

Original Article

Direction-Specific Interlimb Asymmetries, Dynamic Balance, Jump Performance, and Body Composition in Elite Male Combat Athletes

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Abstract

Objectives: This study investigated direction-specific interlimb asymmetries and their relationships with balance, jump performance, body mass index (BMI), body fat percentage (BF%), and training age in male combat athletes. **Methods:** Thirty-eight elite male boxing (n = 13), kickboxing (n = 13), and taekwondo (n = 12) athletes participated. BF%, countermovement jump (CMJ), squat jump (SJ), and Y-Balance Test (YBT) performance were assessed. Direction-specific asymmetry magnitude was calculated using higher- and lower-performing limbs. Correlation and multiple regression analyses were performed, with false discovery rate (FDR) correction for exploratory correlations. **Results:** Asymmetry differed across YBT directions ($p < .001$), with greater anterior than posteromedial and posterolateral asymmetry. After FDR correction, only the negative BF%–CMJ association remained significant; no asymmetry–performance correlations remained significant. The CMJ ($R^2 = .332$, $p = .003$) and SJ ($R^2 = .305$, $p = .006$) regression models were significant, with BF% negatively associated with CMJ ($\beta = -.565$, $p < .001$) and SJ ($\beta = -.531$, $p = .002$). BMI was not significantly associated with either outcome. **Conclusions:** Direction-specific interlimb asymmetry showed limited associations with balance and jump performance. BF% was associated with jump performance. Findings should be interpreted considering the exploratory, cross-sectional design.

Keywords: Explosive Performance, Interlimb Asymmetry, Neuromuscular Control, Y-Balance Test, Weight-Class Athletes

Introduction

Combat sports performance depends not only on technical proficiency but also on the ability to effectively maintain lower-extremity balance during movement¹. Because a substantial proportion of actions, such as kicking, punching, and rapid changes of direction, are executed during single-leg support, dynamic postural control is considered a fundamental component of athletic performance². In this context, neuromuscular control of the lower extremities

contributes to the maintenance of stability by integrating sensory input with appropriate motor output³. However, because different tests of dynamic balance assess distinct components of postural control, interpreting balance performance based on a single assessment is inherently limited⁴. Indeed, superior performance in the Y-Balance Test has been associated with coordinated movement strategies among the ankle, knee, and hip joints⁵. Similarly, neuromuscular training interventions have been shown to enhance dynamic balance performance and support athletic performance¹. Moreover, the capacity of the neuromuscular system to generate multiple movement solutions suggests that balance performance depends not only on muscle strength but also on the quality of movement coordination³. Therefore, a comprehensive evaluation of lower-extremity function in combat athletes may contribute to a more accurate interpretation of both athletic performance and injury risk⁴. In this context, one variable that has attracted increasing research interest in recent years is interlimb asymmetry.

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Interlimb asymmetry is defined as the difference between limbs in terms of strength, power, movement quality, or functional performance⁶. Such asymmetries are recognized as important biomechanical characteristics that may influence both athletic performance and injury risk⁷. For example, in elite youth female football players, greater vertical and horizontal interlimb asymmetries have been associated with lower jump performance and slower sprint times⁸. However, the influence of interlimb asymmetry on athletic performance has not been consistently demonstrated across studies⁹. One of the primary reasons for these inconsistent findings is the task- and test-specific nature of asymmetry¹⁰. In other words, an asymmetry that is evident in one test may not be present or may even reverse direction in another test within the same athlete. Likewise, findings from a systematic review indicate that different performance assessments, including sprinting, jumping, and change-of-direction tasks, do not exhibit comparable relationships with interlimb asymmetry⁹. Consequently, asymmetry values obtained from a single test cannot be readily generalized⁶. Therefore, it has been recommended that the assessment of interlimb asymmetry should consider not only its magnitude but also the specific movement task and performance direction in which it is measured¹⁰. Such task- and direction-specific evaluations may provide a more accurate representation of athletes' functional characteristics and strengthen the interpretation of performance outcomes.

Combat athletes' habitual adoption of the same guard stance and the repetitive execution of kicks with the dominant leg provide the basis for the development of structural and functional adaptations in the lower extremities over time¹¹. However, the extent to which these adaptations are reflected in performance appears to depend on the assessment method employed¹². Indeed, biomechanical differences between the dominant and non-dominant limbs have been reported in joint kinetics, movement velocity, and force production¹³. Nevertheless, important methodological differences across studies hinder the establishment of consistent conclusions. In taekwondo athletes, balance and single-leg performance are often reported to be comparable between limbs, suggesting that the presence and magnitude of asymmetry may depend on the specific assessment method used¹². Likewise, functional hop, balance, and single-leg performance tests do not demonstrate consistent associations with injury risk; while some assessments reveal significant relationships, others fail to exhibit comparable sensitivity¹⁴. Furthermore, the observation that performance-related asymmetric adaptations manifest differently across body composition measures and sport-specific performance tests indicates that no single assessment can provide a comprehensive profile of an athlete's functional characteristics¹⁵. Collectively, the available evidence provides only limited interpretability because studies frequently combine athletes from different combat sport disciplines, weight

categories, and performance assessments. Consequently, further research focusing on direction-specific interlimb asymmetries in homogeneous groups of elite combat athletes is warranted.

