Invest Clin 65(2): 192 - 205, 2024 https://doi.org/10.54817/IC.v65n2a06

Gender-based comparative analysis of knee injury risk during cutting maneuvers in non-professional athletes: a kinetic and kinematic perspective.

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Keywords: anterior cruciate ligament; Q angle; accelerometry; force platform.

Abstract. This study aimed to compare the risk of knee injury between men and women by integrating kinetic and kinematic parameters in a non-professional athlete population. Two hundred non-professional athletes were recruited for the present study. Three change of direction tests were conducted, consisting of two open cuts at 30 (SC_{30}) and 45 degrees (SC_{45}) and one closed cut at 45 degrees (SC_{45cl}). Kinetic variables, including three-dimensional force and accelerations in the three axes of movement and ground contact time, were assessed using force platform and accelerometers. The initial and maximum angles of the ankle, knee, hip, and trunk were analyzed by photogrammetry. The data was compared between males and females to examine gender differences. Gender analysis demonstrated significant differences in force values, with women displaying higher medial-lateral (ML) force in SC_{30} and men exhibiting higher vertical ground reaction force (VGRF) and anterior-posterior (AP) force in SC_{45}. Gender-specific analysis indicated higher partial knee accelerations in women during SC_{30} and SC_{45}, with significant differences observed in acceleration in the vertical axe. Gender differences were observed in certain kinematic variables, with women displaying higher ankle flexion at initial contact in SC_{30} and higher ankle flexion at maximum flexion and ankle dorsiflexion range in SC_{45}. Men showed lower knee flexion angles in both SC_{45cl} and SC_{45}. These findings provide valuable insights into the kinetics and kinematics of change of direction movements and highlight gender-specific differences that may have implications for training and injury prevention strategies. Further research is needed to understand the underlying factors contributing to these differences and their impact on performance and injury risk.

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Análisis comparativo, basado en el género, del riesgo de lesión de rodilla durante cambios de dirección en atletas no profesionales: una perspectiva cinética y cinemática.

Invest Clin 2024; 65 (2): 192 – 205

Palabras clave: ligamento cruzado anterior; ángulo Q; acelerómetro; plataforma de fuerza.

Resumen. El objetivo de este estudio fue comparar el riesgo de lesión de rodilla entre hombres y mujeres mediante la integración de parámetros cinéticos y cinemáticos en una población de atletas no profesionales. Doscientos atletas no profesionales fueron reclutados para el presente estudio. Se realizaron tres pruebas de cambio de dirección, consistentes en dos cortes abiertos a 30 (SC_{30}) y 45 grados (SC_{45}), y un corte cerrado a 45 grados (SC_{45cl}). Se evaluaron las variables cinéticas, incluida la fuerza tridimensional, así como las aceleraciones en los tres ejes de movimiento y el tiempo de contacto con el suelo mediante plataforma de fuerza y acelerometría. Se analizaron los ángulos iniciales y máximos del tobillo, la rodilla, la cadera y el tronco a través de fotogrametría. Se realizó una comparación de los datos entre hombres y mujeres para examinar las diferencias de género. El análisis de género demostró diferencias significativas en los valores de fuerza, mostrando las mujeres una mayor fuerza medial-lateral (ML) en SC_{30}, y los hombres una mayor fuerza de reacción vertical al suelo (VGRF) y fuerza anteroposterior (AP) en SC_{45}. Los análisis específicos de género indicaron mayores aceleraciones parciales de rodilla en las mujeres durante SC_{30} y SC_{45}, observándose diferencias significativas en la aceleración en el eje vertical. Se observaron diferencias de género en determinadas variables cinemáticas, mostrando las mujeres mayor flexión del tobillo en el contacto inicial en SC_{30} y mayor flexión del tobillo en flexión máxima y rango de dorsiflexión del tobillo en SC_{45}. Los hombres mostraron ángulos de flexión de rodilla más bajos tanto en SC_{45cl} como en SC_{45}. Estos resultados proporcionan información valiosa sobre la cinética y la cinemática de los movimientos de cambio de dirección y ponen de relieve las diferencias específicas de género que pueden tener implicaciones para las estrategias de entrenamiento y prevención de lesiones. Se necesita más investigación para comprender mejor los factores subyacentes que contribuyen a estas diferencias y su impacto en el rendimiento y el riesgo de lesiones.

Received: 12-10-2023 Accepted: 08-02-2024

INTRODUCTION

Gender is a significant factor to consider in the incidence and prevention of knee injuries during changes of direction [1,2]. One of the structures with a higher incidence of injury is the anterior cruciate ligament (ACL), and research has demonstrated that women have an increased risk compared to men in sports involving frequent changes of direction and deceleration [3].

