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Relationship between Body Composition Asymmetry and Specific Performance in Taekwondo Athletes: A Cross-Sectional Study

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Abstract: Currently, there is interest in investigating how interlimb asymmetries (IA) of body composition impact sport-specific performance outcomes. This study aimed to examine the relationship between body composition inter-limb asymmetry and specific performance outcomes in taekwondo athletes. Seventeen national and international athletes (males, n = 8, mean age = 23.3 ± 3.1 years, mean stature = 177.2 ± 8.5 cm, mean body mass = 80.0 ± 7.3 kg; females, n = 9, mean age = 25.0 ± 4.0 years, mean stature = 161.1 ± 4.4 cm, mean body mass = 59.8 ± 5.7 kg) participated in the study. During a non-consecutive 2-day period, body composition (BC) and IA were assessed using dual X-ray absorptiometry, and the magnitude (%) of IA was calculated. Specific-performance included taekwondo specific agility test (TSAT) and Frequency Speed of Kick Test Multiple ($FSKT_{MULT}$). The relationship between BC asymmetry and performance outcomes was analyzed using a partial correlation approach (controlling for gender, age, and training time). The influence of the significant results was examined using forward stepwise linear regression models. The main results showed no significant differences between the lower limbs ($p < 0.05$). The IA ranged from 1.37% to 2.96%. Moderate to large negative correlations (r = −0.56 to −0.76, $p < 0.05$) were documented between IA of body mass, free fat mass (FFM), and lean soft tissue mass (LSTM) with most $FSKT_{MULT}$ outcomes. Bone mineral density (BMD) was correlated with set 5 (rho = −0.49, $p = 0.04$). The FFM and LSTM asymmetries influenced the KDI reduction by 21%. Meanwhile, IA BMD negatively influenced set 5 performance by 48%. The findings of our study indicate that asymmetries independent of the magnitude of muscle and bone mass-related outcomes may have detrimental effects on high-intensity performance in taekwondo athletes. This underscores the importance of implementing comprehensive training programs and paying attention to achieving body composition inter-limb symmetry to improve overall performance levels in this sport.

Keywords: asymmetry; body composition; athletic performance; taekwondo

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1. Introduction

In the field of sports science, inter-limb asymmetries (IA) refer to discrepancies in athletic performance and function between two limbs that are not related to lateral dominance. These disparities can have a notable impact on athletic performance, and several studies have provided evidence of the relationship between IA and physical performance outcomes [1–5]. Moreover, recent research, such as that conducted by Fox et al. [5] and Ličen and Kozinc [4], has suggested that IA may negatively affect performance, particularly in high-intensity tasks that require coordinated use of both lower limbs, such as the change of direction speed (CODS). CODS involve quickly changing the body's speed and/or direction through a predetermined motor task [6].

There is significant interest within the scientific community regarding combat sports [7]. Actually, the effects of combat sports on the physical fitness, mental health and overall performance of athletes have been the subject of systematic-reviews [8,9]. One particular area of interest is the analysis of acute IA effects on performance outcomes, including CODS in judo [10,11] and karate [12]. For this purpose, taekwondo coaches utilize the taekwondo agility-specific test (TSAT) [13] and the frequency speed of kick test multiple ($FSKT_{MULT}$) [14,15]. However, improvements in performance are dependent on anatomical adaptations provoked by sports training, such as hypertrophy [16]. Therefore, the anatomical IA of athletes may be a determinant of their test performance. Although functional tests involving one side of the body, such as isokinetic dynamometry, unilateral tasks, such as vertical jumps, and hand grip dynamometer tests have received more attention from sports scientists [17,18]. A recent systematic review highlighted the lack of research examining the effects of body composition (BC) asymmetries on physical performance [2]. Moreover, few descriptive studies have compared asymmetries derived from BC between different combat sports such as judo, karate, fencing, wrestling, taekwondo, and kickboxing [19]. Despite the relevance of IA responses to specific performance outcomes, little is known about their impact on combat sports.

