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Differences in movement patterns related to anterior cruciate ligament injury risk in elite judokas according to sex: A cross-sectional clinical approach study

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ABSTRACT

The anterior cruciate ligament (ACL) injury stands as a significant concern in judo, necessitating preventive measures. The primary injury mechanism involves knee collapse in valgus, often linked to deficiencies in core strength, neuromuscular control, external rotators, hip abductors, and limitations in ankle and hip mobility. Sex-wise, the injury is more prevalent in women across various sports. Therefore, in the present study we observed this possible intersexual disparity in the difference of movement patterns among elite judokas according to their sex, in order to identify those athletes with a higher risk of ACL injury. Notably, there were no discernible differences between sexes in the single leg squat test. Both men and women exhibited compromised neuromuscular control in the non-dominant leg. While ankle dorsiflexion and hip external rotation showed no gender disparities, differences in internal rotation were noted. This particular movement restriction may elevate the risk of ACL injury.

Keywords: anterior cruciate ligament, judo, biomechanics, knee injury, sex differences

INTRODUCTION

Judo is a very popular and commonly practiced martial art and Olympic sports of Japanese origin [1], with more than 20 million judokas worldwide [2]. It has been observed that 79.0% of judokas suffer or have suffered an injury lasting more than three weeks [3]. Of all the injuries recorded, the most serious is anterior cruciate ligament (ACL) rupture [2]. ACL rupture had a time loss of three-12 weeks in 10.0%, three-six months in 26.0%, six-nine months in 32.0%, nine-12 months in 18.0% and more than 12 months in 14.0% of the injured judokas. Regarding the post-injury sport level, 32.0% reached the same level, 39% slightly reduced, 24.0% quite reduced, and 5.0% gave up judo [2]. It is especially important to note that ACL injuries can lead to the development of osteoarthritis and/or joint instability, which can affect sports practice as well as work or daily life [4].

According to multiple literature sources, the mechanism of ACL injury is knee collapse in knee valgus [5-13]. Dynamic knee valgus is a multiplanar movement pattern of the lower extremity that is potentially composed of a combination of femoral adduction and internal rotation, knee abduction, anterior tibial translation, external tibial rotation and ankle eversion [7, 9].

The origin of ACL injury is multifactorial and is largely caused by neuromuscular deficits in structures such as the core, hamstring and quadriceps muscles, hip abductors and external rotators, decreased ankle dorsiflexion and hip mobility [7,8]. Of all these there are differences between men and women, which can lead to a dynamic valgus of the knee and, consequently, to the risk of ACL injury [7, 8, 10-23]. A study in [7] demonstrated that men and women exhibit different activation and muscle recruitment strategies at the hip and knee joints. In judo, the most common mechanism of suffering an ACL tear is through direct contact (70.1%), or indirect contact (20.1%), unlike other sports such as basketball, where the injury usually occurs without contact, in movements such as braking, jumping, or pivoting [5]. Most cases occurred when the injured judoka was attacked (67.4%), especially when the leg was used as a fulcrum to knock down the opponent.

Examples include osoto-gari (18.6%) (**Figure 1**), harai-goshi (11.6%) (**Figure 2**), kosoto-gari/gake (14.0%) (**Figure 3**), or kouchi-gari/gake (9.3%) (**Figure 4**).

Figure 1. Osoto-gari (Source: Authors, reprinted with informed consent and authorisation of the patients)

Figure 2. Harai-goshi (Source: Authors, reprinted with informed consent and authorisation of the patients)

Figure 3. Kosoto-gari/gake (Source: Authors, reprinted with informed consent and authorisation of the patients)

Figure 4. Kouchi-gari/gake (Source: Authors, reprinted with informed consent and authorisation of the patients)

Other examples include counterattacks (18.6%) (**Figure 5**), attacks (14.0%), and the tai-otoshi technique (11.6%) (**Figure 6**) being of note [5, 24].

It has been observed that more injuries occur when judokas fight between judokas of different laterality (kenka-yotsu), that is, right-handed vs. left-handed, than when they are of the same laterality (ai-yotsu), right-handed vs. right-handed, or left-handed vs. left-handed (**Figure 7**) [1, 2].