From a kinetic standpoint, the mechanism of injury during knee changes of directions involves a combination of torsional and axial loading forces applied to the ACL [3]. The knee is vulnerable during direction changes due to the combination of rotational and axial loading movements on the ligament [4]. The assessment of the ACL using force platforms is well-established [5-7]. However, there is limited evidence on its analysis using other parameters such as accelerometry in each axis and ground contact time during changes of directions.

In women, hip anatomy and knee biomechanics during changes of directions may contribute to a higher incidence of ACL injuries [8]. Women have wider hips and a larger Q angle, which can increase internal knee rotation during direction changes and thus increase the risk of ACL injuries [4]. Consequently, women exhibit a smaller flexion angle and greater dynamic valgus during knee changes, associated with lower knee stability and an increased risk of injury [3].

These kinetic and kinematic factors related to the risk of knee injuries include not only the direction and magnitude of forces applied to the knee during changes of direction [9], but also depend on the knee angle maintained and ground contact time during changes of direction [10]. However, there is limited research integrating both factors. Despite knowledge of the risk factors most associated with an increased risk of knee injuries, there is a lack of evidence in evaluating these risk factors in a non-professional athlete population, necessitating studies that assess kinetic and kinematic parameters, integrating them into a comprehensive analysis with innovative parameters such as acceleration or contact time.

Therefore, this study aimed to compare the risk of knee injury between men and women by integrating kinetic and kinematic parameters in a non-professional athlete population.

MATERIALS AND METHODS

Subjects

Two hundred non-professional athletes were recruited for the present study. After the initial meeting, the inclusion criteria were explained. These criteria consisted of engaging in physical activity for at least 30 minutes per day, three days per week, and having no history of knee or ankle injury in the past 12 months. Following this meeting, 38 athletes withdrew from the study, resulting in one hundred sixty-two participants (75% males, 25% females). All participants completed surveys to assess their weekly and daily levels of physical activity, as well as their height and body mass (Table 1). The potential risks of the tests were verbally communicated to the participants, and they provided signed informed consent. The Ethics Committee of the University of Seville approved the study.

Table 1
Characteristics of the participants.

Variables	Mean	Men (n=122)	Women (n=40)	*p*
Age (years)	24 ± 3	25 ± 2	22 ±1	0.110
Body mass (Kg)	72.84 ± 12.76	76.92 ± 8.12	65.36 ± 4.52	0.103
Height (m)	1.74 ± 0.07	1.80 ± 0.09	1.63 ± 0.06	0.071
BMI (kg/m^2)	23.78 ± 2.86	24.75 ± 1.12	21.34 ± 2.12	0.096
PA (hours/week)	8.38 ± 4.01	8.79 ± 3.96	7.91 ± 2.34	0.101
PA_{day} (hours/day)	1.97 ± 1.66	2.03 ± .098	1.86 ± 1.10	0.510

*p ≤ 0.05 Men vs Women. Statistical analysis was done using a repeated-measures two-way ANOVA. Results expressed as mean±standard error of the mean. BMI: body mass index. PA: physical activity.

Procedures

The participants completed a Maximum Voluntary Contraction (MVC) test using the Biodex Multi-joint System (Shirley, New York). The exercise was knee flexion at 45° to assess the strength of the posterior thigh musculature and knee extension at 45° to assess the anterior thigh musculature. Following this, they underwent a directional change test with the dominant foot, which included two open cuts at 45° (SC_{45}) and 30° (SC_{30}), as well as a closed cut (SC_{45cl}) on a force platform (Kistler 9260 AA6, Winterthur, Switzerland). Prior to the test, all participants underwent a standardized warm-up, which involved a 5-minute cycling session on a cycloergometer (Ergoline 900, Ergometrics, Bitz, Germany) at an intensity of 60 W (60 rpm). Additionally, they familiarized themselves with sports-specific side-cutting maneuvers through five to eight practice attempts. The velocity of the movements was regulated using a metronome set at 4-5.5 m/s, and the designated direction for the movements was indicated on the floor using tape.

Kinetics

A force plate (Kistler 9260 AA6, Winterthur, Switzerland) assessed the Ground Reaction Forces (GRF) in the vertical, mediolateral, and anteroposterior axes. Additionally, triaxial accelerometers (xyz-PLUX, PLUX-Wireless Biosignals, S.A., Lisbon, Portugal) were employed to measure accelerations at the knee and ankle joints. The knee accelerometer was positioned on the lateral condyle. In contrast, the ankle accelerometer was placed on the malleolus (Fig. 1). Antero-posterior (AP), Medial-Lateral (ML), and Longitudinal (Z) axes were calculated, and all signals were recorded at a sampling rate of 1000 Hz. Contact Time was determined during side-cutting by measuring the duration from the initial ground contact until the foot entered the flight phase.

Fig. 1. Location of accelerometers.