Performance in combat sports cannot be explained solely by technical proficiency; body composition is also a key determinant influencing balance, jumping ability, and movement economy¹⁶. In particular, fat mass and fat-free mass represent distinct and independent components of body composition in elite athletes and should therefore be considered simultaneously when evaluating athlete-specific body composition profiles¹⁷. However, BMI should not be interpreted as a direct measure of body composition because it does not distinguish between fat mass and fat-free mass, which is particularly relevant in athletic populations with relatively high levels of lean mass¹⁸. In combat athletes, body composition indicators such as body fat percentage, skeletal muscle mass, and phase angle have also been reported to be associated with aerobic capacity and overall physical fitness¹⁶. Moreover, body composition in combat athletes may change across different phases of training, with reductions in body mass and body fat reported between preparatory and pre-competitive periods in professional mixed martial arts athletes¹⁹. Despite this, training experience has received comparatively limited attention as a factor associated with balance and interlimb differences, and its relationship with physical performance appears to depend on the task and sporting context²⁰. Similarly, studies simultaneously examining the independent contributions of BMI, body fat percentage, and training age beyond the effects of interlimb asymmetry in elite combat athletes remain scarce.

The existing literature has predominantly examined interlimb asymmetry in specific sports such as soccer, tennis, and taekwondo^{6,20,14}. Consequently, evidence regarding direction-specific interlimb asymmetries in relatively homogeneous samples of elite combat athletes matched for sex, competitive level, and weight category remains limited. Furthermore, the relationships between these asymmetries and dynamic balance and jumping performance, as well as the relationships of BMI, BF%, and training age with these performance outcomes, remain unclear. Although boxing, kickboxing, and taekwondo differ in their technical characteristics, they share several fundamental performance demands, including a high level of lower-extremity neuromuscular control, unilateral postural stability, and explosive force production. Therefore, evaluating athletes from these disciplines within the same sex, competitive level, and weight category improves sample comparability with respect to these characteristics while enabling a more comprehensive investigation of the neuromuscular performance characteristics common to combat sports. Accordingly, the present study aimed to determine direction-specific interlimb asymmetries in elite combat athletes competing within the same weight category and to examine the

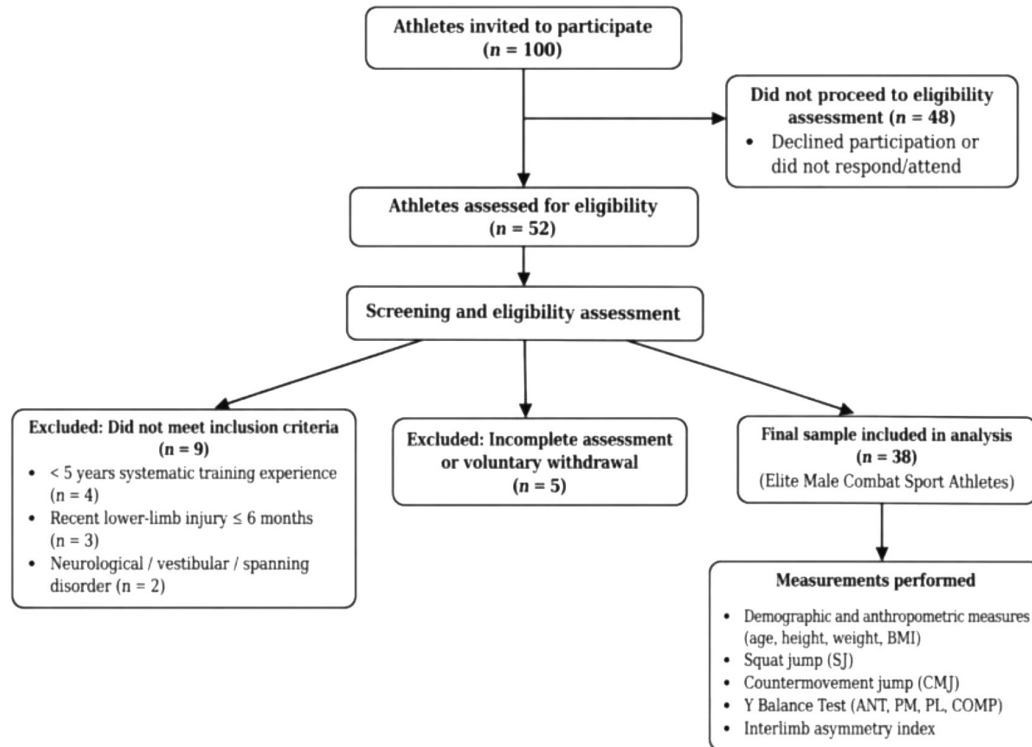


Figure 1. Participant recruitment and selection flow diagram.

relationships between these asymmetries and dynamic balance, jump performance, and selected anthropometric characteristics. In addition, the relationships of BMI, BF%, and training age with dynamic balance and jump performance were evaluated. It was hypothesized that: (i) the magnitude of interlimb asymmetry would differ across Y-Balance Test reach directions; (ii) greater interlimb asymmetry would be associated with poorer dynamic balance and jump performance; and (iii) BMI, BF%, and training age would be associated with dynamic balance and jump performance.

Materials and Methods

Participants

Participants were recruited using a purposive sampling strategy from boxing, kickboxing, and taekwondo clubs, national team training camps, and university sport programs located in Ankara, Türkiye, between November 2025 and February 2026. A total of 100 athletes were invited to participate, and recruitment was conducted on a voluntary basis. Of these, 52 agreed to participate and were assessed for eligibility. Athletes were eligible for inclusion if they (i) were actively competing at the national or international level in a combat sport discipline, (ii) had

a minimum of 5 years of systematic training experience, (iii) were free from musculoskeletal injury to the lower extremities within the previous 6 months, and (iv) were able to complete all testing procedures without pain or functional limitation. Exclusion criteria included any history of neurological, vestibular, or systemic disorders, current musculoskeletal injury, recent surgery, or engagement in strenuous training or competition within 48 hours prior to testing. Of the 52 athletes assessed for eligibility, 14 were excluded, including nine who did not meet the eligibility criteria (insufficient training experience, $n = 4$; recent lower-limb injury, $n = 3$; neurological, vestibular, or systemic disorders, $n = 2$) and five due to incomplete assessments or voluntary withdrawal during the testing procedures. The participant recruitment and selection process is presented in Figure 1. Consequently, 38 elite male combat sport athletes aged 18–30 years (mean $\pm$ SD: age 22.66 ± 3.39 years; body mass 72.88 ± 1.54 kg; height 179.68 ± 4.44 cm) were included in the final analysis. Only male athletes were included to reduce the potential influence of biological sex on neuromuscular performance, body composition, muscle power, balance, and jump-related outcomes, thereby increasing sample homogeneity²¹. The final sample comprised boxers ($n = 13$; mean age = 23.15 ± 3.80 years, height = 180.85 ± 5.01

Table 1. Descriptive values for the total sample (n=38).