The existing literature does not provide comprehensive information on the influence of an individual's BC on their performance in physical assessments. Bell et al. [20], in their study of collegiate athletes, found that asymmetries in lower-limb fat-free mass (FFM) significantly affected strength and power. Conversely, Chapelle et al. [21] found no significant correlation between FFM inequality and unilateral performance measures in tennis players. These findings often contradict each other and tend to favor functional imbalances over tasks that involve the simultaneous use of both limbs. Friesen et al. [22] investigated the effect of BC on the performance of female softball pitchers using handheld dynamometers and inclinometers to examine differences in bilateral isometric strength symmetry and range of motion between individuals with varying body fat mass levels (%FM). They found significant variations in these factors, and dual-energy X-ray absorptiometry (DXA) revealed distinct BC asymmetries between the groups. These findings demonstrate the impact of BC discrepancies on pitching techniques, particularly for windmill pitches. Therefore, further research is necessary to analyze these discrepancies and understand the underlying mechanisms.

In sports such as taekwondo, where competition is categorized by body mass [23], it is imperative to optimize the balance and symmetry of an athlete's body composition (BC) to achieve better performance. Contemporary methods, including bioelectrical impedance and DXA, have facilitated the detection and measurement of intraclass amplitude (IA) BC in body composition outcomes [20,24–29]. BC plays a crucial role in performance and can vary between body mass categories [30]. Coaches consider factors such as fat-free mass (FFM), lean body mass (LSTM), and other components to be essential for monitoring estimated muscle mass, as they are critical for muscle force production [16]. Moreover, an increase in bone mineral density (BMD) can lead to fragile bones and increase the risk of fractures, whereas an increase in fat mass can impair performance in taekwondo, which is considered a non-functional tissue [30,31].

The findings of this study that highlight the impact of body composition asymmetry on sport-specific performance outcomes in taekwondo athletes could be utilized for monitoring and assessing the training cycle (e.g., pre-season). The results of this study may provide valuable insights into small adjustments that can offer athletes a competitive advantage. It is plausible to speculate that the relationship between BC inter-limb asymmetries and performance in taekwondo has implications beyond sports and may impact other sports disciplines or health-related areas. Any discrepancy in BC outcomes may negatively affect technical execution, overall efficiency during training and competition, and the risk of injury. This study aimed to examine the relationship between body composition asymmetry and specific performance outcomes in taekwondo athletes. The null hypothesis was that there would have no statistically significant negative influence between BC asymmetries and specific performance outcomes in taekwondo athletes.

2. Material and Methods

2.1. Participants

Seventeen national- and international-level taekwondo athletes: males (n = 8, age: 23.37 ± 3.06 years, stature: 177.2 ± 8.5 cm, body mass: 80.01 ± 7.27 kg) and females (n = 9, age = 25.0 ± 4.03 years, stature: 161.1 ± 4.4 cm, body mass: 59.82 ± 5.65 kg) participated in this study. All athletes were part of a university taekwondo team associated with the World Taekwondo Federation. The athletes competed in the 49–80 kg body mass categories. The study included athletes who were in the post-competitive period. They aimed to maintain their physical performance at the time of the study. To be included in the study, participants had to meet the following criteria: (i) at least three years of taekwondo training, (ii) training at least three times per week, (iii) competition in national and/or international tournaments, (iv) at least an intermediate expertise level (blue belt), (v) lack of competitive weight loss, and (vi) no musculoskeletal injuries or similar. A minimum sample size of 16 athletes was selected a priori, considering a statistical power of 0.80 and an alpha level of 0.05. The study participants were identified using a simple random method. The minimum sample size was determined using G*Power software (version 3.1, University of Dusseldorf, Germany) with the following settings: bivariate normal model test, two-tailed, $\alpha = 0.05$, $\beta = 0.10$, and r = 0.70, in accordance with previous studies [31]. This study followed the guidelines of the STROBE declaration [32] was approved by the Institutional Ethics Committee (CODE: BIOPUCV-H 520-2022).

2.2. Measures

2.2.1. Anthropometric Measures and Body Composition Outcomes

The athletes' stature and body mass were measured using a stadiometer (Seca 217, Hamburg, Germany; accuracy, 0.1 cm) and calibrated scale (Seca 803, Hamburg, Germany; accuracy, 0.01 kg), respectively, following standard protocols. To a fan beam scanner (Lunar Prodigy, GE Healthcare, Madison, WI, USA) was used to assess BC, which was analyzed using the GE EnCORE 2015 software v18 (GE Healthcare). The race/ethnicity of each athlete was chosen from the available software options to accurately reflect their ancestry. The standard thickness mode, determined by the automatic scanning function, was utilized and subsequently analyzed using Encore software [20].