Figure 5. Counterattack (Source: Authors, reprinted with informed consent and authorisation of the patients)

Figure 6. Tai-otoshi (Source: Authors, reprinted with informed consent and authorisation of the patients)

Figure 7. Grip styles: Kenka-yotsu grip style–A judoka & opponent have different grip sides (left) & Ai-yotsu grip style–A judoka & opponent have same grip side (Source: Authors, reprinted with informed consent and authorisation of the patients)

It is speculated that the higher risk of injury in kenka-yotsu is due to a greater likelihood of being counter-attacked, a common condition of ACL tears [3, 24].

In a study of ACL injuries in soccer [25], researchers examined 107 case videos of 134 Italian men's professional soccer matches over 10 years. It was found that 44.0% of the injuries were non-contact, 44.0% were indirect contact, and 12.0% were direct contact.

Four main injury situations were identified: pressing and tackling, tackling, regaining balance after a kick, and landing after a jump. Knee valgus loading was the primary injury pattern in all patients (81.0%). Most injuries (62.0%) occurred during the first half of the matches, with peaks at the start and end of the season.

Under a physiological load in a position commonly assumed in sports, women tend to position their entire lower extremity and activate muscles in a manner that could increase strain on the ACL [26].

Figure 8. CeAR sport facilities (left) & CeAR judo mat in a judo training (right) (Source: Authors, reprinted with informed consent and authorisation of the patients)

Therefore, the main objective of the present study was to detect the possible existence of differences in movement patterns among elite judokas according to their sex to identify athletes with a higher risk of ACL injury.

MATERIALS & METHODS

Study Design

We conducted an observational cross-sectional study of 14 male (61.0%) and nine female (39.0%) professional judokas (n=23) performed between November 2022 and March 2023. The procedures were conducted following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement and checklist [27].

Participants

In order to reach an approximation to this athlete profile, the sample was composed of a group of elite judokas from the Specialized High-Performance Center (CeAR) of Judo from Valencia (**Figure 8**). The selected athletes had to meet a series of requirements to be included in the study: judoka from the Valencia Judo CeAR, be competing at the time of the measurements in national and international championships, be over 18 years of age, not suffer any injury, have not undergone recent surgery, or are in a period of readaptation.

Clinical Measurements

In the present study, the SLS test was used to assess the risk of ACL injury was the single leg squat (SLS) test. The reason for choosing this test is that, as noted above, the mechanism of ACL injury production in judo is through a displacement of the center of mass towards one leg together with direct contact on that leg, which makes it similar to a monopodal squat. According to Zeller et al. [26], the SLS test is a promising candidate for assessing the risk of ACL injury. Based on Baldazzi et al. [28], the SLS test includes single leg closed chain movements, which are typical of open-skill sports, and are also used for knee stability and the likelihood of ACL injury.

The SLS test was performed as described by Ugalde et al. (**Figure 9**) [29]. The barefooted athletes were asked to place their hands on their hips, stand on one limb, and flex the opposite limb to 90°. They were then instructed to perform a single leg squat to 30° of knee flexion and return to a fully extended knee position. We checked that the range of motion of the SLS was 30° of knee flexion using the goniometer. SLS was performed thrice in a row on each leg. The investigator noted any abnormal responses that consisted of arms flailing, Trendelenberg, or collapse of the supporting knee into valgus, indicating an abnormal response. We defined a positive SLS

Figure 9. Single leg squat test: First stage of test (left) & Second stage of test (right) (Source: Authors, reprinted with informed consent and authorisation of the patients)

Figure 10. Lunge test (Source: Authors, reprinted with informed consent and authorisation of the patients)

test as >2/3 abnormal responses on either leg of the six total trials (three SLS trials on each leg). Each participant was given either a Positive or Negative score on their SLS test. A Positive SLS test result may be suggestive of poor lower extremity mechanics, reduced core strength, or hip abductor weakness.

