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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 sport of Japanese origin [1] with more than 20 million judokas worldwide [2]. It is 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 the anterior cruciate ligament (ACL) rupture [2]. ACL rupture affects with 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, 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]. The study in [7] demonstrate 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]. It has also been seen that most cases occur when the injured judoka is attacked (67.4%), especially in those techniques in which the leg is used as a fulcrum to knock the opponent down.

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 counterattacking (18.6%) (**Figure 5**) or attacking (14.0%), with 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), i.e., 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 situation of suffering an ACL tear [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 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 from a jump. Knee valgus loading was the primary injury pattern in all situations (81.0%). Most injuries (62.0%) occurred in the first half of matches, with peaks at the start and end of the season.

Under a physiologic 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 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 a differences in movement patterns among elite judokas according to their sex, in order to identify those athletes with a higher risk of ACL injury.

## MATERIALS & METHODS

### Study Design

We conducted an observational cross-sectional study on 14 male (61.0%) and nine female (39.0%) professional judokas (n=23) performed between November 2022 and March 2023. 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 be judoka from the Valencia Judo CeAR and be competing at the time of the measurements in national and international championships; be over 18 years of age, not suffer any injury, not have undergone recent surgery or be in a period of readaptation.

### Clinical Measurements

For the present study, the test chosen 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 centre 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], SLS test can be considered a promising candidate for the assessment of risk of ACL injury. Based on Baldazzi et al. [28], SLS test includes single leg closed chain movements, which are typical of open-skill sports, and is also used for knee stability and on 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 and stand on one limb and flex the opposing limb to ninety degrees. They were then instructed to perform a single leg squat to 30 degrees of knee flexion and then return to a fully extended knee position. We checked that the range of motion of the SLS was 30 degrees of knee flexion previously with the goniometer. They performed the SLS three times in a row on each leg. The investigator noted any abnormal responses which consisted of arms flailing, Trendelenberg or collapse of the supporting knee into valgus which indicated an abnormal respons. We defined a positive SLS test as >2/3 abnormal responses on either leg out of the 6 total trials (3 SLS trials on each leg). Each participant was given either a Positive or Negative score on their SLS test. A Positive SLS test may be suggestive of poor lower extremity mechanics, reduced core strength, or hip abductor weakness.

**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)

The SLS test is a simple screening tool that can be employed in physician's offices or during pre-sport physicals to screen for athletes with poor knee control with no additional equipment. In young adults, SLS showed good inter-rater and intra-rater reliability that correlated well with 3D analysis of peak knee flexion, knee medio-lateral displacement and hip adduction. The 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, the SLS can reliably predict dynamic knee valgus [29].

Assessment of ankle dorsiflexion was performed using Lunge test method [31] (**Figure 10**). The patient placed the foot of the ankle to be measured along the tape measure, with the big toe against the wall and the toe and heel on the centre line of the tape. The patient was instructed to bring his knee as close to the wall as stiffness or pain would allow. Pronation was not controlled. The patient was allowed to lean against the wall if necessary. The therapist firmly held the patient's heel to the floor. Progressively, they were asked to move their toe

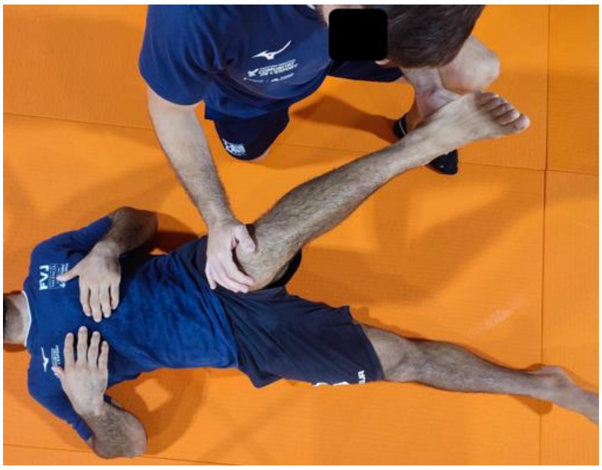

**Figure 11.** Passive hip internal rotation (Source: Authors, reprinted with informed consent and authorisation of the patients)

backwards away from the wall on the treadmill, repeating the lunging motion until the maximum 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 taken [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 has even shown excellent reliability, with ICCs greater than 0.90 [32].

Passive hip mobility was assessed bilaterally by Hip mobility test. For this purpose, the participant was placed in the supine position with the hip to be assessed in 90° flexion. The contralateral limb was placed in full extension. While performing 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 with each hip and measured with a universal goniometer and the average value was calculated [21].

In order to perform the tests, it was necessary to use a tape measure with an accuracy of one mm for 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 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 the percentage were collected for the SLS. On the Lunge test the values were collected in centimeters, and on the hip mobility test, in degrees.

### Statistical Analysis

For statistical analysis, the program 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 established at $p<0.05$. Shapiro-Wilk test was used to test the distribution of the quantitative variables. Quantitative variables were described with mean (M)±standard deviation (SD) and qualitative variables with absolute and relative values (%). The presence of significant differences in the quantitative outcome variables based on sex was analyzed using the student's t-test (after verification of the assumption of homogeneity of variances with Levene test) or with 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). In the case of 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 variables; 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 cases the objective was to evaluate the effect of the dominant leg on the results depending on sex.