Variable	Mean $\pm$ SD	95% CI
Age (years)	22.66 $\pm$ 3.39	21.54–23.77
Height (cm)	179.68 $\pm$ 4.44	178.22–181.14
Body mass (kg)	72.88 $\pm$ 1.54	72.38–73.39
BF (%)	11.30 $\pm$ 2.46	10.49–12.11
BMI (kg·m ⁻²)	22.60 $\pm$ 0.92	22.30–22.90
Training age (years)	10.79 $\pm$ 3.67	9.58–12.00
CMJ (cm)	41.57 $\pm$ 4.63	40.05–43.10
SJ (cm)	39.16 $\pm$ 4.38	37.72–40.60
ANT (%)	65.22 $\pm$ 6.72	63.01–67.43
PM (%)	107.93 $\pm$ 7.04	105.62–110.24
PL (%)	104.30 $\pm$ 6.68	102.10–106.50
COMP (%)	92.60 $\pm$ 5.62	90.75–94.45

BF: Body fat percentage; BMI: Body Mass Index, CMJ: Countermovement jump; SJ: Squat jump; ANT: Anterior; PM: Posteromedial; PL: Posterolateral; COMP: Composite score.

cm, body mass = 72.75 $\pm$ 1.60 kg, training age = 11.15 $\pm$ 3.89 years), kickboxers (n = 13; mean age = 22.85 $\pm$ 3.65 years, height = 179.46 $\pm$ 2.30 cm, body mass = 72.56 $\pm$ 1.56 kg, training age = 11.85 $\pm$ 3.98 years), and taekwondo athletes (n = 12; mean age = 21.92 $\pm$ 2.71 years, height = 178.67 $\pm$ 5.52 cm, body mass = 73.37 $\pm$ 1.46 kg, training age = 9.25 $\pm$ 2.73 years), all competing in the same 71–75 kg weight category. Restricting the sample to a single weight category was intended to reduce potential confounding related to body mass and weight-class-specific performance characteristics and to allow more homogeneous comparisons across disciplines. All athletes competed at national or international level and trained approximately 3–5 hours per day, 5–6 days per week. Participant demographic characteristics are presented in Table 1.

Sample Size Calculation

An a priori power analysis was performed using G*Power software (version 3.1.9.7). The analysis was conducted using the F tests family and the Linear multiple regression: Fixed model, R² deviation from zero statistical test. The calculation was based on an a priori power analysis assuming a large effect size ($f^2 = 0.35$), an alpha level of 0.05, a statistical power of 0.80, and three predictors. The analysis indicated that a minimum sample size of 36 participants was required. The selected effect size corresponded to Cohen's conventional benchmark for a large effect in multiple regression²² and was considered reasonable in light of previous studies reporting moderate-to-large associations between anthropometric or physical performance characteristics in combat sport athletes^{23,24}. The power analysis was based on a three-predictor regression model; secondary correlation analyses and smaller effect sizes were not specifically powered.

Study Design and Procedures

This was a cross-sectional observational study. Participants were instructed to avoid strenuous exercise and competition for at least 48 hours before the testing session. Upon arrival at the laboratory, demographic information was collected, followed by anthropometric measurements. Participants then completed a standardized warm-up consisting of 5 minutes of light jogging at a self-selected intensity and dynamic stretching exercises targeting the lower extremities. Before each performance test, the procedure was explained and demonstrated, and participants performed submaximal practice trials for familiarization. The assessments were administered in a fixed order: squat jump (SJ), countermovement jump (CMJ), and Y Balance Test (YBT). A rest period of 3–5 minutes was provided between consecutive tests to minimize fatigue. All measurements were completed on the same day using standardized procedures and identical equipment and were administered by the same experienced researcher to minimize measurement bias and inter-rater variability.

Study Outcomes

Anthropometric Measurements

The participants were weighed barefoot on a scale with a sensitivity of up to 20 g (Angel brand), wearing only shorts and a T-shirt. Height measurements were taken using a Holtain stadiometer while the participants stood upright, with the sliding headpiece adjusted to touch the vertex of the head, and height was recorded with an accuracy of 1 mm. Body mass index (BMI) was calculated using the formula BMI: body weight / height² (kg/m²). Skinfold thickness was measured at seven anatomical sites—subscapular, triceps, chest, midaxillary, suprailiac, abdominal, and thigh—using a Harpenden skinfold caliper.

Body fat percentage was subsequently estimated using the athlete-specific seven-site equation developed by Evans et al.²⁵. Each site was measured twice by the same experienced assessor. When the difference between the two measurements exceeded 5%, a third measurement was obtained. The mean of the two measurements, or the median when three measurements were obtained, was used for analysis²⁶.