The SLS test is a simple screening tool that can be employed in physicians' offices or by pre-sport physicians to screen for athletes with poor knee control with no additional equipment. In young adults, SLS showed good inter- and intra-rater reliability, which correlated well with the 3D analysis of peak knee flexion, knee medio-lateral displacement, and hip adduction. SLS compared to 2D and 3D video analysis was valid and reliable in young, healthy adults for medio-lateral knee motion and hip function. Thus, SLS can reliably predict dynamic knee valgus [29].

Ankle dorsiflexion was assessed using the lunge test method [31] (**Figure 10**). The foot of the ankle was placed along the tape measure, with the big toe against the wall and the toe and heel on the center line of the tape. The patient was instructed to bring his knee close to the wall, as stiffness or pain would allow. Pronation was not controlled. When necessary, the patient was allowed to lean against the wall. The therapist firmly held the patient's heel on the floor. They were asked to move their toes progressively backward away from the wall on the treadmill, repeating the lunging motion until the maximum

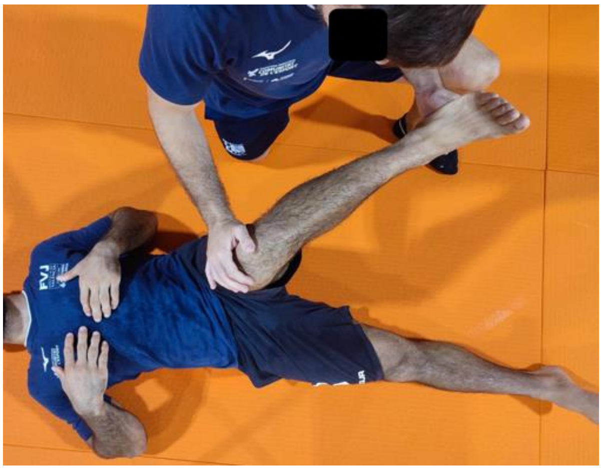

Figure 11. Passive hip internal rotation (Source: Authors, reprinted with informed consent and authorisation of the patients)

distance the knee could be brought towards the wall without the heel being lifted. The point at which the patient's heel was felt to lift indicated the limit of motion at which the measurement was performed [31]. The lunge test has demonstrated good to excellent reliability, with intraclass correlation coefficients (ICC) between 0.80 and 0.96 for the asymptomatic side. On the symptomatic side, the lunge test showed excellent reliability, with ICCs greater than 0.90 [32].

Passive hip mobility was assessed bilaterally using the hip mobility test. For this purpose, the participant was placed in the supine position with the hip assessed at 90° flexion. The contralateral limb was then fully extended. While performing the internal and external rotations of the hip to be measured, the pelvis was stabilized so that the head and neck of the femur contacted the acetabular rim (**Figure 11**).

These measurements were performed three times for each hip and measured using a universal goniometer, and the average value was calculated [21].

To perform the tests, it was necessary to use a tape measure with an accuracy of one mm for the lunge test and a goniometer for the hip mobility test. The application of a goniometer in these circumstances provides good reliability for the symptomatic side [30]. All of these possibilities refer to possible abnormalities during the SLS test that could make it positive: arms (arms failing), nothing (no abnormal movements, negative), pelvis (Trendelenberg), valgus (knee valgus), valgus, and arms (knee valgus and arm failing), valgus, arms, and pelvis (all of them). The number of participants with these characteristics and their percentages were collected for SLS. On the lunge test, the values were collected in centimeters, and on the hip mobility test, in degrees.

Statistical Analysis

For statistical analysis, R ver. 4.1.3 (R Foundation for Statistical Computing, Institute for Statistics and Mathematics, Welthandelsplatz 1, 1020 Vienna, Austria) was used. The level of significance was set at $p<0.05$. The Shapiro-Wilk test was used to test the distribution of the quantitative variables. Quantitative variables were described as mean (M)±standard deviation (SD) and qualitative variables as absolute and relative values (%). The presence of significant differences in the quantitative outcome variables based on sex were analyzed using Student's t-test (after verification of the assumption of homogeneity of variances with Levene's test) or the the Mann-Whitney U test depending on its distribution, while Fisher's exact test was applied to the qualitative variables. The effect size was calculated using Cohen's d in the quantitative variables with a normal distribution, defined as small (<0.5), medium (0.5-0.8) and large (0.8), or with the non-parametric estimator r in the variables with a non-normal distribution defined as small (<0.4), medium (0.4-0.6) and large (>0.6). For qualitative variables, Cramer's V was used, defining it as small (<0.1), medium (0.1-0.2) and large (>0.2). Linear regression models were applied with the quantitative outcome variables as dependent and sex and dominance as explanatory variable; In the case of SLS, it was dichotomized as negative (absence of response) and positive (presence of any response) to apply similar binary logistic regression models. In both case, the objective was to evaluate the effect of the dominant leg on the result, depending on sex.