BC outcomes included left and right lower-limb body mass (BM), free fat mass (FFM), fat mass (FM), percentage fat mass (%FM), free fat mass (FFM), lean soft tissue mass (LSTM), bone mineral content (BMC), and bone mineral density (BMD) [33,34]. DXA measurements were performed in accordance with standardized protocols previously used in research on combat sports athletes [30].

2.2.2. Specific Change of Direction Speed (CODS)

Specific CODS performance (i.e., time in seconds) was measured using the taekwondo specific agility test (TSAT) [13] with an electronic timing system (Brower Timing Systems, Salt Lake City, UT, USA). Briefly, the protocol included a guard position with both feet behind the start/finish line. The athlete was instructed to (i) advance to guard position, without crossing the feet, as fast as possible to the center point, (ii) turn towards partner 1 adopting lateral displacement and execute the left leg roundhouse kick, (iii) move towards partner 2 and execute the right leg roundhouse kick (dollyo-chagi), (iv) return to the center, (v) move forward into guard position and execute the double roundhouse kick (narae-chagi) towards partner 3, and (vi) move back to the start/finish line in the guard position. Opponents 1 and 2 hold one kicking target, whereas Opponent 3 holds two. The participants were instructed to maintain the kick target at the height of the tested athlete's torso. If the participant did not follow these instructions (e.g., crossing one foot in front of the other during various movements or did not touch the target with force when kicking), the test was terminated and restarted after a three-minute recovery period. To determine the athlete's performance outcome, the shortest time (s) between the three attempts was selected.

2.2.3. Specific Repeated High-Intensity Efforts

The ability to repeat specific high-intensity efforts was measured by performing the frequency speed of kick test multiple ($FSKT_{MULT}$), following previously described protocols [14,15]. Briefly, the $FSKT_{MULT}$ consisted of five sets with a duration of 10 s each and a pause interval of 10 s between sets. The athletes performed the test using a training dummy (bob-type punching dummy) attached to the breast plate. The training dummy was aligned around the iliac crest of each athlete, and the timing of the set was used for the cell phone application Time Plus Workouts Timer (1. 0.9) [Mobile App] Google Play) connected to a sound system (Bose© Soundlink Mobile Bose Corporation, 100 Mountain Road, Framingham, MA, USA). Following the sound signal, the athlete executed the maximum possible number of kicks, alternating between the right and left legs. The performance outcomes were determined by the number of kicks in each set, the total number of kicks (total kicks), and the kick decreased index (KDI) during the test. The KDI indicated that performance decreased during the test. To calculate KDI, the number of kicks executed during each set was determined using a previously described equation [15]. Owing to the high-intensity actions of the test, one attempt was performed to determine the athlete's performance outcome.

2.2.4. Procedures

The athletes participated in two assessment sessions during a non-consecutive 2-day period, which were conducted in an exercise and sports science laboratory maintained at a temperature of 21 °C. DXA-certified professionals measured anthropometric and BC outcomes. After a 24-h period, the athletes performed specific tests in an indoor gymnasium with a "tatami" floor, which is commonly used in taekwondo competitions.

To minimize the learning effect, the athletes were informed of the procedures and practiced the test for three weeks before the start of the study. On the day before the specific test measurements, the coach contacted the athletes via telephone to request that they avoid high-intensity exercise, make no changes to their diet, hydrate normally, maintain regular sleep habits, and refrain from consuming stimulant beverages.

On the day of the measurements, the athletes warmed up by running on a treadmill at a speed of 9 km/h for five min, followed by joint mobility and ballistic stretching exercises, and low-intensity kicking techniques. The equipment was also checked to ensure that it functioned properly, including the calibration of the timing gates, batteries, and charge levels.

Athletes performed TSAT and $FSKT_{MULT}$ for 10 min between each test to promote complete recovery.

