Journal of Human Kinetics volume xx/xxxx, x–x DOI: 10.5114/jhk/219151 x
Section III – Sports and Physical Activity

Intra- and Inter-Limb Isokinetic Strength Asymmetry in Competitive Judokas: Differences in Magnitude across Competition Levels and Sex

by
Joachim D'Hondt [1,], Laurent Chapelle [1], Brecht Pletinckx [1], Marie Sadouni [1], Liese Bosman [1], Tijl Lindekens [1], Peter Clarys [1]*

This study aimed to examine differences in the magnitude of intra- and inter-limb asymmetry across different competitive levels (i.e., regional, national, and international) and between sexes in competitive judokas. The magnitude of intra-limb (i.e., hamstring/quadriceps ratio [H/Q]) and inter-limb (i.e., quadriceps/quadriceps ratio [Q/Q], hamstring/hamstring ratio [H/H], hamstring/quadriceps : hamstring/quadriceps ratio [H/Q:H/Q] and the percentage difference method [PDM] for knee extension and flexion) isokinetic strength asymmetry was assessed in 27 male and 20 female judokas, aged 18–59 years. No significant differences in the H/Q ratio for the left and the right leg as well as the PDM for knee extension and flexion, the H/H ratio, the Q/Q ratio, and the H/Q:H/Q ratio were found across competitive levels (p = 0.183–0.953). Similarly, no significant sex-based differences in asymmetry were observed (p = 0.439–0.983). Since most asymmetry indices did not significantly vary by competitive level or sex, and asymmetry magnitude values were generally relatively low, group-level asymmetry reduction may not be a general priority, though individual assessment remains important. Therefore, practitioners should assess limb asymmetry on an individual basis to determine if any corrective action is needed.

***Keywords**: functional; bilateral; ipsilateral; side-to-side difference; isokinetic dynamometry*

Introduction

Judo is a high-intensity combat sport that requires the combination of excellent maximal strength, power and endurance to effectively execute judo techniques (Franchini et al., 2011). This sport demands the coordinated use of both the upper and lower limbs, each performing distinct yet complementary functions (Calmet et al., 2010; Dopico-Calvo et al., 2014). While correct grip techniques are essential at the upper limb level, the lower limbs play a critical role in generating force and maintaining stability during combat (Ermis et al., 2019). Specifically, one leg functions as the driving leg, responsible for lifting, rotating, or destabilizing the opponent to successfully complete the kake (i.e., the throwing phase), while the other leg serves as the support leg, bearing the weight of the tori (i.e., the individual executing the technique) and, in many cases, also supporting the mass of the uke (i.e., the opponent being thrown) (Imamura et al., 2006).

Although achieving equally powerful, strong and stable lower limbs may seem beneficial in judo (Kons et al., 2018, 2026), the sport is inherently asymmetrical since most techniques rely on unilateral actions (Sogabe et al., 2015). Consequently, judokas tend to develop a preferred and dominant side, possibly leading to functional and morphological differences between limbs (D'Hondt et al., 2025a; Tirp et al., 2014). Typically, one lower limb is primarily responsible for executing throwing techniques, while the other limb mainly plays a supporting role in maintaining balance and movement during judo-specific tasks (Dopico-Calvo et al., 2014). Additionally, the high-

[1] *Movement and Nutrition for Health and Performance (MOVE) Research Group, Department of Movement and Sport Sciences, Faculty of Physical Education and Physiotherapy, Vrije Universiteit Brussel, Brussels, Belgium.*
* Correspondence: Joachim.dhondt@vub.be

CC BY

intensity unilateral actions in both training and competition could further reinforce these imbalances (Sogabe et al., 2015). Research reported that judokas can perform a higher number of throws, the most important performance indicator in the Special Judo Fitness Test (SJFT) battery, when using their dominant side compared to their non-dominant side, indicating sport-specific muscular adaptations developed over years of training (Detanico et al., 2024; Sogabe et al., 2015). As a result, prolonged judo practice may contribute to muscle imbalances, particularly when one side of the body is used more frequently than the other.

Body imbalances manifest in various dimensions, including morphological (e.g., muscle mass or leg length) and functional (e.g., strength or agility) asymmetries (Chapelle et al., 2022; Detanico et al., 2024; D'Hondt et al., 2022). These asymmetries can occur between limbs (inter-limb) or within a single limb (intra-limb), both of which are defined as differences in performance or function either between limbs or between agonist and antagonist muscles within the same limb, respectively. Research consistently demonstrates that asymmetry is highly individualized and varies depending on time and task demands (Chapelle et al., 2023; D'Hondt and Chapelle, 2024; D'Hondt et al., 2025b). Moreover, previous studies reported negative associations between the magnitude of inter-limb asymmetry and sports performance (Bishop et al., 2018b; D'Hondt et al., 2024; Fox et al., 2023). Specially in judo, Kons et al. (2020) found that greater asymmetry in jump height during a unilateral jump was negatively correlated ($r = -0.68$, $p = 0.014$) with the total number of throws in the SJFT among male judokas, suggesting that higher magnitude of functional inter-limb asymmetry may impair judo-specific tasks, such as throwing. Additionally, both intra- and inter-limb asymmetries have been identified as potential risk factors for non-contact injuries (Darbandi et al., 2024; Guan et al., 2023). For example, Guan et al. (2023) demonstrated that increased unilateral jump height asymmetry was associated with a higher risk of non-contact lower limb injuries in male (odds ratio: 1.053 [95% CI: 1.027–1.080], $p < 0.001$) and female (odds ratio: 1.070 [95% CI: 1.016–1.128], $p = 0.011$) youth taekwondo athletes. More specifically, magnitude exceeding 15% inter-limb asymmetry was identified as a cut-off point for predicting non-contact lower limb injuries in boys (odds ratio: 4.652 [95% CI: 2.577–8.398], $p < 0.001$) (Guan et al., 2023). Given that lower limb injuries, such as anterior cruciate ligament (ACL), are common among judokas and that inter-limb asymmetries may play a role in injury prevention and athletic training programs, a comprehensive understanding of lower limb asymmetries in judo athletes is warranted (Kim et al., 2015).