RESULTS

The study involved 23 players, with the majority being men (60.9%) and the right dominant leg (69.6%) (**Table 1**).

The presence of significant differences was verified in the variable internal rotation dominant leg (°) (Z=2.588, p=0.01) with a medium and significant effect size and higher values in women at 12.389 (2.651, 22.127) degrees compared to men. Significant differences are also shown in the variable internal rotation of the non-dominant leg (°) (t[15.614]=2.615, p=0.014) with a large and significant effect size and values were also higher in women at 12 (2.253, 21.747) degrees compared to men (**Table 2** and **Figure 12**).

Table 1. Demographic characteristics of participants & overall outcomes (n=23)

Characteristics	n (%)
Sex	
Female	9 (39.1)
Male	14 (60.9)
Dominant leg	
Left	7 (30.4)
Right	16 (69.6)
SLS dominant leg	
Arms	2 (8.7)
Nothing	12 (52.2)
Pelvis	1 (4.3)
Valgus	6 (26.1)
Valgus & arms	1 (4.3)
Valgus, arms, & pelvis	1 (4.3)
SLS non-dominant leg	
Arms	5 (21.7)
Arms & pelvis	2 (8.7)
Nothing	10 (43.5)
Pelvis & valgus	2 (8.7)
Valgus	2 (8.7)
Valgus & arms	1 (4.3)
Valgus & pelvis	1 (4.3)
	M±SD
Lunge test dominant leg (cm)	13.04±3.47
Lunge test non-dominant leg (cm)	13.17±3.02
External rotation dominant leg (°)	90.52±8.70
Internal rotation dominant leg (°)	54.35±12.32
External rotation non-dominant leg (°)	87.91±10.25
Internal rotation non-dominant leg (°)	52.91±11.72

Note. Data are expressed as M±SD or with absolute and relative values (%); SLS: single leg squat test

Table 2. Outcomes by sex

Variable	Female (n=9)	Male (n=14)	Levene test[a]	[a]p	Average difference (95% CI)	Effect size (95% CI)
SLS dominant leg						
Arms	0 (0.0)	2 (14.3)		0.486		0.440 (0.466, 1.000)⸭
Nothing	5 (55.6)	7 (50.0)				
Pelvis	0 (0.0)	1 (7.1)				
Valgus	3 (33.3)	3 (21.4)				
Valgus & arms	0 (0.0)	1 (7.1)				
Valgus, arms, & pelvis	1 (11.1)	0 (0.0)				
SLS non-dominant leg						
Arms	2 (22.2)	3 (21.4)		0.719		0.400 (0.511, 1.000)⸭
Arms & pelvis	1 (11.1)	1 (7.1)				
Nothing	4 (44.4)	6 (42.9)				
Pelvis & valgus	0 (0.0)	2 (14.3)				
Valgus	1 (11.1)	1 (7.1)				
Valgus & arms	0 (0.0)	1 (7.1)				
Valgus & pelvis	1 (11.1)	0 (0.0)				
Lunge test dominant leg (cm)	12.11±2.98	13.64±3.73	0.354	0.313	-1.532 (-4.468, 1.405)	-0.442 (-1.341, 0.457)*
Lunge test non-dominant leg (cm)	12.33±2.65	13.71±3.22	0.451	0.296	-1.381 (-3.955, 1.193)	-0.458 (-1.358, 0.441)*
External rotation dominant leg (°)	93.11±8.88	88.86±8.47	0.698	0.262	4.254 (-3.624, 12.132)	0.493 (-0.408, 1.394)*
Internal rotation dominant leg (°)	61.89±10.69	49.50±11.04	0.884	0.010	12.389 (2.651, 22.127)	0.540 (0.160, 0.798)†
External rotation non-dominant leg (°)	92.56±12.95	84.93±7.08	0.017	0.134	7.627 (-2.735, 17.989)	0.783 (-0.137, 1.703)*
Internal rotation non-dominant leg (°)	60.00±11.18	48.00±9.65	0.790	0.014	12.000 (2.253, 21.747)	1.166 (0.190, 2.142)*