2.3. Statistical Analysis

Continuous and categorical data are presented as mean ± standard deviation (SD) and percentage, respectively, with a 95% confidence interval (95% CI). Data were collected with Microsoft Excel and processed with the Mac JASP Team statistical package (version 0.16.4). To assess normality and homoscedasticity, the variance was tested using the Shapiro-Wilk and Levene tests, respectively ($p > 0.05$). Differences according to gender were analyzed using the *t*-test for independent samples. BC asymmetries were quantified as the percentage difference between the lower limbs using a formula proposed in Microsoft Excel [31].

Absolute and relative reliability between TSAT performance outcome attempts were determined by an intraclass correlation coefficient (ICC; 1.1) $\geq$ 0.80 [35] and a coefficient of variation (CV%) $\leq$ 10% [36] (r = 0.93, 95% CI 0.83 to 0.95, and CV = 0.83%). The relationship between BC asymmetries and specific performance outcomes, was examined using a partial correlation statistical approach, controlling for gender, age and training time. Results were analyzed with r-Pearson and rho-Spearman, according to distribution [37]. Correlation magnitudes were interpreted using the following thresholds:0–0.30 [low], 0.31 to 0.49 [moderate], 0.50 to 0.69 [large], 0.70 to 0.89 [very large], and 0.90 to 1.0 [near perfect to perfect correlation] [37]. Additionally, the influence of significant results was analyzed using independent simple forward stepwise linear regression models [38–40]. One-way analysis of variance was used to determine the differences between independent variables. Standard residues were analyzed to detect outliers [38]. In addition, the possibility of collinearity between predictor variables in multiple regression models was verified using the variance inflation factor (VIF) and tolerance (i.e., VIF < 10 and tolerance > 0.2; VIF = 1.00, and tolerance = 1.00) [38,39] and verified using the Durbin-Watson test. Statistical significance was set at $p < 0.05$.

3. Results

3.1. Descriptive Results

The results are normally distributed with exception of %FM (w = 0.77, $p < 0.01$), BMD (w = 0.87, $p = 0.02$), and BMC (w = 0.85, $p = 0.02$) asymmetries. There were no significant gender differences in most outcomes, with the exception of stature (t = 4.81, $p < 0.01$, d = −0.45) and TSAT outcome (t = −2.83, $p = 0.01$, d = −1.37) (Table 1). BC outcomes between lower limbs also reported no significant differences ($p > 0.05$) with low magnitudes (d= −0.12 to 0.32) (Table 2). The estimated BC asymmetries ranged from 1.37% to 2.96%.

Table 1. Differences between both genders in descriptive and performance outcomes (n = 17).

	Mean	SD	95%CI Lower	95%CI Upper	t	*p*	95%CI Lower	995%CI Upper	*d*
Age (years)	2.42	3.59	22.52	25.94	−0.92	0.36	−5.36	2.11	−0.45
Stature (cm)	167.5	10.2	162.3	172.7	4.81	0.001 *	8.88	23.35	0.90
Set 1 (kicks)	19	2.26	20	18	0.22	0.82	−2.16	2.66	0.10
Set 2 (kicks)	18	2.33	19	17	0.68	0.50	−1.67	3.25	0.33
Set 3 (kicks)	18	2.26	19	17	1.24	0.23	−0.96	3.65	0.60
Set 4 (kicks)	17	2.22	16	18	1.21	0.24	−0.97	3.55	0.59
Set 5 (kicks)	17	2.12	18	16	1.21	0.24	−0.93	3.40	0.59
Total kicks (kicks)	91	10	86	96	0.95	0.35	−6.24	16.32	0.46
KDI index (%)	4.83	3.35	6.43	3.24	−1.48	0.15	−5.68	1.01	−0.72
TSAT (s)	6.73	0.94	7.18	6.28	−2.83	0.01 *	−1.90	−0.27	−1.37

Data are expressed as mean standard deviation (SD) with 95% confidence interval, t: *t*-test value, *p*: *p*-value, *: $p < 0.05$. The magnitude of the effect is expressed as d-cohen (d). Means: BM: body mass, FFM: free fat mass, LSTM: lean soft tissue mass, %FM: percentage fat mass, BMC: bone mineral content, BMD: bone mineral density. KDI: Kick decrement index, TSAT: taekwondo−specific agility test.

Table 2. Differences between body composition lower limbs and asymmetries estimated according to gender (n = 17).