While field-based methods such as hop testing are commonly used for the convenient assessment of inter-limb asymmetries, isokinetic measurements are considered the gold standard for evaluating muscle strength (Drouin et al., 2004; Kosti et al., 2025). Consequently, this method has been widely employed to assess both intra-limb (hamstring/quadriceps ratio [H/Q ratio]) and inter-limb (e.g., hamstring/hamstring ratio [H/H ratio], quadriceps/quadriceps ratio [Q/Q ratio] or hamstring/quadriceps : hamstring/quadriceps ratio [H/Q:H/Q ratio]) strength asymmetries, yielding mixed findings regarding their impact on performance and injury risk (Bagordo et al., 2020; Darbandi et al., 2024; Ermis et al., 2019; Green et al., 2018). Despite being conducted in a controlled laboratory setting, isokinetic testing has yielded inconsistent results (Ermis et al., 2019; Malovic et al., 2020). Malovic et al. (2020) suggest that intra-limb asymmetry decreases with age, implying that long-term training adaptations may help mitigate inter-limb strength asymmetry. Conversely, Ermis et al. (2019) indicate that significant inter-limb asymmetry, particularly in quadriceps and hamstring strength, persists even at the highest levels of competition. This variability underscores the complexity of limb asymmetry assessments, even in isokinetic testing, where outcomes are influenced by factors such as the specific ratio measured (e.g., H/H, Q/Q, or H/Q), the test velocity applied, and the device used (Osternig et al., 1983).

Although intra- and inter-limb asymmetry may impair judo performance and increase injury risk (Darbandi et al., 2024; Kons et al., 2020), findings on limb asymmetry across studies remain inconsistent. It is still unclear whether the magnitude of these asymmetries varies among judokas of different competitive levels, potentially increasing the risk of injury or performance decline in certain groups. Furthermore, most research on inter-limb asymmetry has focused on male judokas, and to the best of our knowledge, no

study has yet examined sex differences in intra- and inter-limb asymmetries among judokas. Therefore, this study aimed to examine the magnitude of intra- and inter-limb asymmetry across different competitive levels (i.e., regional, national, and international) and between sexes in competitive judokas. We hypothesized that national-level judokas, due to increased engagement in judo-specific training, would exhibit greater magnitude of intra- and inter-limb asymmetry compared to regional-level judokas. Conversely, we expected international-level judokas to exhibit lower asymmetry levels than their regional- and national-level counterparts, as they often master judo-specific techniques on both sides and often incorporate additional strength training to minimize side-to-side differences beyond judo-specific training. Given the conflicting findings in previous research and the individual-specific nature of asymmetry, it was difficult to predict which sex would exhibit greater asymmetry (Cady et al., 2025; Chapelle et al., 2023; D'Hondt et al., 2025a). Nonetheless, studies have reported significantly higher asymmetry in females compared to males during strength and jumping tasks (Bailey et al., 2015; Cady et al., 2025; Fort-Vanmeerhaeghe et al., 2016). Moreover, as female athletes are approximately 3.5 times more likely to sustain an ACL injury, and considering that intra-limb asymmetry may contribute to injury risk, it was plausible that female judokas would exhibit higher levels of intra-limb asymmetry compared to male judokas (Aagaard et al., 1998; Voskanian, 2013).

Methods

Participants

A total of 27 male and 20 female judokas, aged 18 to 59 years, were recruited for this cross-sectional study using convenience and snowball sampling methods. Participants competed at regional (n = 16), national (n = 14), and international (n = 17) levels. To be eligible, athletes had to be at least 18 years old and free of lower limb injuries at the time of data collection. Upper limb injuries were permitted as long as they did not affect the athlete's ability to perform the tests at full capacity. Exclusion criteria included having a lower limb injury within the past month, failure to meet the age requirement, or an inability to successfully complete isokinetic testing. All participants were thoroughly informed about the study's purpose and procedures and provided written informed consent before participation. The study protocol was carried out in accordance with The Code of Ethics of the World Medical Association and was approved by the local ethics committee of the Vrije Universiteit Brussel, Brussels, Belgium (protocol code: B.U.N. 143201836107; approval date: 08 November 2023).

Procedures

Basic Anthropometry

Body height was measured using a portable stadiometer (SECA 216, SECA, Germany) with precision of 1 mm, while body mass was assessed using a digital scale (Radwag WLT60/10/X/3, Radwag, Poland) with accuracy of 2 g. All measurements were conducted with minimal clothing.

Isokinetic Dynamometry

Before the start of the isokinetic measurements, participants completed a five-minute warm-up on a cycling ergometer set to 100 watts of resistance. This was followed by a familiarization test, during which each judoka performed two submaximal trials on an isokinetic dynamometer (System 4, Biodex Medical Systems Inc., Shirley, NY, USA).

The dynamometer was calibrated according to the manufacturer's guidelines. Judokas were seated with an 85° torso inclination, and the seat was adjusted to their height. The dynamometer's rotation axis was aligned with the lateral condyle of the femur. To ensure stability and minimize excessive movement, the trunk, the hip and the tested leg's thigh were secured with straps, and participants were permitted to hold the seat handles during testing.

The range of motion was individually set, spanning from maximal knee flexion to maximal knee extension, with 90° defined as anatomical zero. No corrections for limb weight were applied. All measurements were conducted by the same researcher to ensure consistency. The testing protocol consisted of three sets of five repetitions of isokinetic knee extension and flexion at an angular velocity of 90°/s targeting maximal peak torque for both the left and the right leg. No visual or verbal encouragement was provided beyond start and stop signals. A one-minute rest interval was maintained between sets to allow adequate

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

recovery. Testing always started with the left limb, regardless of limb dominance.