Note. CI: Confidence interval; Data expressed as M±SD or with absolute & relative values (%); SLS: Single Leg Squat test; *: Cohen's d effect size; †: Non-parametric r effect size; ⸭: Cramer's V effect size; & [a]Significant if p<0.05 (shown in red)

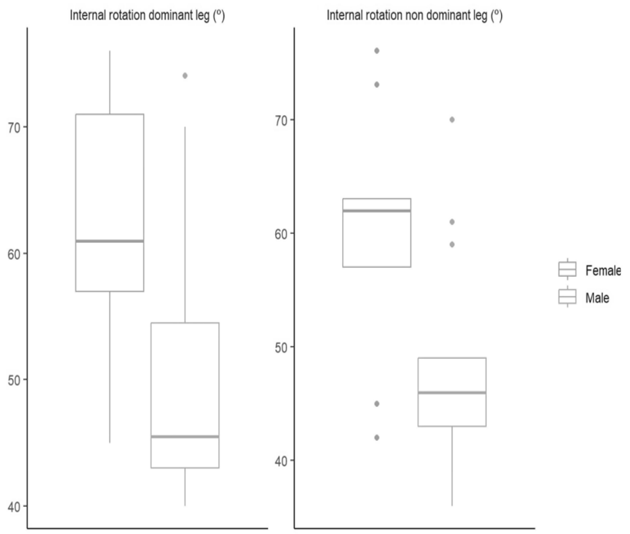

Figure 12. Significant variables box-plots (Source: Authors' own elaboration)

Table 3 shows how neither the dominant leg nor the interaction sex (dominant leg) are significant, which indicates that dominance does not influence the results.

DISCUSSION

The main objective of the present study was to detect the possible existence of a differences in movement patterns among elite judokas according to their sex, to identify the athletes with a higher risk of ACL injury.

First, no differences were observed between sexes in the SLS test, neither in the dominant nor in the non-dominant leg. Furthermore, no differences were observed between men and women in the different hip external rotation tests of both lower limbs and in the lunge test bilaterally. In contrast, in the hip, internal rotation tests, differences were observed between men and women in both the dominant and non-dominant legs.

Table 3. Dominant leg covariable effect over sex

Sex	Lunge test dominant leg (cm)	F(1)=1.154, p=0.296	External rotation dominant leg (°)	F(1)=1.230, p=0.281	External rotation non-dominant leg (°)	F(1)=3.793, p=0.066	SLS dominant leg	Z=0.438, p=0.661
Dominant leg		F(1)=3.642, p=0.072		F(1)=0.270, p=0.609		F(1)=4.157, p=0.056		Z=-0.299, p=0.765
Sex: Dominant leg		F(1)=0.000, p=0.987		F(1)=0.149, p=0.703		F(1)=0.565, p=0.461		Z=-0.244, p=0.807
Sex	Lunge test non-dominant leg (cm)	F(1)=1.269, p=0.274	Internal rotation dominant leg (°)	F(1)=7.36, p=0.014	Internal rotation non-dominant leg (°)	F(1)=7.616, p=0.013	SLS non-dominant leg	Z=0.008, p=0.993
Dominant leg		F(1)=4.159, p=0.056		F(1)=2.334, p=0.143		F(1)=1.161, p=0.295		Z=1.546, p=0.122
Sex: Dominant leg		F(1)=0.018, p=0.895		F(1)=0.551, p=0.467		F(1)=1.903, p=0.185		Z=-0.009, p=0.993

Note. SLS: Single Leg Squat test; [a]Significant if p<0.05 (shown in red)

With regard to the SLS test, no differences were observed between men and women in either the dominant or non-dominant lower limb.