Kinematics

An analysis of knee, ankle, hip, and trunk angles was conducted. Reflective markers were positioned on the lateral malleolus, lateral condyle, greater trochanter, and acromion to capture the movements precisely. The angles were calculated at two specific time points: first, during the initial contact between the foot and the ground, and second, when the Vertical Ground Reaction Force (VGRF) was recorded. Three video cameras (240 Fps) were positioned perpendicularly, one for each type of change of direction, at a distance of two meters from the central point of the force platform. Subsequently, the Kinovea software was employed for digitization and angle extraction by 2D analysis.

Statistical analysis

Statistical analysis was performed using the SPSS 22.0 software package (SPSS Inc., Chicago, IL, USA). The Kolmogorov-Smirnov test assessed the data distribution, and parametric variables were identified. Baseline data were compared using an independent-sample t-test. Potential statistical differences were evaluated using a repeated-measures two-way ANOVA (time x group). Mean values are reported with standard deviation (SD), and statistical significance was set at $p \leq 0.05$.

The effect size (Cohen's d) was calculated by dividing the difference between the means of the groups by the combined standard deviation of both groups, considering the sample size. Effect sizes of 0.2 were considered small, 0.5 moderate, and 0.8 large.

RESULTS

Kinetic

During the SC_{30}, subjects exhibited a higher value of VGRF of 2135.49 ± 633.14 N, which corresponds to approximately three times their body weight, while ML Force (625.44 ± 170.99 N) and AP Force (945.62 ± 421.53 N) were lower. For the SC_{45}, VGRF was lower compared to SC_{30}, with a value of 2015.83 (± 687.27 N), while ML Force was 566.87 (± 189.22 N) and AP Force was 765.75 (± 417.06 N). In SC_{45cl}, VGRF was 1790.60 (± 517.55 N), and ML Force exhibited the smallest force value among all measured changes of directions (515.41 ± 181.53 N), as well as in AP Force (670.37 ± 368.42 N). For more specific results, the force was normalized to each subject's body weight for each directional change, as shown in Table 2.

Regarding the SC_{30}, the results showed the highest applied force in all axes, including VGRF, AP Force, and ML Force. The gender analysis in Table 2 revealed that during the SC_{30} directional change, women exhibited significantly higher force values than men in ML Force ($p = 0.045$). On the other hand, in the SC_{45}, men demonstrated higher values than women in both VGRF ($p = 0.025$) and AP Force ($p = 0.020$). Finally, in SC_{45cl}, significant differences were only observed in the force exerted in AP Force, where women displayed a higher force value than males ($p = 0.020$).

The analysis of partial knee and ankle accelerations during changes of directions is presented in Table 3. The SC_{30} exhibited the lowest $ACC_{KNEE}AP$ (1.72 ± 1.48 g). Similarly, $ACC_{ANKLE}Z$ had the lowest values compared to the other changes of directions (4.11 ±

Table 2
Descriptive analysis of force during direction change.

	Variables	Mean	Men	Women	*p*	d-Cohen
SC_{30}	VGRF (N/Kg)	29.49±7.75	29.54±7.42	29.33±8.81	0.465	0.02
	ForceAP (N/Kg)	12.99±5.32	13.54±5.45	11.26±4.53	0.159	0.43
	ForceML (N/Kg)	8.64±2.08	8.60±1.83	8.75±2.76	0.045*	-0.07
SC_{45}	VGRF (N/Kg)	27.70±7.81	28.20±8.32	26.14±5.76	0.025*	0.26
	ForceAP (N/Kg)	10.54±5.39	11.14±5.68	8.68±3.90	0.020*	0.46
	ForceML (N/Kg)	7.78±2.09	7.96±2.15	7.23±1.77	0.568	0.35
SC_{45cl}	VGRF (N/Kg)	25.13±7.59	24.02±6.92	28.60±8.61	0.159	-0.62
	ForceAP (N/Kg)	9.35±5.09	9.02±4.54	10.39±6.48	0.020*	-0.26
	ForceML (N/Kg)	7.17±2.40	7.13±2.40	7.32±2.45	0.612	-0.07

*p ≤ 0.05 Men vs Women. Statistical analysis was done using a repeated-measures two-way ANOVA. Results expressed as mean±standard error of the mean. d-Cohen = the effect size. VGRF (N) = Ground reaction force. ForceML (N) = Force in medio-lateral axe. ForceAP (N)= Force in antero-posterior axe.

Table 3
Descriptive analysis of the acceleration in the three axes during direction changes.