Calculation of Intra- and Inter-Limb Asymmetry

Test outcomes included average peak torque (Nm) for knee flexors and extensors. Intra-limb asymmetry was assessed using the hamstring-to-quadriceps (H/Q) ratio, calculated as:

$$\frac{Hamstring\ Peak\ Torque}{Quadriceps\ Peak\ Torque} \times 100$$

The magnitude of inter-limb asymmetry for knee extension and knee flexion was quantified using the Percentage Difference Method (PDM) (Bishop et al., 2018a):

$$\frac{Dominant\ Value - Non - Dominant\ Value}{Dominant\ Value} \times 100$$

This method evaluated the magnitude of inter-limb asymmetry by identifying the highest value for each movement (knee extension and knee flexion separately) as the dominant side, and comparing it with the corresponding value from the non-dominant side (i.e., the best result for the opposite limb) (Chapelle et al., 2023). Additionally, inter-limb ratios were determined for both quadriceps (Q/Q) and hamstrings (H/H), respectively:

$$\frac{Dominant\ Quadriceps\ Peak\ Torque}{Non - dominant\ Quadriceps\ Peak\ Torque} \times 100$$

and

$$\frac{Dominant\ Hamstring\ Peak\ Torque}{Non-dominant\ Hamstring\ Peak\ Torque} \times 100.$$

Finally, the H/Q:H/Q ratio was calculated by dividing the highest H/Q value by the lowest, regardless of limb dominance:

$$\frac{Highest\ \frac{H}{Q}\ Value}{Lowest\ \frac{H}{Q}\ Value}.$$

Statistical Analysis

All statistical analyses were conducted using the Statistical Package for the Social Sciences version 29 (SPSS Inc., Chicago, IL, USA). The significance level was set at $p < 0.05$. Data were tested for normality using the Shapiro-Wilk test, histograms and Q-Q plots and for homogeneity of variances using the Levene's test. Descriptive statistics (mean ± standard deviation) were calculated for all variables. To compare intra- and inter-limb isokinetic strength asymmetry competitive levels within each sex, the Kruskal-Wallis H test was applied. Where significant effects were found, Bonferroni-adjusted Mann-Whitney U tests were used for post hoc comparisons. The Mann-Whitney U test was also used to assess sex-based differences. Effect sizes for the Kruskal-Wallis test were calculated using eta squared η^2, based on the formula: $\eta^2 = \frac{H-k+1}{n-k}$ where H was the Kruskal-Wallis test statistic, k was the number of groups, and n was the total sample size. To facilitate interpretation, Cohen's f was derived from η^2 using the following transformation: $f = \sqrt{\frac{\eta^2}{1-\eta^2}}$. Effect sizes were interpreted according to Cohen's guidelines: small (f = 0.10), medium (f = 0.25), and large (f = 0.40) (Cohen, 2008, 2013). For the Mann-Whitney U test, effect sizes were calculated using $f = \sqrt{\frac{\eta^2}{1-\eta^2}}$. Effect sizes were interpreted according to Cohen's guidelines: small (f = 0.10), medium (f = 0.25), and large (f = 0.40) (Cohen, 2008, 2013). For the Mann-Whitney U test, effect sizes were calculated using $r = \frac{Z}{\sqrt{N}}$ and were interpreted as follows: 0.10 to 0.30 = small, 0.30 to 0.50 = medium, and ≥0.50 = large (Fritz et al., 2012).

Results

Descriptive characteristics, including demographic information and intra- and inter-limb asymmetry values, are presented in Table 1 for male judokas and Table 2 for female judokas.

A statistically significant difference in the number of training sessions was found across competitive levels (males: H = 15.623, $p < 0.001$, f = 0.568; females: H = 6.662, $p = 0.036$, f = 0.615). More specifically, male international judokas engaged in significantly more judo-specific training compared to their regional counterparts (U = 5.000, $p < 0.001$, r = −0.861). Among female judokas, a similar trend toward significance was observed. However, it did not reach statistical significance due to the stringent Bonferroni correction (U = 5.000, $p < 0.030$, r = −0.703). A trend toward a higher training frequency was also observed in male international judokas compared to male national judokas (U = 17.000, $p = 0.056$, r = −0.477). No significant difference in training frequency was found

between these groups among female judokas (U = 19.000, $p = 0.221$, r = −0.316). Furthermore, there was no significant difference in training frequency between regional and national judokas. However, a trend toward higher training frequency among national judokas was observed in male judokas (males: U = 20.000, $p = 0.021$, r = −0.544; females: U = 10.00, $p = 0.106$, r = −0.467).

The Kruskal-Wallis H test showed no statistically significant difference in intra-limb (i.e., H/Q ratio) asymmetry across competitive levels in the left and the right leg (male: H = 0.679–0.999, p = 0.607–0.712, f = 0.209–0.241; female: H = 0.156–1.056, $p = 0.590$–0.925, f = 0.242–0.349). Likewise, no significant differences in inter-limb asymmetry were observed for PDM knee extension, PDM knee flexion, the Q/Q ratio, the H/H ratio and the H/Q:H/Q ratio in both sexes (male: H = 0.245–3.392, p = 0.183–0.885, f = 0.237–0.281; female: H = 0.096–3.316, $p = 0.190$–0.953, f = 0.154–0.355).

Regarding sex differences in the magnitude of intra- and inter-limb asymmetry, no significant differences were found for any indices or ratios (p = 0.439–0.983) (Table 3).

Discussion

This cross-sectional study aimed to evaluate differences in the magnitude of lower intra- and inter-limb asymmetry across various competitive levels and between sexes in competitive judokas. Contrary to our initial hypothesis, the results revealed no statistically significant differences in intra- or inter-limb asymmetry between competitive levels for most indices. Additionally, no significant differences in magnitude of intra- and inter-limb asymmetry were observed between sexes.

Table 1. Descriptive characteristics (Mean ± Standard Deviation) of male judokas across competitive levels.

