors regardless of the side and the proposed cutting angle, with more significant angular errors with the greater change of direction angles (60° and 90°).

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