	Left	SD	Right	SD	t	*p*	*d*	%IA	SD	95%CI Lower	95%CI Upper
BM (kg)	12.08	2.00	12.03	1.97	−0.60	0.55	−0.15	2.09	1.65	1.26	2.93
FFM (kg)	8.62	2.11	8.56	1.97	−0.77	0.45	−0.20	2.70	1.62	1.93	3.47
LSTM (kg)	7.60	2.79	7.55	2.82	−0.72	0.48	−0.18	2.91	1.77	2.07	3.75
%FM	26.14	7.22	26.47	7.72	1.25	0.23	0.32	2.13	2.43	0.97	3.29
FM (kg)	2.93	0.68	2.95	0.71	0.56	0.58	0.14	2.96	2.56	1.74	4.18
BMC (g)	513.0	121.5	513.0	119.8	−0.85	0.40	−0.22	1.68	1.71	0.71	2.02
BMD (g cm^2)	1.31	0.12	1.31	0.12	−0.48	0.63	−0.12	1.37	1.37	0.71	2.02

Data are expressed as mean ± standard deviation (SD) with 95% confidence interval, t: *t*-test value, *p*: *p*-value. %IA: Asymmetries are expressed as percentage. The magnitude of the effect is expressed as d-cohen (d). BM: body mass, FFM: free fat mass, LSTM: lean soft tissue mass, %FM: percentage fat mass, BMC: bone mineral content, BMD: bone mineral density.

3.2. Correlation between Asymmetries of BC and Specific Performance Outcomes in Taekwondo

The study revealed significant negative correlations between several muscle asymmetries, including BM, FFM, LSTM, and BMD, and the most of the $FSKT_{MULT}$ test outcomes. Specifically, BM Asymmetry was negatively correlated with performance outcomes in sets 1, 2, 3, 4, 5, and the total number of kicks, with the strongest correlation observed in set 1 (r = −0.67, p = 0.02). FFM asymmetry was negatively correlated with performance outcomes in sets 2, 3, and 4 and the total number of kicks (r = −0.64, p = 0.03; r = −0.66, p = 0.02; r = −0.62, p = 0.01; r = −0.70, p = 0.003; r = −0.60, p = 0.01, respectively). LSTM asymmetry was negatively correlated with performance outcomes in sets 2, 3, and 4 and the total number of kicks (r = −0.63, p = 0.03; r = −0.65, p = 0.02; r = −0.66, p = 0.02; r = −0.60, p = 0.01, respectively). Finally, BMD asymmetries was negatively correlated with set 5 (rho = −0.49, p = 0.04). For details, see Supplementary Table S1.

3.3. Influence of Body Composition Asymmetries Outcomes on Taekwondo Specific Performance Outcomes

The results of the stepwise multiple linear regression model revealed that FFM asymmetry significantly influenced the variance in KDI performance by 21% (F = 5.34, β = 0.24, p = 0.03; Durbin-Watson value = 2.45). Similarly, LSTM asymmetry influenced 21% of the variance in the performance of this outcome (F = 5.407, β = 0.273, p = 0.03; Durbin-Watson value = 2.76). Finally, DMO asymmetry influenced the outcome of set 5 by 48.3% (F = 15.92, β = −0.46, p = 0.01; Durbin-Watson value = 2.32).

4. Discussion

This study aimed to examine the relationship between BC asymmetry and specific performance outcomes in taekwondo athletes. Although the results showed no significant differences between the lower limbs, significant correlations were reported between asymmetries of the BM, FFM, LSTM, and BMD and most $FSKT_{MULT}$ outcomes. TSAT showed no significant correlation with BC asymmetries. The asymmetries of FFM and LSTM had a significant impact on reducing the KDI index by 21%. Furthermore, BMD negatively affected the performance of set 5 by 48%. These data suggest that even when the magnitude of BC asymmetries is low, they have an adverse effect on high-intensity performance outcomes in taekwondo athletes.