	Regional N = 11	**National N = 7**	**International N = 9**
Demographic information			
Age (y)	**25.5 ± 7.0**	**24.7 ± 7.6**	**22.3 ± 3.1**
Body height (cm)	**179.9 ± 6.0**	**177.4 ± 5.5**	**172.7 ± 3.7**
Body mass (kg)	**77.8 ± 15.2**	**77.2 ± 14.3**	**71.9 ± 5.4**
BMI (kg/m²)	**21.9 ± 7.6**	**21.5 ± 9.2**	**19.3 ± 9.8**
Sport-specific information			
Training count (#/week)	**1.9 ± 0.3[b]**	**2.4 ± 0.5**	**2.9 ± 0.3[b]**
Intra-limb asymmetry			
H/Q Right	**63.4 ± 7.3**	**66.9 ± 4.6**	**64.6 ± 4.5**
H/Q Left	**61.9 ± 6.9**	**61.2 ± 4.6**	**67.1 ± 13.4**
Inter-limb asymmetry			
PDM knee extension (%)	**6.1 ± 4.2**	**7.8 ± 6.5**	**8.8 ± 12.8**
PDM knee flexion (%)	**10.1 ± 8.3**	**8.2 ± 6.4**	**7.3 ± 5.2**
Q/Q	**101.0 ± 7.4**	**103.2 ± 9.4**	**95.2 ± 10.7**
H/H	**99.0 ± 11.5**	**94.3 ± 7.4**	**97.2 ± 8.2**
H/Q:H/Q	**108.0 ± 5.9**	**109.4 ± 6.9**	**112.5 ± 10.7**

H/Q: hamstring/quadricep ratio, PDM: percentage difference method, Q/Q: quadricep/quadricep ratio, H/H: hamstring/hamstring ratio, H/Q:H/Q = hamstring/quadriceps : hamstring/quadriceps ratio. a: significant difference between regional and national level judokas ($p < 0.05$); b: significant difference between regional and international level judokas ($p < 0.05$); c: significant difference between national and international level judokas ($p < 0.05$)

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

Table 2. Descriptive characteristics (Mean ± Standard Deviation) of female judokas across competitive levels.

	Regional N = 5	**National N = 7**	**International N = 8**
Demographic information			
Age (y)	**30.0 ± 16.5**	**23.4 ± 3.9**	**24.5 ± 9.8**
Body height (cm)	**165.4 ± 5.7**	**166.3 ± 5.0**	**164.2 ± 8.0**
Body mass (kg)	**64.7 ± 11.8**	**66.4 ± 3.8**	**59.6 ± 10.9**
BMI (kg / m²)	**23.5 ± 3.2**	**21.0 ± 8.4**	**22.0 ± 3.0**
Sport-specific information			
Judo training count (# / week)	**2.0 ± 0.0**	**2.4 ± 0.5**	**2.8 ± 0.5**
Intra-limb asymmetry			
H/Q Right	**67.2 ± 12.7**	**64.8 ± 10.0**	**64.6 ± 11.8**
H/Q Left	**62.8 ± 8.9**	**66.8 ± 13.6**	**60.9 ± 11.4**
Inter-limb asymmetry			
PDM knee extension (%)	**4.7 ± 4.5**	**11.3 ± 7.7**	**7.5 ± 5.1**
PDM knee flexion (%)	**9.3 ± 8.8**	**11.5 ± 13.9**	**9.3 ± 7.8**
Q/Q	**100.1 ± 6.8**	**93.8 ± 1.5**	**100.8 ± 8.8**
H/H	**94.4 ± 9.5**	**96.6 ± 13.8**	**95.1 ± 9.2**
H/Q:H/Q	**112.1 ± 14.0**	**111.5 ± 10.4**	**107.9 ± 6.5**

H/Q: hamstring/quadricep ratio, PDM: percentage difference method, Q/Q: quadricep/quadricep ratio, H/H: hamstring/hamstring ratio, H/Q:H/Q: bilateral hamstring/quadricep ratio, H/Q:H/Q = hamstring/quadriceps : hamstring/quadriceps ratio. a: significant difference between regional and national level judokas ($p < 0.05$); b: significant difference between regional and international level judokas ($p < 0.05$); c: significant difference between national and international level judokas ($p < 0.05$)

Table 3. Intra- and inter-limb asymmetry values and differences between male and female judokas.

Variable	**Male (N = 27)**	**Female (N = 20)**	**U**	***p***	***r***
	Mean ± SD	**Mean ± SD**			
Intra-limb asymmetry					
H/Q Right	64.70 ± 5.8	65.3 ± 10.9	269.0	0.983	−0.003
H/Q Left	63.5 ± 9.2	63.4 ± 11.4	247.5	0.628	−0.071
Inter-limb asymmetry					
PDM knee extension (%)	7.4 ± 8.2	8.1 ± 6.3	237.0	0.478	−0.104
PDM knee flexion (%)	8.7 ± 6.8	10.1 ± 10.1	266.0	0.931	−0.012
Q/Q	99.6 ± 9.3	98.2 ± 9.2	234.0	0.439	−0.113
H/H	97.2 ± 9.4	95.4 ± 10.5	256.0	0.763	−0.044
H/Q:H/Q	109.9 ± 8.0	110.2 ± 9.8	258.0	0.796	−0.038

SD: standard deviation, U: Mann-Whitney U value, p: statistical significance, H/Q: hamstring / quadricep ratio, PDM: percentage difference method, Q/Q: quadricep/quadricep ratio, H/H: hamstring/hamstring ratio, H/Q:H/Q: bilateral hamstring/quadricep ratio

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

According to a recent systematic review by Rašković et al. (2023), intra-limb asymmetry in judokas typically ranges between 54% and 85%, with the exception of two studies by Drid et al. (2009, 2011) reporting surprisingly lower values of 45.9% to 47.8%, indicating a deficiency of hamstring strength in these elite judokas. In the present study, H/Q ratios ranged from 61% to 67%, with no statistically significant differences observed between competitive levels and sexes. These findings suggest that although elite judokas generally produce higher overall muscle torque values (Drid et al., 2015), advancing to higher competitive levels does not necessarily result in greater intra-limb asymmetry, and thus may not increase injury risk associated with intra-limb asymmetry. One possible explanation is that competing at the international level may not be directly associated with a higher unilateral training volume. International athletes are likely to adopt a more professional training approach, accounting for side-to-side differences both between and within limbs. Although speculative, international judokas train to perform techniques in both right and left directions, potentially reducing any asymmetries (Iglesias-Soler et al., 2018). While we do not have data to confirm this hypothesis, it is also plausible that supplementary strength training, in conjunction with judo-specific training, helps mitigate potential imbalances.