Countermovement (CMJ) and Squat jump (SJ)

The athletes' jump performance was assessed using a contact mat system (Smart Jump; Fusion Sport, Coopers Plains, Brisbane, Australia), with jump height calculated from flight time. The Smart Jump showed high reliability of the countermovement jump test (CMJ) and squat jump (SJ) (ICC = 0.94 and 0.96, respectively) in a prior study²⁷. For the SJ, participants initiated the movement from a static position with approximately 90° of knee flexion and maintained this posture for about 2 seconds before performing the jump, without any preliminary countermovement. In the CMJ, participants performed a rapid downward phase to a self-selected depth, immediately followed by a maximal vertical take-off. Both jump types were executed with the hands placed on the hips to minimize the contribution of arm swing. Participants were instructed to exert maximal effort during each jump. Participants were allowed up to five valid trials for each jump condition, with approximately 15 seconds of rest between attempts. The highest recorded jump height for both the SJ and CMJ was retained for subsequent analyses. Previous investigations have reported excellent reliability for this assessment method, with intraclass correlation coefficients exceeding 0.96 for both jump types²⁸. The same investigator supervised all jump assessments under standardized testing conditions.

Dynamic balance test

Dynamic balance was assessed using the Y Balance Test Kit according to the standardized protocol described by Shaffer et al.²⁹, which has demonstrated good interrater test-retest reliability (ICC = 0.80–0.93). Leg length was measured bilaterally in the supine position, from the anterior superior iliac spine to the distal aspect of the medial malleolus, and recorded in centimeters. The leg length measured for each limb was subsequently used to normalize the reach distances obtained while that limb served as the stance limb. For the anterior (ANT) direction, reach distance was measured from the tip of the stance foot toes to the furthest point reached. For the posteromedial (PM) and posterolateral (PL) directions, reach distance was defined as the maximum distance from the heel of the stance foot to the point lightly touched by the reaching foot. During the test, participants stood barefoot with the stance foot positioned at the center of the grid intersection and were instructed to reach as far as possible with the

free limb. Participants were required to keep their hands on the iliac crests and the heel of the stance foot in contact with the ground while lightly touching the furthest point with the toes of the reaching foot. Prior to data collection, a brief demonstration of the test procedure was provided by an experienced researcher, and participants were allowed to perform at least three practice trials in each direction. Following the familiarization trials, a 2-minute rest period was provided before participants completed three recorded trials in each direction. The testing order was standardized for all participants. Testing began with the self-reported dominant limb, and reach directions were assessed in the same sequence (ANT, PM, and PL) for both limbs. Trials were considered invalid and repeated if participants transferred body weight onto the reaching foot, lifted the heel of the stance foot off the ground, or removed their hands from the hips during the reach. All reach distances were recorded in centimeters. For each reach direction, the maximum reach distance obtained from the three trials was retained for analysis and normalized to the corresponding stance-limb length using the following formula: normalized reach distance (%) = (maximum reach distance / corresponding stance-limb length) × 100. Accordingly, ANT, PM, and PL scores represented the normalized maximum reach distance for each respective direction. The composite score (COMP) was calculated as the mean of the three normalized reach scores: COMP (%) = [ANT (%) + PM (%) + PL (%)] / 3.

Definition of variables

For the purposes of the present analysis, limbs were classified separately for each Y Balance Test direction according to performance rather than functional or stance-based dominance. The limb demonstrating the greater normalized reach distance was classified as the higher-performing limb (HPL), whereas the contralateral limb was classified as the lower-performing limb (LPL). Interlimb asymmetry was expressed as the magnitude of the between-limb difference and calculated as $|HPL - LPL| / \max(HPL, LPL) \times 100$. Accordingly, the asymmetry values represent the magnitude of performance imbalance and do not indicate the anatomical or stance-related direction of asymmetry.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics (version 23.0; IBM Corp., Armonk, NY, USA). Descriptive statistics are presented as mean ± standard deviation (SD), with 95% confidence intervals (CIs) calculated for all descriptive variables. Complete data were available for all 38 participants included in the analyses; therefore, no missing-data imputation was required. Data normality was assessed using the Shapiro-Wilk test. Differences in asymmetry magnitude across the three YBT reach directions (ANT, PM, and PL) were

Table 2. Y Balance Test performance and interlimb asymmetry between higher- and lower-performing limbs (N = 38).

YBT Test	Mean $\pm$ SD	HPL-LPL Difference	95% CI	ASYM (%)
HPL_ANT (%)	67.79 $\pm$ 6.72	5.14 $\pm$ 2.49	4.33–5.96	7.63 $\pm$ 3.85 ^a
LPL_ANT (%)	62.65 $\pm$ 6.95			
HPL_PM (%)	109.98 $\pm$ 7.10	4.11 $\pm$ 2.40	3.32–4.90	3.73 $\pm$ 2.17 ^b
LPL_PM (%)	105.87 $\pm$ 7.18			
HPL_PL (%)	106.33 $\pm$ 6.84	4.06 $\pm$ 2.92	3.10–5.02	3.80 $\pm$ 2.69 ^b
LPL_PL (%)	102.27 $\pm$ 6.84			
HPL_COMP (%)	94.70 $\pm$ 5.67	4.20 $\pm$ 1.72	3.63–4.77	4.44 $\pm$ 1.81
LPL_COMP (%)	90.50 $\pm$ 5.70			

Data are presented as mean $\pm$ SD. HPL = higher-performing limb; LPL = lower-performing limb; ANT = anterior; PM = posteromedial; PL = posterolateral; COMP = composite score; ASYM = asymmetry magnitude. N = 38 for all analyses. Different superscript letters in the ASYM column indicate significant pairwise differences based on Wilcoxon signed-rank tests with Holm adjustment ($p < 0.05$).

Table 3. Correlations Between Y-Balance, Jump Performance, and Anthropometric Characteristics.