	SC_{30}	SC_{45}	SC_{45ml}
ACC_{KNEE_ML}	2.46±1.50	2.39±1.58	2.49±1.49
ACC_{KNEE_AP}	1.72±1.48	2.03±1.55	2.08±1.55
ACC_{KNEE_Z}	1.63±1.37	1.53±1.30	1.69±1.40
ACC_{ANKLE_ML}	4.19±0.78	4.23±0.75	4.14±0.88
ACC_{ANKLE_AP}	4.04±0.98	4.05±0.92	3.98±0.99
ACC_{ANKLE_Z}	4.11±0.81	4.13±0.68	4.20±0.79

Results expressed as mean±standard error of the mean. ACC_{KNEE}ML (g) = Acceleration in medio-lateral axe in knee. ACC_{ANKLE}AP (g) = Acceleration in antero-posterior axe in knee. ACC_{ANKLE}Z (g) = Acceleration in vertical axe in knee. ACC_{ANKLE}ML (g) = Acceleration in medio-lateral axe in ankle. ACC_{ANKLE}AP (g) = Acceleration in antero-posterior axe in ankle. ACC_{ANKLE}Z (g) = Acceleration in vertical axe in ankle.

0.81). For the SC_{45}, both ACC_{KNEE}ML (2.39 ± 1.58 g) and ACC_{KNEE}Z (1.53 ± 1.30 g) showed the lowest values. However, both ACC_{ANKLE}ML and ACC_{ANKLE}AP were higher than in the other changes of directions (4.23 ± 0.75 g and 4.05 ± 0.92 g, respectively). During the SC_{45cl}, the highest ACC_{KNEE}ML (2.49 ± 1.49 g), ACC_{KNEE}Z (1.69 ± 1.40 g), and ACC_{ANKLE}Z (4.20 ± 0.79 g) were found. Conversely, ACC_{ANKLE}ML and ACC_{ANKLE}AP were lower during this directional change (4.14 ± 0.88 g and 3.98 ± 0.99 g, respectively).

On the other hand, gender-specific acceleration was also evaluated (Table 4). During the SC_{30}, although no significant differences were observed, partial knee accelerations were higher in women than men. In the ankle, only ACC_{ANKLE}Z showed higher values in women than men (4.20 ± 0.76 g). In the case of SC_{45}, there was a trend towards higher acceleration in women compared to men, both in the knee and ankle. Regarding ACC_{KNEE}Z, the difference between women and men was significant ($p=0.002$), with women displaying an acceleration of 1.82 ± 1.54 g compared to 1.44 ± 1.21 g exhibited by men.

During the SC_{45cl}, no significant gender differences were found, except for ACC_{KNEE}ML where men exhibited higher values (2.49 ± 1.48 g). In the remaining partial knee accelerations, women showed higher values for this parameter, although they were not statistically significant. Regarding the ankle, only a trend towards higher values in men than women was observed for ACC_{ANKLE}Z (4.22 ± 0.81 g), although statistical significance was not reached.

Kinematics

Kinematic factors were also studied during changes of direction. Knee flexion angles at initial contact (KneeFlexInit) and maximum knee flexion angle (KneeFlexMax) were analyzed. The range of ankle dorsiflexion (AnkleDorsiRange), initial hip flexion angle (HipFlexInit), maximum hip flexion angle (HipFlexMax), initial trunk flexion angle (TrunkFlexInit), and maximum trunk flexion angle (TrunkFlexMax) were also analyzed.

Regarding the changes of directions (Table 5), the highest value of KneeFlexInit was observed in SC_{30} (144.6° ± 7.6°), while the lowest value of KneeFlexMax was found during SC_{45} (125.2° ± 8.9°). For the hip, the maximum value of HipFlexMax was 60.6° during SC_{30}, while the trunk flexed 92.9°. Finally, a range of ankle dorsiflexion of 39.4° was found between the initial contact of the directional change and the maximum plantar flexion during the change.

In SC_{45}, KneeFlexMax was 125.2° (extension), similar to the value of 123.3° in

Table 4
Differences between men and women in acceleration during direction changes.

	Variables	Men	Women	*p*	d-Cohen
SC_{30}	ACC_{KNEE_ML}	2.33±1.47	2.86±1.56	0.558	-0.35
	ACC_{KNEE_AP}	1.66±1.50	1.91±1.44	0.573	-0.16
	ACC_{KNEE_Z}	1.57±1.30	1.84±1.55	0.080	-0.19
	ACC_{ANKLE_ML}	4.20±0.73	4.14±0.94	0.215	0.07
	ACC_{ANKLE_AP}	4.04±0.96	4.02±1.06	0.433	0.02
	ACC_{ANKLE_Z}	4.08±0.83	4.20±0.76	0.413	-0.14
SC_{45}	ACC_{KNEE_ML}	2.25±1.54	2.81±1.66	0.516	-0.35
	ACC_{KNEE_AP}	1.92±1.57	2.35±1.49	0.563	-0.27
	ACC_{KNEE_Z}	1.44±1.21	1.82±1.54	0.002*	-0.29
	ACC_{ANKLE_ML}	4.20±0.71	4.32±0.86	0.890	-0.16
	ACC_{ANKLE_AP}	4.04±0.92	4.09±0.95	0.483	-0.05
	ACC_{ANKLE_Z}	4.09±0.70	4.27±0.60	0.344	-0.26
SC_{45ml}	ACC_{KNEE_ML}	2.49±1.48	2.48±1.55	0.866	0.01
	ACC_{KNEE_AP}	1.96±1.53	2.46±1.58	0.795	-0.32
	ACC_{KNEE_Z}	1.64±1.37	1.85±1.51	0.200	-0.14
	ACC_{ANKLE_ML}	4.11±0.87	4.22±0.90	0.937	-0.12
	ACC_{ANKLE_AP}	3.97±1.01	4.01±0.96	0.965	-0.04
	ACC_{ANKLE_Z}	4.22±0.81	4.15±0.71	0.900	0.08