The intra-limb ratios in this study were within the commonly accepted range of 60% to 80% for H/Q ratios at angular velocities between 60°/s and 240°/s, a range typically considered indicative of a balanced strength ratio (Aagaard et al., 1995; Kellis and Baltzopoulos, 1995). H/Q peak torque ratios below 60% have been associated with an increased risk of ACL injuries, as insufficient hamstring strength relative to quadriceps activation compromises knee joint stability (Aagaard et al., 1998). Additionally, our results exceed the recently proposed cutoff value of 43.2% (Darbandi et al., 2024) for classifying injury risk based on intra-lower-limb asymmetry specifically in judokas. Although ACL injuries are common in this sport (Koshida et al., 2010), our findings suggest that athletes in this cohort are at a low risk of sustaining a non-contact ACL injury and do not require specific interventions to correct strength imbalances in this respect (Aagaard et al., 1998; Ghrairi et al., 2014). According to a previous review by Voskanian (2013), female athletes are 3.5 times more likely to suffer from ACL injuries than male athletes. However, as no sex differences were found in intra-limb asymmetry in our study, it is unlikely that this sex difference in ACL injury rates is attributable to intra-limb asymmetry. Taken together, our results suggest that all groups and both sexes in this study generally exhibit similarly low levels of injury risk related to intra-limb asymmetry. However, it is important to note that while traditional prevention strategies have focused on isolated knee strengthening, increasing evidence highlights the importance of targeting the entire kinetic chain, including the trunk, hips, ankles, and feet, to reduce knee stress and enhance dynamic joint stability (Dhahbi et al., 2025).

In sports performance enhancement, injury prevention and injury rehabilitation programs, comparisons between the dominant and non-dominant limbs are commonly made (Bishop et al., 2018b; D'Hondt et al., 2024; Kons et al., 2020). Previous research has reported that inter-limb asymmetry magnitude over 10% is negatively associated with sports performance outcomes (Bishop et al., 2018b). Additionally, a threshold of 15% for inter-limb asymmetry has been proposed across both athletic and non-athletic populations, with individuals exceeding this threshold considered at an elevated risk of injury (Barber et al., 1990; Grindem et al., 2011; Impellizzeri et al., 2007). In our sample, only female national athletes exceeded the 10% threshold for both knee extension and flexion, whereas male regional athletes exceeded this threshold for knee flexion, based on the PDM formula. While it is generally not advisable to make group-level comparisons due to the individual-specific nature of asymmetry (D'Hondt et al., 2024), higher group-level asymmetry values may indicate a greater prevalence of significant individual asymmetries, which could suggest potential performance deficits for certain athletes in this cohort. However, no significant differences were observed between competitive levels or sexes.

With regard to inter-limb asymmetry ratios, none of the groups exceeded the 10% threshold for H/H, Q/Q, or H/Q:H/Q in either sex (Tables 1 to 3). Although one might argue that lower inter-limb asymmetry in judokas could contribute to reduced injury risk and enhanced performance, the fact that all groups exhibited most asymmetry levels below 10% suggests that

none are likely at elevated risk of injury or performance limitations (Barber et al., 1990; Bishop et al., 2018b; Grindem et al., 2011; Impellizzeri et al., 2007). However, it is important to note that asymmetry is highly individual-specific, and coaches should therefore focus on the athlete level rather than the group level (D'Hondt et al., 2024).

Despite these advancements in knowledge, several limitations should be acknowledged. First, data on the specific content of the judo training volume and potential additional strength training were not collected, limiting the ability to assess their impact on the magnitude of asymmetry. Since both unilateral and bilateral strength training methods were effective in reducing inter-limb asymmetries (Bishop et al., 2023), the conclusions of the present study should be interpreted with caution. Longitudinal research is needed to explore whether particular training interventions lead to changes in asymmetry over time. Second, due to the absence of an official judo ranking system that categorizes athletes including regional, national, and international levels, participants were classified based on their competitive rather than performance level. This grouping may not fully capture the differences in training intensity or the skill level across subgroups. Third, this study only used a single angular velocity of 90°/s during isokinetic testing. Given that movement speeds in judo vary greatly depending on the technique being performed, future research should include multiple angular velocities to better represent the full spectrum of judo-specific movement demands. Nevertheless, the isokinetic measurement at low angular velocity may be a good indicator of maximal strength which is important for the typical hold techniques during the ne-waze fight. Fourth, while the present study included judokas from various competitive levels, the sample size was relatively small, especially when stratified by sex and the competition level. This limitation increases the risk of Type II errors and reduces the generalizability of the findings (Akobeng, 2016). A larger sample would enhance statistical power, enabling the detection of more subtle differences in asymmetry patterns. Finally, while the Bonferroni correction was applied to control for multiple comparisons within post-hoc analyses, the examination of numerous asymmetry indices without a family-wise error correction may have increased the risk of inflated Type I errors (Akobeng, 2016). This should be considered when interpreting the results.

Conclusions

In conclusion, contrary to our initial hypothesis, most asymmetry indices did not significantly differ between competitive levels or sexes. Although knee flexion and extension asymmetry in female national athletes and knee flexion asymmetry in male judokas exceeded 10%, all subgroups demonstrated relatively low overall asymmetry levels. Hence, judokas across all subgroups may not need to prioritize reducing intra- and inter-limb strength asymmetry to minimize injury risk or performance deficits. Future research using longitudinal designs should explore the long-term effects of standardized training regimens on development of the magnitude of asymmetry and their impact on athletic performance and injury prevention.