It should also be noted that the prevalence of obtaining a positive test result in this test is quite low: 8.7% for the dominant and 26.1% for the non-dominant. If the data are analyzed in more depth, it can be observed that of all the judokas, a large number obtained at least one positive result in one of the items assessed in the SLS test (in the dominant leg 60.9% and in the non-dominant leg 82.6%). If only one item is positive, the overall test result is negative; therefore it is important to note the high rate of positives in these aspects in isolation. These data are of great interest, as they may support the high prevalence of ACL injuries in judo.

If we analyze the positivity of the test between both legs, we observe a higher positivity of some of the items and of SLS test in the non-dominant leg, which is of great importance because this is the supporting leg in monopodal support techniques.

In addition, more ACL injuries occur in bouts between judokas with opposite laterality and with techniques such as osoto-gari or harai-goshi in which the attacked judoka receives an attack on the non-dominant leg [5]. Of all the possible abnormal movement patterns that can be observed and assessed in the SLS test, such as arm flailing, knee valgus and Trendelenberg, the one that can be seen the least in both legs is pelvic instability or on Trendelenberg sign (8.7% in the dominant lower limb and 21.7% in the non-dominant lower limb). This indicates good control of the core musculature. However, a high percentage of judokas had uncontrolled arm movements (17.4 and 34.8%, respectively) and dynamic knee valgus (34.8 and 26.1%, respectively). From these data, it can be assumed that the judoka's stability cannot depend on the arms, as in the usual combat situations in which ACL injuries usually occur, it is the opponent who attacks and is unlikely to be able to maintain the balance and stability of the attacked knee with the support of the hands on the opponent. However, it is of utmost importance to highlight the role of knee valgus observed in the SLS test, a movement previously mentioned as being mainly responsible for ACL injury [5-13]. Therefore, neuromuscular control exercises should be performed to stabilize the dynamic knee valgus without intervention of the arms.

A study in [25] found that 90.0% of ACL injuries involved loading the injured leg, often with a limb on the ground (70.0%). They stated that proper biomechanics and aligning force vectors for joint stability were crucial. ACL injuries result from mechanical perturbations to the upper or lower body during interactions with opponents, without direct contact with the knee. Hip abduction motion was frequent, resulting in increased hip internal rotation and adduction in most cases, possibly because of an externally oriented knee abduction moment from hip abduction. Injuries were more frequent in the first half of the matches, suggesting that factors other than fatigue played a role, possibly related to hip rotation and myotatic reflexes.

In terms of physical preparation for competition, we evaluated the efficacy of a specific judo injury prevention warm-up program supervised by a coach on the overall injury prevalence and concluded that the intervention did not significantly reduce the prevalence of overall and severe injuries [33]. We found that the type of injury, sport level, treatment method and gender seemed to influence the judoka's psychological preparation and ability to return to sports after injury [34]. However, in the present study no differences were observed between sexes in the external rotation of the athletes participating in the study, neither in the dominant nor in the non-dominant leg. However, statistically significant differences were observed in the internal rotation of both legs, with the mean range of this movement being lower in men than in women. This difference may be related to the dynamic knee valgus observed as the main mechanism of injury [5-13]. This movement involves adduction and internal rotation of the joint [7, 9].

On the other hand, it is of great relevance to highlight that restrictions in hip mobility may be a risk factor for ACL injury [21, 22, 31]. Clinical and radiological studies assessing this injury risk have shown an association between decreased hip rotation and the likelihood of previous ACL injuries [22]. In addition, in silico biomechanical simulations and cadaver studies have provided evidence of the mechanism of hip restriction at the ACL, highlighting the importance of internal rotation restrictions. Indeed, the study in [22] discussed the association between ACL injury risk and hip internal rotation limitation. As the hip IR increases, the likelihood of ACL rupture decreases. However, prospective cohort studies are needed to establish that decreased hip mobility is a risk factor for ACL injury, so this may not be sufficient to determine that men are at a greater risk of ACL injury. However, as mentioned above, it is of great importance to work on neuromuscular control of the external rotators and hip abductors, which are responsible for braking and stabilizing the knee towards valgus collapse. If they do not exercise their function, it could lead to increased ligamentous tension and thus an increased risk of ACL injury [7, 9, 10, 15].