*$p \leq 0.05$ Men vs Women. Statistical analysis was done using a repeated-measures two-way ANOVA. Results expressed as mean±standard error of the mean. d-Cohen = the effect size. ACC_{KNEE}ML (g) = Acceleration in medio-lateral axe in knee. ACC_{ANKLE}AP (g) = Acceleration in antero-posterior axe in knee. ACC_{ANKLE}Z (g) = Acceleration in vertical axe in knee. ACC_{ANKLE}ML (g) = Acceleration in medio-lateral axe in ankle. ACC_{ANKLE}AP (g) = Acceleration in antero-posterior axe in ankle. ACC_{ANKLE}Z (g) = Acceleration in vertical axe in ankle.

Table 5
Description of the kinematics in the experimental phase in direction change.

	SC_{30}	SC_{45}	SC_{45cl}
Variable	Mean	Mean	Mean
$Angle_{in}$Knee (degrees º)	144.63±7.65	143.45±17.86	141.43±9.87
$Angle_{max}$Knee (degrees º)	123.33±10.00	125.16±8.91	119.97±14.18
$Angle_{in}$Hip (degrees º)	42.50±2.94	41.54±5.63	40.92±4.56
$Angle_{max}$Hip (degrees º)	60.57±5.50	51.21±6.36	54.37±5.37
$Angle_{in}$Trunk (degrees º)	104.54±6.35	105.15±5.15	98.98±4.76
$Angle_{max}$Trunk (degrees º)	92.99±5.36	95.02±5.73	77.77±6.54
$Angle_{in}$Ankle (degrees º)	99.12±6.87	98.92±5.30	98.82±5.25
$Angle_{max}$Ankle (degrees º)	59.70±7.45	57.19±5.40	56.97±4.28
Ankle_Dorsi_Angle (degrees º)	39.42±3.32	41.72±5.38	41.84±4.92

Results expressed as mean±standard error of the mean. $Angle_{in}$Knee = Angle of knee in the first contact. $Angle_{max}$Knee = Angle of knee in the maximum flexion. $Angle_{in}$Hip = Angle of hip in the first contact. $Angle_{max}$Hip = Angle of hip in the maximum flexion. $Angle_{in}$Trunk = Angle of trunk in the first contact. $Angle_{max}$Trunk = Angle of trunk in the maximum flexion. $Angle_{in}$Ankle = Angle of ankle in the first contact. $Angle_{max}$Ankle = Angle of ankle in the maximum flexion. Ankle_Dorsi_Angle = Range of ankle dorsiflexion.

SC_{30}. At that moment, HipFlexMax was 51.21°, while TrunkFlexMax showed a flexion of 95.1°. Additionally, the AnkleDorsiRange was 41.7°, defined as the amount of flexion from the first contact until maximum flexion occurred.

In SC_{45cl}, KneeFlexMax was 119.9°, representing the most significant flexion of the three change types. From initiating contact to maximum knee flexion, the hip flexed by 13.5°. As for the trunk, it exhibited a flexion of 77.8° at that moment. Finally, the AnkleDorsiRange was 41.8°.

Finally, a gender analysis of kinematics during direction changes was performed (Table 6). It was observed that during SC_{30}, women exhibited a significantly higher AnkleFlexInit than men ($p=0.040$). However, gender differences during SC_{45} were found in AnkleFlexMax ($p=0.004$) and AnkleDorsiRange ($p=0.007$). Lastly, during SC_{45cl}, gender differences were found in KneeFlexInit ($p<0.001$) and KneeFlexMax ($p=0.006$), where men displayed a lower angle compared to women.

DISCUSSION

The main objective of this study was to compare the risk of knee injury between men and women through the analysis of kinetic and kinematic parameters in a population of non-professional athletes. Both kinetic aspects, such as GRF and accelerations, as well as kinematic elements, such as angles at the moment of directional change, have proven to be crucial, with women likely presenting a higher risk of injury.