Author Contributions: Conceptualization: P.C., L.C., T.L. and J.D.'H.; methodology: P.C., L.C., T.L. and J.D.'H.; validation: P.C., L.C., T.L. and J.D.'H.; formal analysis: J.D.'H.; investigation: T.L., B.P. and M.S.; resources: P.C., L.C., T.L. and J.D.'H.; data curation: P.C., L.C., T.L. and J.D.'H.; writing—original draft preparation: J.D.'H.; writing—review & editing: P.C., L.C., T.L., J.D.'H. and L.B.; visualization: J.D.'H.; supervision: P.C. and L.C.; project administration: P.C. All authors have read and agreed to the published version of the manuscript.

ORCID iD:

Joachim D'Hondt: https://orcid.org/0000-0001-7870-2035

Laurent Chapelle: https://orcid.org/0000-0002-0344-6521

Liese Bosman: https://orcid.org/0000-0002-2632-4527

Peter Clarys: https://orcid.org/0000-0002-6171-6518

Funding Information: This research received no external funding.

Institutional Review Board Statement: This study was conducted following the principles of the Declaration of Helsinki, and approved by the Ethics Committee of the Vrije Universiteit Brussel, Brussels, Belgium (protocol code: B.U.N. 143201836107; approval date: 08 November 2023).

Informed Consent: Informed consent was obtained from all participants included in the study.

Conflicts of Interest: The authors declare no conflict of interest.

Acknowledgements: The authors would like to thank the athletes for participating in this study.

Received: 23 April 2025

Accepted: 11 March 2026

References

Aagaard, P., Simonsen, E. B., Magnusson, S. P., Larsson, B., & Dyhre-Poulsen, P. (1998). A new concept for isokinetic hamstring: quadriceps muscle strength ratio. *American Journal of Sports Medicine*, *26*(2), 231–237. doi:10.1177/03635465980260021201

Aagaard, P., Simonsen, E. B., Trolle, M., Bangsbo, J., & Klausen, K. (1995). Isokinetic Hamstring Quadriceps Strength Ratio - Influence from Joint Angular Velocity, Gravity Correction and Contraction Mode. *Acta Physiologica Scandinavica*, *154*(4), 421–427. doi:10.1111/j.1748-1716.1995.tb09927.x

Akobeng, A. K. (2016). Understanding type I and type II errors, statistical power and sample size. *Acta Paediatrica*, *105*(6), 605–609. doi:10.1111/apa.13384.

Bagordo, A., Ciletti, K., Kemp-Smith, K., Simas, V., Climstein, M., & Furness, J. (2020). Isokinetic Dynamometry as a Tool to Predict Shoulder Injury in an Overhead Athlete Population: A Systematic Review. *Sports*, *8*(9), 124. doi:10.3390/sports8090124

Bailey, C. A., Sato, K., Burnett, A., & Stone, M. H. (2015). Force-production asymmetry in male and female athletes of differing strength levels. *International Journal of Sports Physiology and Performance*, *10*(4), 504–508. doi:10.1123/ijspp.2014-0379

Barber, S. D., Noyes, F. R., Mangine, R. E., & Hartman, W. (1990). Quantitative assessment of functional limitations in normal and anterior cruciate ligament-deficient knees. *Clinical Orthopaedics and Related Research (1976–2007)*, *255*, 204–214.

Bishop, C., Abbott, W., Brashill, C., Loturco, I., Beato, M., & Turner, A. (2023). Seasonal Variation of Physical Performance, Bilateral Deficit, and Interlimb Asymmetry in Elite Academy Soccer Players: Which Metrics Are Sensitive to Change? *Journal of Strength & Conditioning Research*, *37*(2), 358–365. doi:10.1519/JSC.0000000000004248

Bishop, C., de Keijzer, K. L., Turner, A. N., & Beato, M. (2023). Measuring Interlimb Asymmetry for Strength and Power: A Brief Review of Assessment Methods, Data Analysis, Current Evidence, and Practical Recommendations. *Journal of Strength & Conditioning Research*, *37*(3), 745–750. doi:10.1519/JSC.0000000000004384

Bishop, C., Read, P., Lake, J., Chavda, S., & Turner, A. (2018a). Interlimb Asymmetries: Understanding How to Calculate Differences From Bilateral and Unilateral Tests. *Strength & Conditioning Journal*, *40*(4), 1–6. doi:10.1519/Ssc.0000000000000371

Bishop, C., Turner, A., & Read, P. (2018b). Effects of inter-limb asymmetries on physical and sports performance: a systematic review. *Journal of Sports Sciences*, *36*(10), 1135–1144. doi:10.1080/02640414.2017.1361894

Cady, K., De Ste Croix, M., Deighan, M. (2025). Sex Differences in Magnitude and Direction of Interlimb Asymmetries in Eccentric Hip Abduction. *Strength. International Journal of Strength and Conditioning*, *5*(1), 1–10. doi:10.47206/ijsc.v5i1.317

Calmet, M., Miarka, B., & Franchini, E. (2010). Modeling of grasps in judo contests. *International Journal of Performance Analysis in Sport*, *10*(3), 229–240. doi: 10.1080/24748668.2010.11868518

Chapelle, L., Bishop, C., D'Hondt, J., D'Hondt, E., & Clarys, P. (2022). Morphological and functional asymmetry in elite youth tennis players compared to sex- and age-matched controls. *Journal of Sports Sciences*, *40*(14), 1618–1628. doi:10.1080/02640414.2022.2096769

Chapelle, L., Bishop, C., D'Hondt, J., Rommers, N., D'Hondt, E., & Clarys, P. (2023). Development of upper and lower extremity functional asymmetries in male and female elite youth tennis players: a longitudinal study. *Journal of Sports Medicine and Physical Fitness*, *63*(12), 1269–1284. doi:10.23736/S0022-4707.23.15043-2

Cohen, B. H. (2008). *Explaining psychological statistics*. John Wiley & Sons.