## RESULTS

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

The presence of significant differences is 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 in 12.389 (2.651, 22.127) degrees compared to men. Significant differences are also shown in the variable Internal rotation non-dominant leg (°) (t[15.614]=2.615, p=0.014) with a

**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 expressed as M±SD or with absolute & 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)

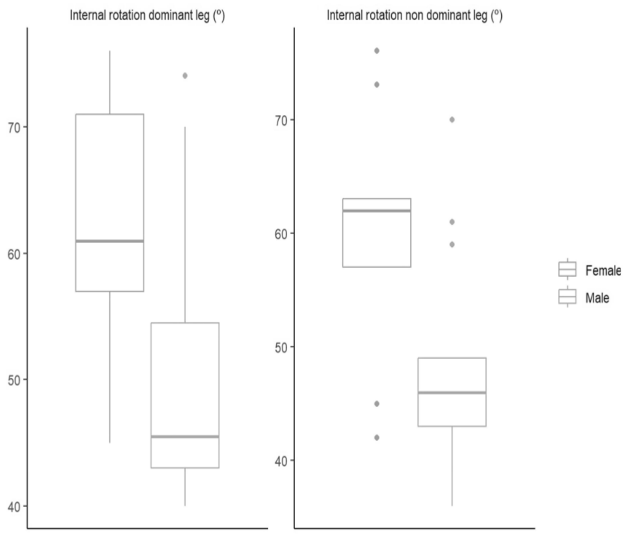


**Figure 12.** Significant variables box-plots (Source: Authors' own elaboration)

large and significant effect size and values also higher in women in 12 (2.253, 21.747) degrees compared to men (**Table 2** and **Figure 12**).

**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, in order to identify those athletes with a higher risk of ACL injury.

Firstly, no differences were observed between sexes in 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 Lunge test bilaterally. On the other hand, in the hip

**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) internal rotation tests, differences were observed between men and women, both in the dominant and non-dominant leg.

With regard to 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 in this test is quite low, 8.7% for the dominant and 26.1% for the non-dominant. If the data is analyzed in more depth, it can be observed that of all the judokas, a large number obtained at least one positive in one of the items assessed in SLS test (in the dominant leg 60.9% and in the non-dominant leg 82.6%). If only one positive in these items, the overall test result is negative, so it is of great importance to note the high rate of positives in these aspects in isolation. This data is of great interest as it may support the high prevalence of ACL injury 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 since this is the support 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 the attack on the non-dominant leg [5]. Of all the possible abnormal movement patterns that can be observed and assessed in 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 trendelenberg sign (8.7% in the dominant lower limb and 21.7% in the non-dominant). This indicates that there is good control of the core musculature. However, there is a high percentage of judokas with 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, since in the usual combat situations in which ACL injuries usually occur, it is the opponent who attacks, being unlikely to be able to maintain the balance and stability of the attacked knee with a support of the hands on the opponent. On the other hand, it is of utmost importance to highlight the role of knee valgus observed in SLS test, a movement previously mentioned as being mainly responsible for ACL injury [5-13]. Therefore, it would be of great interest to perform neuromuscular control exercises to stabilize dynamic knee valgus without the intervention of the arms.

The 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, aligning force vectors for joint stability, were crucial. ACL injuries were the result of 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 due to an externally oriented knee abduction moment from hip abduction. Injuries were more frequent in the first half of 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, it was evaluated the efficacy of a specific judo injury prevention warm-up program supervised by a coach on overall injury prevalence and concluded that the intervention did not significantly reduce the prevalence of overall and severe injuries [33]. It was 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 sport 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. On the other hand, 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]. As for the hip, this movement involves adduction and internal rotation of this 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 rotations and the likelihood of previous ACL injury [22]. In addition, in silico biomechanical simulations and cadaver studies have provided evidence of a mechanism of hip restriction at ACL, highlighting the importance of internal rotation restrictions. Indeed, the study in [22] discusses the association of ACL injury risk with hip internal rotation limitation. As 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 reason to determine that men are at greater risk of ACL injury. However, as mentioned above, it is of great importance to work on the 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, they could lead to increased ligamentous tension and thus an increased risk of ACL injury [7, 9, 10, 15].

Finally, the data obtained in Lunge test was analyzed. This test also does not show different results between men and women in both dominant and non-dominant lower limbs. Although the averages of both legs were higher in the male gender, these differences were not statistically significant, 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 the sports mentioned above, the majority of ACL injuries occur in non-contact actions such as changes of 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 both 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 return to sport following ACL reconstruction [7, 37]. Rehabilitation programs aimed at reducing functional asymmetries prior to return to sport after ACL reconstruction may be necessary to reintegrate these patients more safely into sport [7, 37].

In our study we have assessed mobility and activation of the lower limb joints, observing limitation 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 to lower extremity pathology [38]. The influence of central descending reflexes in improving hip mobility has been demonstrate [39]. Due to the contribution of the sensorimotor cortex in joint flexibility [40].

It would be necessary to find 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 as well repaired 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 between 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 be 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. Even so, significant differences were only found in hip internal rotation.

## CONCLUSIONS

Although in other sports there is a difference between men and women in the prevalence of ACL injury, 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 is worse neuromuscular control of 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 are seen in hip external rotation between men and women, but there are 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 & writing–original draft preparation; **FJP-B:** software, investigation, resources, & visualization; **EAS-R, JNC-Z, & FS-S:** formal analysis, writing–review & editing, & supervision; & **FS-S:** project administration. All authors have agreed 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 approved by the Human Research Ethics Committee from the Universitat de Valencia by number 1675151998994, Valencia, Spain (February 9, 2023). Written informed consents were 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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