Kinetics

During changes of directions, the VGRF relative to body weight was significantly higher in SC_{30} (29.49 N/kg ± 7.75) compared to SC_{45} (27.70 N/kg ± 7.81; $p=0.004$) and SC_{45cl} (25.13 N/kg ± 7.59; $p<0.001$). One possible explanation for these differences is that greater force needs to be exerted in the medial-lateral (ML) axis to perform more forceful or larger amplitude changes (remember that 30° is measured above the horizontal plane). According to Nigg's paradigm [11], which compiled studies spanning over 25 years, it became evident that VGRF plays a particularly important role in injuries among individuals engaged in physical activities such as running, especially in situations where pronation is accentuated, such as during changes of directions. This possibility is also supported by the values of ML force found in our study, as the analyzed subjects displayed significantly higher values during SC_{30} (8.64 N/kg ± 2.08) compared to SC_{45} (7.78 N/kg ± 2.08, $p<0.001$) and SC_{45cl} (7.17 N/kg ± 2.40, $p<0.001$). Therefore, higher levels of force, especially in the ML axis, which need to be attenuated by the lower extremities, suggest the need for increased preventive strategies in these types of actions common in various sports. It is essential to highlight that these 30°-changes of directions do not only increase the ML force but also the AP force (12.9 N/kg ± 5.32) when compared to SC_{45} (10.54 N/kg ± 5.39, $p<0.001$) or SC_{45cl} (9.35 N/kg ± 5.09, $p<0.001$), suggesting that biomechanical modifications in the different involved joints occur in response to these increments, as will be discussed later.

Despite numerous studies regarding the biomechanical and kinetic factors manifested during direction changes, the results are contradictory [12]. The aspect that seems most relevant in explaining this disparity of results may be the variety of procedures carried out in different studies. Brughelli *et al.* [13] differentiate between anticipated and unanticipated changes of directions, changes towards the dominant or non-dominant foot, as elements that influence the final results. Regardless of the methodological variety, it is evident that both VGRF, ML-force, and AP-force are variables closely related to the onset of injury processes [2] and should be controlled and attenuated as much as possible.

While it is evident that higher forces in both axes are associated with a greater risk

Table 6
Kinematics during direction changes and differences between men and women.

	SC_{30}				SC_{45}				SC_{45cl}			
Variables	Men	Women	*p*	d-Cohen	Men	Women	*p*	d-Cohen	Men	Women	*p*	d-Cohen
$Angle_{in}Knee$ (degrees º)	144.04±7.48	146.56±8.06	0.080	-0.33	145.33±7.53	145.13±6.43	0.891	-0.23	139.88±9.39	146.32±10.01	0.000*	-0.67
$Angle_{max}Knee$ (degrees º)	122.86±9.28	125.13±11.97	0.229	-0.23	124.74±8.80	126.75±9.22	0.239	-0.09	118.20±14.34	125.56±12.40	0.006*	-0.53
$Angle_{in}Hip$ (degrees º)	42.63±3.00	42.13±2.77	0.366	0.17	41.42±5.66	41.94±5.68	0.623	-0.15	40.93±4.74	41.00±4.01	0.938	-0.02
$Angle_{max}Hip$ (degrees º)	60.97±5.28	59.37±6.12	0.125	0.29	51.01±6.67	51.97±5.29	0.427	-0.05	54.29±5.42	54.43±5.22	0.891	-0.03
$Angle_{in}Trunk$ (degrees º)	104.45±6.53	104.72±5.87	0.819	-0.04	105.07±5.39	105.32±4.39	0.799	-0.12	98.91±4.87	99.08±4.44	0.855	-0.04
$Angle_{max}Trunk$ (degrees º)	93.09±5.56	92.59±4.76	0.624	0.09	94.82±5.92	95.51±5.10	0.524	0.04	78.00±6.61	76.72±6.18	0.299	0.20
$Angle_{in}Ankle$ (degrees º)	98.47±6.58	101.13±7.55	0.040*	-0.39	99.01±5.51	98.81±4.56	0.837	0.56	98.59±4.98	99.51±6.12	0.357	-0.17
$Angle_{max}Ankle$ (degrees º)	59.10±7.22	61.48±8.05	0.091	-0.32	57.91±5.29	54.97±5.25	0.004*	-0.52	57.13±4.31	56.37±4.24	0.351	0.18
Ankle_Dorsi_ Angle (degrees º)	39.36±3.26	39.64±3.56	0.658	-0.08	41.10±5.10	43.83±5.81	0.007*	-0.23	41.46±4.81	43.13±5.18	0.072	-0.34