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Routledge.

Darbandi, S. M., Hosseinzadeh, M., Zarei, M., & Behm, D. G. (2024). Does ipsilateral and bilateral knee strength status predict lower extremity injuries of elite judokas; a prospective cohort study. *Research in Sports Medicine*, *32*(3), 465–478. doi:10.1080/15438627.2022.2126777

Detanico, D., Gheller, R. G., Athayde, M. S. D., & Kons, R. L. (2024). Shoulder rotator strength in judo athletes: A cross-sectional study with different experience levels. *Isokinetics and Exercise Science*, *32*(1), 21–27. doi:10.3233/Ies-230027

Dhahbi, W., Materne, O., & Chamari, K. (2025). Rethinking knee injury prevention strategies: joint-by-joint training approach paradigm versus traditional focused knee strengthening. *Biology of Sport*, *42*(4), 59–65. doi: 10.5114/biolsport.2025.148544

D'Hondt, J., Chapelle, L., Lindekens, T., & Clarys, P. (2025a). Morphological inter-limb asymmetry in youth judokas is independent of competitive level and sex. *BMC Sports Science, Medicine and Rehabilitation, 17*(1), 380. doi: 10.1186/s13102-025-01440-8

D'Hondt, J., Vanhoudt, M., Maluta, D., Chapelle, L., & Aerenhouts, D. (2025b). Does a muscle fatigue-inducing protocol alter the magnitude of jump inter-limb asymmetry in healthy adolescents? *Journal of Human Kinetics*, Advance online publication. doi: 10.5114/jhk/205705

D'Hondt, J., & Chapelle, L. (2024). Change of Direction Asymmetry in Youth Elite Tennis Players: A Longitudinal Study. *International Journal of Sports Medicine*, *45*(06), 436–442. doi:10.1055/a-2231-9630

D'Hondt, J., Chapelle, L., Bishop, C., Aerenhouts, D., De Pauw, K., Clarys, P., & D'Hondt, E. (2024). Association Between Inter-Limb Asymmetry and Determinants of Middle- and Long-distance Running Performance in Healthy Populations: A Systematic Review. *Sports Medicine Open*, *10*(1), 127. doi:10.21203/rs.3.rs-3787566/v1

D'Hondt, J., Chapelle, L., Van Droogenbroeck, L., Aerenhouts, D., Clarys, P., & D'Hondt, E. (2022). Bioelectrical impedance analysis as a means of quantifying upper and lower limb asymmetry in youth elite tennis players: An explorative study. *European Journal of Sport Science*, *22*(9), 1343–1354. doi:10.1080/17461391.2021.1960624

Dopico-Calvo, X., Iglesias-Soler, E., Carballeira, E., Mayo, X., Ardá, A., & González-Freire, M. (2014). The relationship between motoric dominance and functional dominance while executing judo techniques: a study on laterality. *Archives of Budo*, *10*, 307–314.

Drid, P., Casals, C., Mekic, A., Radjo, I., Stojanovic, M., & Ostojic, S. M. (2015). Fitness and Anthropometric Profiles of International Vs. National Judo Medalists in Half-Heavyweight Category. *Journal of Strength & Conditioning Research*, *29*(8), 2115–2121. doi:10.1519/Jsc.0000000000000861

Drid, P., Drapsin, M., Trivic, T., Lukač, D., Obadov, S., & Milosevic, Z. (2009). Asymmetry of muscle strength in elite athletes. *Biomedical Human Kinetics*, *1*(1), 3–5. doi:10.2478/v10101-009-0002-1

Drid, P., Ostojic, S. M., Vujkov, S., Purkovic, S., Trivic, T., & Stojanovic, M. (2011). Physiological adaptations of a specific muscle-imbalance reduction training programme in the elite female judokas. *Arch of Budo*, *7*(2), 61–64.

Drouin, J. M., Valovich-mcLeod, T. C., Shultz, S. J., Gansneder, B. M., & Perrin, D. H. (2004). Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *European Journal of Applied Physiology*, *91*(1), 22–29. doi:10.1007/s00421-003-0933-0.

Ermis, E., Yilmaz, A. K., Kabadayi, M., Bostanci, Ö., & Mayda, M. H. (2019). Bilateral and ipsilateral peak torque of quadriceps and hamstring muscles in elite judokas. *Journal of Musculoskeletal & Neuronal Interactions*, *19*(3), 286–293.

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

Fox, K. T., Pearson, L. T., & Hicks, K. M. (2023). The effect of lower inter-limb asymmetries on athletic performance: A systematic review and meta-analysis. *PLoS One*, *18*(6), e0286942. doi:10.1371/journal.pone.0286942

Fort-Vanmeerhaeghe, A., Gual, G., Romero-Rodriguez, D., & Unnitha, V. (2016). Lower limb neuromuscular asymmetry in volleyball and basketball players. *Journal of Human Kinetics*, *50*, 135–143. doi:10.1515/hukin-2015-0150

Fritz, C. O., Morris, P. E., & Richler, J. J. (2012). Effect size estimates: current use, calculations, and interpretation. *Journal of Experimental Psychology: Journal of Experimental Psychology*, *141*(1), 2. doi:10.1037/a0024338

Franchini, E., Del Vecchio, F. B., Matsushigue, K. A., & Artioli, G. G. (2011). Physiological profiles of elite judo athletes. *Sports Medicine*, *41*(2), 147–166. doi:10.2165/11538580-000000000-00000

Ghrairi, M., Hammouda, O., & Malliaropoulos, N. (2014). Muscular strength profile in Tunisian male national judo team. *Muscles, Ligaments and Tendons Journal*, *4*(2), 149–153. doi:10.11138/mltj/2014.4.2.149