Finally, the data obtained in the lunge test were analyzed. This test also did not show different results between men and women for both the dominant and non-dominant lower limbs. Although the averages of both legs were higher in the male sex, these differences were not statistically significant; therefore, so neither can we show a disparity in the risk of ACL injury between the sexes due to ankle dorsiflexion restriction.

As already noted, there is no biomechanical factor that is really a demonstrable cause to conclude that, as in other sports such as basketball, handball, volleyball or football, the risk of ACL injury is higher in women than in men [5-7, 35]. This is probably due to the way in which they occur. In all sports mentioned above, the majority of ACL injuries occur in non-contact actions such as changes in direction, braking and jumping. Based on these results, neuromuscular training methods were developed to reduce the risk of non-contact ACL injuries. Due to the characteristics of judo as a martial art, a non-contact mechanism is not the main cause of ACL injuries, and a neuromuscular training approach may not be suitable for prevention [5]. As developed in [5], the occurrence of ACL injury is more common in movements where the leg is used as a fulcrum, when the injured judoka is attacked, and when the judoka is on the opposite side of the body. Therefore, the difference observed between the sexes in other sports may not be extrapolated to judo [36]. Deficits in postural control and neuromuscular function of the knee and hip are highly predictive of the risk of a second ACL injury after returning to sports following ACL reconstruction [7, 37]. Rehabilitation programs aimed at reducing functional asymmetries prior to returning to sports after ACL reconstruction may be necessary to safely reintegrate these patients into sport [7, 37].

In our study, we assessed mobility and activation of the lower limb joints, observing limitations in hip internal rotation that could modify the force vectors in the entire lower limb, increasing the risk of injury. Impaired hip rotation ROM is commonly associated with lower extremity pathology [38]. The influence of central descending reflexes in improving hip mobility has been demonstrated [39]. The sensorimotor cortex contributes to joint flexibility [40].

It is necessary to identify and modulate the mobility dysfunctions produced by the central descending reflexes in order to improve neuromuscular activation and, therefore, joint stability. In this way, the judoka would be repaired as much as possible to respond and protect himself from the opponent's impacts.

Limitations & Strengths

This study also presents a series of limitations, such as the proportion of both sexes and the number of participants because they are elite athletes.

In addition, no data was collected on previous injuries because they were competing at a high level and thus, were able to assess the possible dysfunctions that they could create.

This would have been of great interest as a previous ACL injury significantly increases the likelihood of sustaining another ACL injury. However, significant differences were found only in hip internal rotation.

CONCLUSIONS

Although there is a difference between men and women in the prevalence of ACL injuries in other sports, there is no sex disparity in judo. This may be due to the fact that the most common mechanism of injury in judo is contact, unlike in other sports, where it is non-contact.

There was worse neuromuscular control of the non-dominant leg in men and women. Motor control is defined here as the way in which the nervous system controls posture and movement to perform a specific motor task and includes consideration of all the associated motor, sensory, and integrative processes.

No differences were observed in hip external rotation between men and women, but there were differences in internal rotation, possibly produced by central descending reflexes, a movement whose restriction may be related to an increased risk of ACL injury.

Author contributions: FJP-B, EAS-R, JNC-Z, & FS-S: validation; **FJP-B, JNC-Z, & FS-S:** methodology; **FJP-B & JNC-Z:** data curation; **FJP-B & FS-S:** conceptualization and writing–original draft preparation; **FJP-B:** software, investigation, resources, and visualization; **EAS-R, JNC-Z, & FS-S:** formal analysis, writing–review & editing, & supervision; & **FS-S:** project administration. All authors agree with the results and conclusions.

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Ethical statement: The authors stated that the study was conducted in accordance with the Declaration of Helsinki and was approved by the Human Research Ethics Committee of the Universitat de Valencia, Valencia, Spain by number 1675151998994 on February 9, 2023. Written informed consent was obtained from all subjects involved in this study.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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