We identified significant negative correlations between BC, FFM, and LSTM asymmetries with most $FSKT_{MULT}$ test outcomes. This observation is consistent with the findings of Bell et al. [20], who examined the relationship between BC asymmetry and bilateral performance in collegiate athletes. In this study, 167 college athletes participated (age: 20 ± 1.3 years, n = 103 males; n = 63). The relevant findings documented that lower-limb FFM asymmetries influenced strength asymmetry by 20%. Additionally, they noted a downward trend in performance when the power asymmetry exceeded 10%. In this population, 95% demonstrated strength asymmetry ranging from −11.8% to 16.8% and power asymmetry ranging from −9.9% to 11.5%. Only a small segment (<4%) showed asymmetry of >15% between the limbs. Parallel to these findings, in our investigation, although the asymmetries were low in magnitude (range, 2–3.3%), we found negative correlations of moderate to high magnitude as the $FSKT_{MULT}$ test progressed. Friesen et al. [22] used a different approach to analyze the relationship between asymmetries and performance. Focusing on softball pitchers, they compared the functional characteristics of 41 individuals with healthy %FM and a group with high %FM. For this assessment, bilateral symmetry in isometric strength and range was measured using a handgrip dynamometer and inclinometer, respectively. Through DXA analysis, the authors identified asymmetries and subtle differences in functional characteristics between the %FM groups. These differences suggest that variations in BC can negatively affect specific movements.

In contrast, Chapelle et al. [21] investigated BC asymmetry in tennis players. They analyzed 22 players with an average age of 22 ± 3.6 years, focusing on the correlation between asymmetries in FFM and asymmetries in functional tasks. Although they identified notable differences in FFM between the upper and lower limbs (both dominant and non-dominant limbs), they found no significant correlation between these asymmetries and measures such as grip strength, unilateral CODS time, or performance in unilateral jumping tests. However, our results differ from these findings. A possible explanation for these discrepancies could be the type of test used. In their review of this topic, Ličen and Koine [4] highlighted that the manifestation of asymmetries could be strongly influenced by the nature of the task under analysis, how asymmetries are computed, and the tests used (unilateral or bilateral). This perspective is supported by Virgile and Bishop [41], who emphasize the importance of considering the type of test when investigating asymmetries.

An analysis of IA in specific performance, although using a different methodology, was performed by Kons et al. [11] in judo athletes. The authors investigated how lower limb asymmetries affect performance in judo using the Special Judo Fitness Test (SJFT), jumping tests, and measurements of the rectus femoris and vastus lateralis muscles. The results showed that Stronger limbs had higher muscle thicknesses. The results showed asymmetry in jump height and number of throws in SJFT (r = −0.68, p = 0.014), asymmetry of maximal velocity and the third Set of SJFT (r = −0.58, p = 0.045), maximal force and jump height asymmetry with the SJFT index (r = 0.50, p = 0.04; r = 0.58, p = 0.03), and a relationship between echo intensity and vastus lateralis muscle asymmetry and SJFT30B (r = −0.59, p = 0.041). Later, Kons et al. [10] analyzed four simulated judo combats (n = 14; 23.3 ± 3.0 years, 74.4 ± 22.3 kg, 176.0 ± 5.2 cm, 14.6 ± 5.2%FM), observing that asymmetries derived from countermovement jump tests showed a significant increase after the second combat (p = 0.001). Although handgrip strength decreased consistently throughout the combats ($p < 0.001$), this reduction was similar in both hands with no evidence of pronounced asymmetry between them.

Similar to our results, Kons et al. [10] identified negative correlations with specific performance in their study. This parallel finding reinforces the idea that asymmetries in the BC play a determining role in force generation, particularly in relation to the FFM and LSTM asymmetries. Kavvoura et al. [42] analyzed the influence of muscle mass and FFM on strength and power production in taekwondo athletes. Specifically, we studied the relationship between lower limb FFM and the rate of force development (RFD) in taekwondo athletes. Employing tests such as the countermovement jump and muscle architecture assessment, they discovered a robust correlation (r = 0.81, p = 0.016) between muscle mass and RFD, particularly during the first 250 ms of movement. Employing tests such as countermovement jumping and muscle architecture assessment, they discovered a robust correlation (r = 0.81, p = 0.01) between muscle mass and RFD, particularly during the first 250 ms of movement. When vastus lateralis muscle thickness was considered in relation to RFD, notable differences in performance emerged between taekwondo athletes and throwers. The findings of this study further support the significance of muscle thickness as a valid measure of strength and power in taekwondo athletes. This highlights the importance of muscle morphology in strength development in Taekwondo athletes.