Variable	ANT	PM	PL	COMP	CMJ	SJ
Training age (year)	-0.271 (.100)	0.244 (.140)	0.299 (.068)	0.119 (.478)	-0.242 (.143)	-0.190 (.253)
BMI ($\text{kg}\cdot\text{m}^{-2}$)	0.156 (.350)	0.123 (.461)	0.020 (.906)	0.161 (.334)	-0.101 (.548)	-0.238 (.151)
BF (%)	-0.175 (.292)	-0.011 (.947)	0.008 (.962)	-0.091 (.585)	-0.509 (.001) ^a	-0.418 (.009)

ANT: Anterior; PM: Posteromedial; PL: Posterolateral; COMP: Composite score; CMJ: Countermovement jump; SJ: Squat jump. Values are Spearman's ρ (p-value). N = 38 for all analyses. To account for multiple testing within this correlation family, p-values were adjusted using the Benjamini–Hochberg false discovery rate (FDR) procedure. Following FDR correction, only the association between BF% and CMJ remained statistically significant ($q = 0.020$). ^aIndicates statistical significance after FDR correction ($q = 0.020$).

Table 4. Correlations between interlimb asymmetry, Y-Balance and jump performance.

Variable	ANT	PM	PL	COMP	SJ	CMJ
ASYM_ANT	-.313 (.056)	-.392 (.015)	-.176 (.289)	-.314 (.055)	.101 (.545)	.086 (.606)
ASYM_PM	.264 (.109)	-.174 (.297)	-.074 (.660)	-.032 (.851)	.072 (.668)	.257 (.119)
ASYM_PL	.122 (.466)	-.129 (.441)	-.001 (.995)	-.027 (.873)	-.212 (.201)	-.213 (.200)
ASYM_COMP	.245 (.138)	-.299 (.068)	-.203 (.221)	-.125 (.456)	-.133 (.426)	.098 (.556)

ANT = anterior; PM = posteromedial; PL = posterolateral; COMP = composite score; CMJ = countermovement jump; SJ = squat jump. Values are Spearman's ρ (unadjusted p-value). N = 38 for all analyses. The Benjamini–Hochberg false discovery rate (FDR) procedure was applied to this correlation family to account for multiple testing. None of the associations remained statistically significant following FDR correction.

examined using the Friedman test, followed by pairwise Wilcoxon signed-rank tests with Holm adjustment when the omnibus test was statistically significant. Kendall's W was reported as a measure of effect size. Relationships among anthropometric characteristics, dynamic balance, interlimb asymmetry, and jump performance variables were examined using Spearman's rank correlation coefficient because at least one variable deviated from

normality. Correlation coefficients were interpreted according to Cohen²², with values of 0.10, 0.30, and 0.50 representing small, moderate, and large associations, respectively. Given the exploratory nature of the correlation analyses, the Benjamini–Hochberg false discovery rate (FDR) procedure was applied separately to the sets of correlations reported in Tables 3 and 4 to control for multiple testing. Unadjusted p-values are reported for

Table 5. Multiple linear regression analyses predicting balance and jump performance.

Condition	Model statistics	Predictors	B	SE	Standardized β	t	p	VIF	95% CI for B
ANT (%)	$R^2 = .109$; Adj $R^2 = .030$; $F(3,34) = 1.38$; $p = .264$	Training age (year)	-0.37	0.32	-0.200	-1.15	.259	1.156	[-1.01, 0.28]
		BMI ($\text{kg}\cdot\text{m}^{-2}$)	1.13	1.24	0.154	0.91	.370	1.090	[-1.39, 3.64]
		BF (%)	-0.28	0.48	-0.102	-0.58	.565	1.169	[-1.25, 0.70]
PM (%)	$R^2 = .167$; Adj $R^2 = .093$; $F(3,34) = 2.27$; $p = .098$	Training age (year)	0.788	0.323	0.411	2.441	.020	1.156	[0.132, 1.444]
		BMI ($\text{kg}\cdot\text{m}^{-2}$)	1.610	1.254	0.210	1.283	.208	1.090	[-0.939, 4.158]
		BF (%)	-0.257	0.485	-0.090	-0.530	.599	1.169	[-1.243, 0.728]
PL (%)	$R^2 = .131$; Adj $R^2 = .054$; $F(3,34) = 1.71$; $p = .184$	Training age (year)	0.693	0.313	0.381	2.214	.034	1.156	[0.057, 1.330]
		BMI ($\text{kg}\cdot\text{m}^{-2}$)	0.602	1.217	0.083	0.495	.624	1.090	[-1.870, 3.075]
		BF (%)	-0.486	0.470	-0.178	-1.032	.309	1.169	[-1.442, 0.470]
COMP (%)	$R^2 = .086$; Adj $R^2 = .005$; $F(3,34) = 1.07$; $p = .376$	Training age (year)	0.36	0.27	0.238	1.35	.185	1.156	[-0.18, 0.91]
		BMI ($\text{kg}\cdot\text{m}^{-2}$)	1.17	1.05	0.191	1.12	.272	1.090	[-0.96, 3.30]
		BF (%)	-0.35	0.41	-0.152	-0.86	.398	1.169	[-1.17, 0.48]
CMJ (cm)	$R^2 = .332$; Adj $R^2 = .273$; $F(3,34) = 5.62$; $p = .003a$	Training age (year)	-0.09	0.19	-0.069	-0.46	.651	1.156	[-0.47, 0.30]
		BMI ($\text{kg}\cdot\text{m}^{-2}$)	-1.13	0.74	-0.223	-1.52	.137	1.090	[-2.63, 0.38]
		BF (%)	-1.07	0.29	-0.565	-3.73	<.001	1.169	[-1.65, -0.48]
SJ (cm)	$R^2 = .305$; Adj $R^2 = .244$; $F(3,34) = 4.98$; $p = .006b$	Training age (year)	-0.05	0.18	-0.046	-0.30	.768	1.156	[-0.43, 0.32]
		BMI ($\text{kg}\cdot\text{m}^{-2}$)	-1.42	0.71	-0.297	-1.99	.055	1.090	[-2.86, 0.03]
		BF (%)	-0.95	0.28	-0.531	-3.44	.002	1.169	[-1.51, -0.39]