*p ≤ 0.05 Men vs Women. Statistical analysis was done using a repeated-measures two-way ANOVA. Results expressed as mean±standard error of the mean. d-Cohen = the effect size. $Angle_{in}Knee$ = Angle of knee in the first contact. $Angle_{max}Knee$ = Angle of knee in the maximum flexion. $Angle_{in}Hip$ = Angle of hip in the first contact. $Angle_{max}Hip$ = Angle of hip in the maximum flexion. $Angle_{in}Trunk$ = Angle of trunk in the first contact. $Angle_{max}Trunk$ = Angle of trunk in the maximum flexion. $Angle_{in}Ankle$ = Angle of ankle in the first contact. $Angle_{max}Ankle$ = Angle of ankle in the maximum flexion. Ankle_Dorsi_Angle = Range of ankle dorsiflexion.

of injury in this population group, it is essential to mention the differences observed in the different variables according to gender. Sigward and Powers [14] suggested that an increased risk of knee injury through increased valgus can occur due to greater forces in either axis in both men and women. In fact, their work reflected values that were very similar to those found in the present study regarding VGRF during changes of directions. Our results show that during SC_{30}, where women sustained higher relative loads than men ($p=0.045$), there were significant differences in the force exerted in the ML axis. This finding has been widely observed in studies with athletes, where women have shown significantly greater valgus than men [15]. Differences in the ML axis between men and women could be related to an increased risk of injury in females due to the biomechanical position of the knee in abduction or adduction during ground contact [1,16].

On the other hand, during SC_{45}, the differences were found in VGRF ($p=0.025$) and AP force ($p=0.020$), where men significantly exceeded women. Our results are consistent with those of Liu *et al.* [17], who related a reduction of VGRF and $Force_{AP}$ with a reduction of the load supported by the knee during open direction changes. However, authors such as James *et al.* [18] found the opposite during maximum speed changes of directions. One possible explanation for these differences could be the openness of the directional change at a non-maximal speed. SC_{45} may involve less demand than SC_{30}, so being a more vertical change and closer to straight-line running, it is possible that AP force is increased, as well as VGRF in men.

Another important finding was that women exhibited a significantly higher AP force during SC_{45cl} ($p=0.020$) than men. Our results align with those presented by McLean *et al.* [2], who found higher AP force in women compared to men during a directional change with an angle of exit between 35° and 55° (women = 1.80BW [± 0.54]; men 1.54BW [± 0.76]). Moreover, although not statistically significant, women in our study also showed higher VGRF during SC_{45cl}. Recently, de Hoyo *et al.* [19] reported very similar data in male athletes who performed a closed change with a 60° opening (24.1 N/kg ± 8.4). Unfortunately, these authors only conducted their intervention with male subjects, making a comparison impossible. Nevertheless, there is limited research on the role of gender in VGRF during closed changes of directions. This is the first study to assess vertical force in men and women during closed changes.

What seems evident is the increased risk of knee injury through ML force values during changes of directions based on gender [1]. Authors like Sigward and Powers [14] indicated that women who exerted greater ML force also exhibited a greater valgus moment, which increased the risk of a knee injury. Although our results do not provide data on impulse outcomes, a possible contribution can be inferred from the partial knee and ankle acceleration. As described previously, women reported significantly higher ML force during SC_{30} than men and a slightly higher trend was observed in this variable during SC_{45cl}. In this regard, it can also be observed that women experience 18.53% more ML knee acceleration than men during SC_{30} and 19.93% during SC_{45}, with almost no difference (0.4%) during SC_{45cl}. This ML knee acceleration could represent valgus moments, although this fact should be corroborated in future studies through a kinematic analysis in the frontal plane.

There were significant differences between the different changes of direction. $ACC_{KNEE}AP$ was significantly higher in SC_{45cl} compared to SC_{30} ($p=0.006$). This finding suggests an increased risk in closed changes compared to open changes, as the load is mobilized more rapidly in the sagittal axis, potentially leading to an increase in tibial translation. However, ForceAP was significantly lower in SC_{45cl} than SC_{30} ($p<0.001$). These differences also existed between open changes, as $ACC_{KNEE}AP$ was significantly higher in SC_{45} than SC_{30} ($p=0.023$). One possible explanation for these differences could be the biomechanical demand, with SC_{45} being less demanding than SC_{30}, resulting in a faster strategy during less open changes. Analyzing $ACC_{KNEE}ML$ between changes of directions, SC_{30} showed a significantly higher acceleration than SC_{45} ($p<0.001$) and SC_{45cl} ($p<0.001$). Sigward and Powers [14] suggest that frontal plane control is necessary to reduce the relative risk of knee injury. Our data indicate that SC_{30} poses an increased risk compared to the other changes of directions, characterized by higher ForceML and $ACC_{KNEE}ML$, which are associated with an increase in knee valgus.