As elegantly pointed out in their review by Rodríguez-Rosell et al. [43], muscle structural factors have a profound relationship with the rate of force development and explosive strength. The authors highlighted the relevance of muscular morphology among other factors. In other words, there is critical interdependence between muscle fiber composition, particularly myosin heavy chain isoforms, and RFD. In addition, the impact of the cross-sectional area (CSA) of myofibers and muscles as a whole. This study highlights that a more prominent CSA in the quadriceps femoris is positively correlated with greater RFD in the knee extensors. Moreover, there is evidence that specific training programs can induce simultaneous increases in CSA and RFD. It is relevant to highlight that older athletes with larger CSA fast-type fibers tend to have greater RFD. This relationship underlines the prevalence of type II myofibers and suggests that strengthening these fibers could be a strategy to enhance RFD.

To our knowledge, this is the first study to analyze the negative relationship between BMD asymmetry and $FSKT_{MULT}$. From a health perspective, Nasri et al. [44] investigated the relationship between combat sports and BMD. They compared 50 combat athletes with 30 sedentary individuals and adolescents. The results showed that BMD was higher in athletes than in sedentary individuals. Factors such as weight, body mass, and FFM were correlated with BMD. The activity index (had a strong correlation with BMD and was the main predictor of BMD in several body limbs). This study suggests that the activity index is the best predictor of BMD in adolescent combat sports athletes and that these sports may benefit bone accrual in young people.

4.1. Limitation and Futures Studies

This study had some limitations. One of them is the impossibility of assessing the relative reliability of the measurements due to the restrictions inherent to the use of DXA technology. Despite these limitations, it is important to emphasize that DXA is highly valid and reliable. Another limitation that may have influenced our outcomes is the small number of athletes evaluated. Nevertheless, the outcomes of the partial correlations suggest that the findings are consistent regardless of the athletes' sex, age, or duration of practice. Although the statistical approach used, including *t*-test limited significant differences in height and performance outcomes on the TSAT and partial correlations controlling for sex as a covariate might be appropriate to address this aspect in the study.

However, it is important to note that both genders have physiological, morphological, and performance differences that should be taken into account when analyzing the results [45,46]. The limited availability of access to high-level competitive female athletes is a recognized limitation in the field of sports science [46]. This is noted, for example, in the recent review by Kim [47] on physical and fitness profiles. In which, studies on males (n = 430, age: 20.10 $\pm$ 1.00 years) are reported in higher proportion than on females (n = 99, age: 19.40 $\pm$ 1.18 years, career: approximately 7.7 years). However, the partial statistical approach could resolve this issue although further studies are required to confirm this. In addition, future studies could focus on analyzing the phenomenon of body composition IA in female athletes.

4.2. Highlights and Practical Perspectives

To our knowledge, this is the first study to investigate the relationship between BC inter-limb asymmetry using DXA and specific performance outcomes in combat sports athletes. Our findings suggest several directions for future research. Further analyses of these correlations using complementary technologies, assessment of asymmetries in strength, or inclusion of a larger sample of athletes could potentially provide insights into the mechanisms underlying this relationship. Future studies should explore how training can be adjusted to address and correct these asymmetries, thereby optimizing athletic performance. From a practical training perspective, coaches should include BC asymmetries as part of their assessments and reduce or minimize them. From a preventive perspective, it is essential to analyze the possible relationship between BC asymmetries and injury risk. An imbalance in BC may result in an inequitable distribution of loads during training and competition, thereby increasing the potential risk of injury to specific extremities. Finally, it is important to investigate the factors that contribute to these asymmetries. It is necessary to determine whether they are the result of training, sport-specific techniques, or postural habits adopted outside the sports context. Understanding these underlying causes will facilitate the design of targeted and effective interventions.

5. Conclusions

The results demonstrated a significant negative correlation between different types of asymmetries in BC and performance on taekwondo-specific tests. These findings suggest that greater BC asymmetry is associated with reduced taekwondo-specific performance. This underscores the importance of balanced training and attention to body symmetry for improving performance in this sport. These findings could have practical implications for coaches and athletes when designing personalized training programs.

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