B = unstandardized regression coefficient; SE = standard error; β = standardized regression coefficient; CI = confidence interval; VIF = variance inflation factor; BMI = body mass index; BF% = body fat percentage; ANT = anterior; PM = posteromedial; PL = posterolateral; COMP = composite score; CMJ = countermovement jump; SJ = squat jump. N = 38 for all analyses.

the exploratory correlation analyses, and statistical significance after Benjamini-Hochberg FDR correction was evaluated using an adjusted q-value threshold of < 0.05. Multiple linear regression analyses were performed to examine the adjusted associations of training age, body mass index (BMI), and body fat percentage (BF%) with dynamic balance and jump performance outcomes. Prior to regression analyses, the assumptions of linearity, normality of residuals, homoscedasticity, and multicollinearity were evaluated. Multicollinearity was assessed using variance inflation factors (VIFs), and predictor intercorrelations were examined to aid the

interpretation of regression coefficients. Potentially influential observations were evaluated using studentized residuals, leverage values, and Cook's distance, with $|\text{studentized residual}| > 2$, leverage $> 2p/n$, or Cook's distance $> 4/n$ considered indicative of potential influence. Sensitivity analyses were conducted by repeating the regression models after excluding observations meeting at least one of these criteria. All statistical tests were two-tailed, and statistical significance was set at $p < 0.05$.

Results

Descriptive characteristics and performance outcomes are presented in Table 1. The mean age of the participants was 22.66 ± 3.39 years, with a mean training age of 10.79 ± 3.67 years. Mean body mass index (BMI) and body fat percentage (BF%) were $22.60 \pm 0.92 \text{ kg}\cdot\text{m}^{-2}$ and $11.30 \pm 2.46\%$, respectively. Mean CMJ and SJ heights were $41.57 \pm 4.63 \text{ cm}$ and $39.16 \pm 4.38 \text{ cm}$. Mean normalized Y-Balance Test (Y-BT) scores were $65.22 \pm 6.72\%$ for the anterior (ANT), $107.93 \pm 7.04\%$ for the posteromedial (PM), and $104.30 \pm 6.68\%$ for the posterolateral (PL) directions, with a composite score of $92.60 \pm 5.62\%$ (Table 1).

Interlimb asymmetry differed across the three Y-BT reach directions (Friedman $\chi^2(2) = 22.79$, $p < .001$, Kendall's $W = .300$). Asymmetry was greatest in the ANT direction ($7.63 \pm 3.85\%$), compared with the PM ($3.73 \pm 2.17\%$) and PL ($3.80 \pm 2.69\%$) directions. Holm-adjusted post-hoc comparisons showed greater asymmetry in ANT than in both PM (adjusted $p < .001$) and PL (adjusted $p < .001$), whereas PM and PL did not differ (adjusted $p = .875$). Descriptive interlimb differences and asymmetry magnitudes are presented in Table 2.

Bivariate associations among training age, body-composition measures, dynamic balance, and jump performance are presented in Table 3. Body fat percentage was negatively associated with countermovement jump (CMJ) ($\rho = -.509$, $p = .001$) and squat jump (SJ) performance ($\rho = -.418$, $p = .009$). After FDR adjustment, only the association between BF% and CMJ remained statistically significant ($q = .020$). None of the remaining associations met the FDR-adjusted significance criterion.

Associations between direction-specific asymmetry magnitudes and performance outcomes are presented in Table 4. Greater ANT asymmetry was associated with lower PM performance ($\rho = -.392$, $p = .015$); however, this association did not remain statistically significant after FDR adjustment. No other asymmetry–performance associations reached statistical significance, and none met the FDR-adjusted significance criterion.

Multivariable regression analyses examining the adjusted associations of training age, BMI, and body fat percentage with dynamic balance and jump performance are presented in Table 5. The models for ANT ($R^2 = .109$, adjusted $R^2 = .030$, $F(3, 34) = 1.38$, $p = .264$), PM ($R^2 = .167$, adjusted $R^2 = .093$, $F(3, 34) = 2.27$, $p = .098$), PL ($R^2 = .131$, adjusted $R^2 = .054$, $F(3, 34) = 1.71$, $p = .184$), and composite Y-Balance Test performance ($R^2 = .086$, adjusted $R^2 = .005$, $F(3, 34) = 1.07$, $p = .376$) were not statistically significant overall. The CMJ model was statistically significant ($R^2 = .332$, adjusted $R^2 = .273$, $F(3, 34) = 5.62$, $p = .003$), accounting for 33.2% of the variance in CMJ performance. Within this model, body fat percentage was negatively associated with CMJ performance ($\beta = -.565$, $p < .001$), whereas BMI ($\beta = -.223$, $p = .137$) and training

age ($\beta = -.069$, $p = .651$) were not statistically significant. The SJ model was also statistically significant ($R^2 = .305$, adjusted $R^2 = .244$, $F(3, 34) = 4.98$, $p = .006$), accounting for 30.5% of the variance in SJ performance. Body fat percentage was negatively associated with SJ performance ($\beta = -.531$, $p = .002$), whereas BMI ($\beta = -.297$, $p = .055$) and training age ($\beta = -.046$, $p = .768$) were not statistically significant. Correlations among the three regression predictors ranged from $r = -.246$ to $.338$, and variance inflation factors ranged from 1.090 to 1.169, indicating no substantial multicollinearity. Examination of regression diagnostics identified several observations meeting at least one prespecified criterion for potential influence. Sensitivity analysis for the CMJ model after exclusion of these observations ($n = 29$) produced substantively similar results: the overall model remained statistically significant ($R^2 = .465$, adjusted $R^2 = .400$, $F(3, 25) = 7.23$, $p = .001$), and BF% remained negatively associated with CMJ performance ($B = -1.17$, $p = .001$).