Regarding gender differences during changes of directions, significant differences were found only in SC_{45} ($p\leq0.05$), with women exhibiting higher $ACC_{KNEE}Z$ than men. One possible explanation could be that Chapell *et al.* [20] suggested that women experience greater shear force in the tibia during ground contact. This negative strategy indicates that energy absorption by women is less efficient than in men, or at least faster, which may be related to an increased risk of knee injury. Surprisingly, this trend is not observed in SC_{30}, which would be expected to be more demanding at this level. However, the trend still favored women, who presented 14.67% more $ACC_{KNEE}Z$ during SC_{30} and 11.35% more during SC_{45cl}.

Kinematics

It is evident that a knee angle close to the extension increases the risk of injury [20-22]. Our results indicate a higher KneeAnglein during SC_{30} compared to the other changes of directions (144.63° ±7.65). However, the maximum KneeAngle reached is highest during SC_{45} (125.16° ±8.91). Concerning the 180° representing full knee extension, the KneeAngle during SC_{30} averaged 35.37°. Markolf *et al.* [23] mentioned that knee flexion of 40º or less increases tibial translation supported by the ACL and, consequently, the tension sustained by the joint complex, leading to an increased risk of injury. A preventive strategy should involve increasing knee flexion to absorb impact. Cochrane *et al.* [24] went further by identifying angles below 30º of flexion during initial contact as a critical factor in ACL injuries during changes of directions. Consistent with Markolf *et al.* [23], our results showed that for all changes of directions, the KneeAnglein exceeded 30° (SC_{30} = 35.37°; SC_{45}= 36.55°; SC_{45cl} = 38.57°) but remained below 40°, suggesting that participants subjected the joint to excessive stress, which could partially explain the previously reported increases in force.

Despite the relationship between knee flexion angle and the relative risk of joint injury, it is evident that the biomechanical strategy during direction changes is not exclusive to the knee. Several studies have attributed a determining role to other joints reflecting greater or lesser knee flexion. Imwalle *et al.* [25] confirmed a direct influence of the hip on the knee during direction changes. Potter *et al.* [26] stated that open and closed changes of directions influence the biomechanical strategies manifested by subjects, with significantly greater hip flexion in open changes than in closed changes. However, our results do not align with those reported by these authors, as hip flexion was practically the same regardless of the type of directional change. One possible explanation could be that kinematic aspects were evaluated in an agility circuit with open and closed changes of direction, where athletes performed different direction changes depending on their own technique.

Moreover, gender-based differentiation in knee kinematics has been observed, showing different biomechanical strategies related to an increased risk of knee injury between men and women [27]. In our study, during SC_{30}, women exhibited a KneeAnglemax (in extension) of 33.4°, although without significant differences compared to men (p = .080), who exhibited an angle close to 36°. Significant differences were found during SC_{45cl}, where women had a KneeAnglein close to 146° and men to 140°. Additionally, significant gender differences were found in KneeAnglemax ($p = 0.006$), with women exhibiting more significant knee extension than men, indicating a higher injury risk. These results are consistent with those reported by James *et al.* [18], who conducted a comparative study by gender during closed direction changes to 60° and found a KneeAnglein in women 5.8° lower than in men. In our study, during SC_{45cl}, women flexed 6.4° less than men, with significant differences compared to men. This indicates that the directional change technique employed by women may be associated with an increased risk of knee injury during closed direction changes. Furthermore, in the study mentioned above, the researchers found that women significantly exceeded men in KneeAnglemax, with greater extension (64.1° and 61.4°, respectively). Our results are very similar, with men exhibiting an average of 61.8° and women 54.4°.

Regarding open changes of directions, a slightly higher, but not significant, trend in extension can be observed in women compared to men during SC_{30}. Additionally, during SC_{45}, the KneeAnglein values are practically the same in men and women, with an increase in knee extension in women at the moment of VGRF. Dai *et al.* [28] evaluated knee kinematics in men and women during SC_{45} and also found greater extension in women compared to men at the moment of VGRF. A greater range of knee flexion during the first contact could serve as a biomechanical strategy to absorb impact and reduce the load. In this sense, women have a higher relative risk of knee injury than men, as they exhibit more significant knee extension during changes of direction [29].

In conclusion, the study highlights the importance of controlling GRF and biomechanical strategies during changes in direction to reduce the risk of knee injuries. Significant gender differences in forces and accelerations during changes of directions were observed, underscoring the need to consider specific gender factors in injury prevention. Variables such as VGRF, $Force_{ML}$, and ForceAP, as well as acceleration in the vertical axis, appear to be deterministic kinetic variables that explain these gender differences and knee flexion angles. The results can be helpful in informing the design of preventive strategies in the sports field and improving the understanding of the underlying mechanisms of knee injuries during changes of direction.

Funding

None.

Conflict of interests

The authors declared that they have no competing interests.

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Conception (AFM), design and acquisition of data (AFM), formal analysis (BS), interpretation of data (AFM and BS), investigation (AFM and BS), writing the original draft preparation (AFM), writing the review and editing (TH), supervision (TH and BS).

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