Green, B., Bourne, M. N., & Pizzari, T. (2018). Isokinetic strength assessment offers limited predictive validity for detecting risk of future hamstring strain in sport: a systematic review and meta-analysis. *British Journal of Sports Medicine*, *52*(5), 329. doi:10.1136/bjsports-2017-098101

Grindem, H., Logerstedt, D., Eitzen, I., Moksnes, H., Axe, M. J., Snyder-Mackler, L., Risberg, M. A. (2011). Single-Legged Hop Tests as Predictors of Self-Reported Knee Function in Nonoperatively Treated Individuals With Anterior Cruciate Ligament Injury. *American Journal of Sports Medicine*, *39*(11), 2347–2354. doi:10.1177/0363546511417085

Guan, Y. F., Bredin, S. S. D., Taunton, J., Jiang, Q. X., Wu, N. N., & Warburton, D. E. R. (2023). Predicting the Risk of Injuries Through Assessments of Asymmetric Lower Limb Functional Performance: A Prospective Study of 415 Youth Taekwondo Athletes. *Orthopaedic Journal of Sports Medicine*, *11*(8), 23259671231185586. doi:10.1177/23259671231185586

Iglesias-Soler, E., Mayo, X., Dopico, X., Fernandez-Del-Olmo, M., Carballeira, E., Farinas, J., & Fernandez-Uribe, S. (2018). Effects of bilateral and non-dominant practices on the lateral preference in judo matches. *Journal of Sports Sciences*, *36*(1), 111–115. doi:10.1080/02640414.2017.1283431

Imamura, R. T., Hreljac, A., Escamilla, R. F., & Edwards, W. B. (2006). A three-dimensional analysis of the center of mass for three different judo throwing techniques. *Journal of Sports Science & Medicine*, *5*(CSSI), 122–131.

Impellizzeri, F. M., Rampinini, E., Maffiuletti, N., & Marcora, S. M. (2007). A vertical jump force test for assessing bilateral strength asymmetry in athletes. *Medicine and Science in Sports and Exercise*, *39*(11), 2044–2050. doi:10.1249/mss.0b013e31814fb55c

Kellis, E., & Baltzopoulos, V. (1995). Isokinetic eccentric exercise. *Sports medicine*, *19*(3), 202–222. doi:10.2165/00007256-199519030-00005

Kim, K. S., Park, K. J., Lee, J., & Kang, B. Y. (2015). Injuries in national Olympic level judo athletes: an epidemiological study. *British Journal of Sports Medicine*, *49*(17), 1144–1150. doi:10.1136/bjsports-2014-094365

Kons, R. L., Ache-Dias, J., Estacio Costa, F., Dal Pupo, J. & Detanico, D. (2026). Effects of Multiple Judo Bouts in the Bilateral Strength Deficit on the Countermovement Jump Metrics. *Journal of Human Kinetics*, *100*, 17–26. https://doi.org/10.5114/jhk/202147

Kons, R. L., Dal Pupo, J., Ache-Dias, J., & Detanico, D. (2018). Female Judo Athletes' Physical Test Performances Are Unrelated to Technical-Tactical Competition Skills. *Perceptual and Motor Skills*, *125*(4), 802–816. doi:10.1177/0031512518777586

Kons, R. L., Diefenthaeler, F., Orssatto, L. B. R., Sakugawa, R. L., da Silva, J. N., & Detanico, D. (2020). Relationship between lower limb asymmetry and judo-specific test performance. *Sport Sciences for Health*, *16*(2), 305–312. doi:10.1007/s11332-019-00606-5

Koshida, S., Deguchi, T., Miyashita, K., Iwai, K., & Urabe, Y. (2010). The common mechanisms of anterior cruciate ligament injuries in judo: a retrospective analysis. *British Journal of Sports Medicine*, *44*(12), 856–861. doi:10.1136/bjsm.2008.051425

Kosti, C., Tsoukos, A., Pelekis, I., Paschalis, V., Terzis, G. & Bogdanis, G. C. (2026). Isokinetic vs. Hand-Held Dynamometry for Assessing Knee Flexor and Extensor Strength in Athletes: Evaluating a Low-Cost Alternative across the Range of Motion. *Journal of Human Kinetics*, *100*, 51–62. https://doi.org/10.5114/jhk/210346

Malovic, P., Bijelica, D., Atanasov, D., Trivic, T., Drapsin, M., Trajkovic, N., & Drid, P. (2020). Knee strength ratios in male judokas: age-related differences. *Archives of Budo*, *16*, 43–52.

Osternig, L. R., Hamill, J., Sawhill, J. A., & Bates, B. T. (1983). Influence of Torque and Limb Speed on Power Production in Isokinetic Exercise. *American Journal of Physical Medicine & Rehabilitation*, *62*(4), 163–171.

Rašković, B., Dimitrijević, V., Viduka, D., Milankov, V., Ninković, S., Lakićević, N., & Obradovic, B. (2023). Isokinetic Hamstrings-to-Quadriceps Peak Torque Ratio in Combat Sports: A Systematic Review and Meta-analysis. *Sport Mont*, *21*(2), 129–137. doi:10.26773/smj.230720

Sogabe, A., Sterkowicz-Przybycien, K., Maehara, K., Sasaki, T., & Sterkowicz, S. (2015). Effect of preferred body stance side on the performance of Special Judo Fitness Test in Japanese judo athletes. *Archives of Budo*, *11*, 1–6.

Tirp, J., Baker, J., Weigelt, M., & Schorer, J. (2014). Combat stance in judo-Laterality differences between and within competition levels. *International Journal of Performance Analysis in Sport*, *14*(1), 217–224. doi:10.1080/24748668.2014.11868716

Voskanian, N. (2013). ACL Injury prevention in female athletes: review of the literature and practical considerations in implementing an ACL prevention program. *Current Reviews in Musculoskeletal Medicine*, *6*(2), 158–163. doi:10.1007/s12178-013-9158-y

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.