Discussion

The present study demonstrated that interlimb asymmetry during the Y-Balance Test (YBT) varied according to reach direction, with the greatest asymmetry observed in the anterior (ANT) direction compared with the posteromedial (PM) and posterolateral (PL) directions. In addition, direction-specific asymmetry showed limited associations with dynamic balance and countermovement jump (CMJ) and squat jump (SJ) performance. After false discovery rate (FDR) correction, none of the asymmetry–performance correlations remained statistically significant. In contrast, body fat percentage (BF%) showed a clearer relationship with jump performance: its negative association with CMJ remained significant after FDR correction, and BF% was negatively associated with both CMJ and SJ in the multivariable regression models. Body mass index (BMI) was not significantly associated with jump performance in the adjusted models. Collectively, these findings suggest that interlimb asymmetry is direction-specific and that its relationship with physical performance may be limited and task-dependent, whereas body composition, particularly BF%, may be more closely related to explosive jump performance in this sample of elite male combat athletes.

The greater asymmetry observed in ANT supports the view that interlimb asymmetry is not necessarily a uniform characteristic across movement tasks but may depend on the specific mechanical and neuromuscular demands of the assessment. ANT predominantly challenges sagittal-plane control, whereas the posterior reach directions require different combinations of multiplanar postural control, mobility, and intersegmental coordination. Consistent with this interpretation, previous research has shown that both the magnitude and direction of interlimb asymmetry may vary across task-specific

assessments³⁰. Moreover, asymmetry values derived from different tasks or movement directions often show limited agreement within the same athlete³¹. The absence of a significant difference between PM and PL asymmetry in the present study further supports the direction-specific nature of the observed pattern. This is also consistent with previous evidence indicating that the magnitude and direction of interlimb asymmetry may vary according to the movement or performance measure examined^{30,31}. Therefore, assessment of a single YBT direction may not adequately characterize an athlete's overall asymmetry profile. However, because evidence directly comparing YBT asymmetry across reach directions in elite combat athletes remains limited, the greater ANT asymmetry observed here should not be considered a universal characteristic of combat-sport athletes.

Another important finding was the limited relationship between interlimb asymmetry and the performance outcomes examined. Overall, direction-specific asymmetry was not consistently associated with dynamic balance or jump performance, and none of the asymmetry-performance correlations remained statistically significant after FDR correction. This finding is consistent with the growing recognition that the presence or magnitude of interlimb asymmetry does not necessarily translate directly into poorer physical performance. D'Hondt et al.³¹ reported considerable variability in the relationships between interlimb asymmetry and performance indicators, with associations depending on the task, performance variable, and characteristics of the athletes examined. Similarly, asymmetry values obtained from strength, power, and plyometric assessments may show variable consistency across different testing modalities³². These observations suggest that asymmetry should be interpreted within the context of the task from which it is derived rather than as a general indicator of athletic performance^{10,33}.

The training background of the present sample may partly contribute to these limited associations. Combat sports expose athletes to repeated unilateral and bilateral actions, changes of stance, rapid weight transfer, kicking or striking actions, and sport-specific postural demands. Long-term exposure to such tasks may result in neuromuscular strategies that allow athletes to perform effectively despite measurable between-limb differences. Śliwowski et al.³⁴ suggested that experienced athletes may develop neuromuscular properties and preventive strategies through prolonged training exposure that may help limit fatigue and injury and enhance resilience. Furthermore, interlimb asymmetry may vary within a movement task, as kinetic asymmetries during repeated jumping have been shown to become more apparent after kinetic stabilization³⁵. Thus, the relatively weak relationships observed between YBT asymmetry and jump or balance performance may reflect the complexity and task specificity of interlimb asymmetry rather than indicating that asymmetry is inherently irrelevant to

performance. Given the exploratory nature of these analyses and the sample size, however, nonsignificant findings should not be interpreted as evidence that such relationships do not exist.

Body composition showed a clearer relationship with jump performance. Higher BF% was associated with poorer CMJ performance, and this association remained statistically significant after FDR correction. The multivariable analyses further showed significant negative associations of BF% with both CMJ and SJ. From a mechanical perspective, explosive jumping requires the athlete to accelerate body mass vertically; consequently, a greater proportion of non-contractile mass may increase the load that must be displaced without providing a corresponding contribution to force production. The present findings are consistent with evidence from combat-sport athletes indicating an important relationship between body composition and explosive performance. Milošević et al.³⁶, for example, reported associations between muscle mass and explosive performance measures, including CMJ and drop-jump performance, in young judo athletes. Similarly, Monteiro et al.³⁷ demonstrated the importance of neuromuscular and explosive capabilities in elite judo athletes. Collectively, these findings suggest that the composition of body mass, rather than body size alone, may be particularly relevant when interpreting jumping ability in combat-sport athletes.

In contrast to BF%, BMI was not significantly associated with CMJ performance in either the bivariate or multivariable analyses. BMI reflects body mass relative to height but does not distinguish between fat mass and fat-free mass, which may limit its ability to characterize body composition in athletic populations¹⁸. The present findings suggest that BF% may provide more performance-relevant information than BMI when interpreting explosive jump performance in this sample. Nevertheless, these associations should be interpreted cautiously given the cross-sectional design and the relatively small sample.

The regression findings further indicate that the variables examined were more consistently associated with explosive jump performance than with dynamic balance. The models including training age, BMI, and BF% explained 33.2% of the variance in CMJ and 30.5% of the variance in SJ, with BF% showing a significant negative association with both jump outcomes. In contrast, none of the regression models for ANT, PM, PL, or composite YBT performance reached statistical significance. Dynamic balance depends on the integration of multiple factors, including mobility, proprioceptive input, neuromuscular control, intersegmental coordination, and task-specific movement strategies³⁻⁵. Anthropometric characteristics and training experience alone are therefore unlikely to account for the full variability in YBT performance. The more consistent associations observed for jump outcomes may reflect the mechanical relevance of body composition when accelerating body mass during explosive vertical movements.

From a practical perspective, the present findings emphasize the importance of interpreting interlimb asymmetry within the specific task and movement direction in which it is measured. A single asymmetry value should not automatically be considered representative of an athlete's overall asymmetry profile, nor should greater asymmetry necessarily be interpreted as evidence of poorer physical performance. For practitioners working with combat-sport athletes, evaluating individual YBT directions may therefore provide more informative data than relying exclusively on a composite measure. The observed relationship between BF% and jump performance also suggests that body-composition assessment may provide useful complementary information when monitoring explosive performance. Nevertheless, because the present study was cross-sectional, these associations should not be interpreted causally, and the findings do not establish thresholds at which asymmetry or body-composition characteristics become detrimental to performance.

The strengths of the present study include the examination of elite male combat athletes competing within the same weight category, the inclusion of three combat sport disciplines, the evaluation of direction-specific interlimb asymmetries, and the investigation of the adjusted associations of BMI, BF%, and training age with dynamic balance and jump performance using multivariable regression models.

Several limitations should also be acknowledged. The cross-sectional design precludes causal inference, while the relatively small sample size and inclusion of only male athletes limit the generalizability of the findings. Although pooling athletes from different combat sport disciplines enabled the examination of shared characteristics within the overall sample, differences in technical demands and patterns of lower-limb use across disciplines may have contributed to heterogeneity. Given the small discipline-specific sample sizes, sport-specific effects could not be reliably examined or adjusted for; therefore, the findings should be interpreted at the pooled-sample level and should not be assumed to apply equally across individual combat sport disciplines. The purposive sampling strategy and the proportion of invited athletes who did not proceed to eligibility assessment may further limit the representativeness of the sample.

Although the sample size met the a priori requirement for detecting a large effect in the three-predictor regression model, the study may have had limited statistical power to detect smaller associations in the secondary and exploratory analyses. Accordingly, nonsignificant findings should not be interpreted as evidence of the absence of an association. Although FDR correction was applied to the exploratory correlation analyses, the number of statistical tests should be considered when interpreting the secondary findings. In addition, functional or stance-based limb dominance was not independently assessed; therefore, the present analyses characterize the magnitude of between-limb performance differences rather than the anatomical

or stance-related direction of asymmetry. Finally, the fixed testing order (SJ, CMJ, and YBT) may have introduced order or residual fatigue effects despite the standardized recovery intervals provided between assessments.

Ethics Approval

Ethics approval for this study was obtained from the Non-Interventional Clinical Research Ethics Committee of Uşak University (Approval number: 895-895-35). All study procedures were conducted in accordance with the principles of the Declaration of Helsinki.

Consent to participate

Written informed consent was obtained from all athletes before participation in the study. Prior to participation, detailed information about the study procedures was provided to all participants.

Author Contributions

Bahar Ateş: Conceptualization, methodology, investigation, data curation, formal analysis, writing—original draft, writing—review and editing, visualization. The author assumes full responsibility for the integrity of the data analysis and the preparation of the manuscript.

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Supplementary Table S1. Discipline-specific descriptive characteristics and principal study outcomes.

Variable	Boxing (n=13)	Kickboxing (n=13)	Taekwondo (n=12)
Age (years)	23.15 ± 3.80	22.85 ± 3.65	21.92 ± 2.71
Height (cm)	180.85 ± 5.01	179.46 ± 2.30	178.67 ± 5.52
Body mass (kg)	72.75 ± 1.60	72.56 ± 1.56	73.37 ± 1.46
Training age (years)	11.15 ± 3.89	11.85 ± 3.98	9.25 ± 2.73
BMI (kg·m ⁻²)	22.27 ± 0.89	22.54 ± 0.66	23.02 ± 1.08
BF (%)	11.27 ± 1.80	11.88 ± 2.15	10.70 ± 3.30
CMJ (cm)	42.67 ± 4.88	40.61 ± 3.64	41.43 ± 5.40
SJ (cm)	39.87 ± 4.80	38.17 ± 4.13	39.46 ± 4.35
ANT (%)	66.03 ± 9.00	63.61 ± 4.27	66.10 ± 6.26
PM (%)	108.28 ± 7.82	107.30 ± 6.87	108.23 ± 6.90
PL (%)	104.24 ± 6.59	103.83 ± 6.44	104.89 ± 7.55
COMP (%)	92.89 ± 6.53	91.63 ± 5.07	93.36 ± 5.45
ASYM_ANT (%)	7.80 ± 3.98	6.48 ± 4.22	8.68 ± 3.20
ASYM_PM (%)	2.80 ± 2.13	4.23 ± 1.95	4.21 ± 2.25
ASYM_PL (%)	3.42 ± 2.19	3.69 ± 2.77	4.33 ± 3.20
ASYM_COMP (%)	4.17 ± 1.04	4.47 ± 2.18	4.70 ± 2.11

Data are presented as mean ± SD. BMI = body mass index; BF = body fat percentage; CMJ = countermovement jump; SJ = squat jump; ANT = anterior; PM = posteromedial; PL = posterolateral; COMP = composite score; ASYM = asymmetry magnitude. Values are presented descriptively; no inferential comparisons among combat sport disciplines were performed.