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Principal component analysis and association between body composition and muscle strength variables in elite taekwondo athletes: an exploratory study

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Abstract
Introduction. **Combat sports, especially taekwondo, require multi-component preparation programs; however, some are more determinant than others for sports performance.** Aim of Study. **This study aimed to explore the dimensionality of body composition and muscle strength variables in elite taekwondo athletes and to evaluate the associations between these variables.** Material and Methods. **Fifteen elite athletes, five male and ten female (21.5 ± 3.9 years) taekwondo practitioners were evaluated. During the investigation, body composition, punching power, explosive strength, and 1 repetition maximum (1RM) in the half squat were measured.** Results. **Significant differences between men and women were observed in most of the variables analyzed ($p < 0.05$). Moderate and high correlations were found between muscle strength variables (explosive strength, 1RM) and muscle mass, and negative correlations with fat mass. Kicking power was correlated only with height and body mass. Principal component analysis reduced the data to four principal components that together accounted for 86.54% of the total variance. The variables with the highest contributions to the first component (PC1) were related to body size (height), muscle mass, and strength performance (1RM, countermovement jump, Abalakov). The analysis revealed a clear separation in the component scores between male and female athletes.** Conclusions. **It is recommended that proper body composition and a specialized training program can maximize athletic performance in taekwondo.**

KEYWORDS: jumping ability, multivariate analysis, sport performance, muscular strength, kicking.

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Introduction

Taekwondo, one of the few combat sports in the Olympic Games, combines technical, tactical, and physical skills requiring multifaceted preparation. Within this discipline, body composition characteristics and the ability to apply mechanical force, assessed by tests such as the 1 repetition maximum (1RM) estimation test, could be key determinants of sport-specific performance [8, 14, 20]. In addition, specific assessments of speed and power applied to kicking technique, a crucial component in this discipline, have been developed [7]. These tools seek to guide sports preparation programs more effectively.

In taekwondo, muscle strength and power are essential determinants of competitive performance, as they directly influence the speed, accuracy, and power of technical actions such as kicks and punches [13, 19]. Previous research has highlighted the importance of assessing specific physical attributes, such as strength and power, to identify factors that contribute to success in taekwondo [8, 13, 33]. In fact, athletes with tremendous competitive success tend to exhibit greater lower body strength production and greater tolerance to high-intensity efforts compared to their less successful peers [8–10].

Kick power, a key indicator of technical performance in taekwondo, reflects the ability to generate force quickly, an essential skill in high-level competitions [21]. Isokinetic leg torque has been directly associated with kicking speed, highlighting the relevance of strength and power measurements in predicting competitive success [22, 23]. These characteristics not only influence technical execution but also underline the importance of developing specific strategies to optimize physical performance in combat sports [11, 37].

Although numerous studies have analyzed variables such as maximal strength, power, and body composition in isolation, few have integrated these factors into a single analytical model applied to elite taekwondo athletes [21]. Recently, a single study has implemented principal component analysis (PCA) to examine kinematic and kinetic variables of the front roundhouse kick, establishing associations between these and key biomechanical factors for efficient execution [16]. PCA is a multivariate technique that reduces the dimensionality of a set of variables by identifying the underlying patterns that explain the majority of the variability in the data [17]. In the sports domain, PCA has proven effective for integrating multiple physical and technical dimensions, thereby optimizing training programs [27, 29]. This approach is particularly relevant in taekwondo, where the interaction between body composition and muscle strength can be decisive for competitive success [19]. Furthermore, the application of multivariate analysis could generate innovative findings that contribute to optimizing sports preparation in this sport.

Aim of Study

In this context, the present study aimed to explore the dimensionality of body composition and muscle strength variables in elite taekwondo athletes using PCA, evaluate the associations between these variables, and compare the differences between men and women. This approach seeks to identify key factors contributing to optimizing this population's physical performance. Understanding the interaction between these characteristics could improve physical evaluations and the design of specific training in taekwondo athletes.

Material and Methods

Design

A cross-sectional observational study with correlational scope was conducted. This design was selected due to its suitability for exploring relationships between variables at a specific point in time, without interfering with the natural conditions of the participants. Given that the study aimed to analyze the association between body composition and muscle strength variables in elite taekwondo athletes, a cross-sectional design allowed for efficient data collection without disrupting the athletes' competitive environment or the physical preparation program led by their coaches.

Participants

Purposive sampling was used to recruit exclusively elite taekwondo athletes participating in the 2023 National Sports Games of Colombia. The sample consisted of 15 athletes (5 men and 10 women) aged between 18 and 31 years (21.5 ± 3.9) with an average competitive experience of 5.4 years in national and international events. Of the participants, one was a gold medalist, and six obtained bronze medals in the Kyorugi (combat) category.

The inclusion criteria were being called to the district or departmental selection for the athletes' high sports performance, participation in the 2023 National Sports Games of Colombia, having a black belt in taekwondo, and not presenting musculoskeletal injuries at the time of the physical evaluations. These criteria ensured that the sample consisted of high-level athletes, allowing for the collection of representative data from the population of interest.

Instruments and procedures

The assessments were performed on two different days, with an interval of one week between them. First, body composition, kicking power, and 1RM were assessed, and then seven days later, the Bosco test was carried out. This design minimized participant fatigue and ensured measurement accuracy.

Body composition: Body composition was assessed using the OMRON HBF 514C tetrapolar bioimpedance scale. Values of fat percentage, muscle mass percentage, and visceral fat were obtained. For this assessment, the guidelines and orientations given in previous studies were followed [4]. Height was measured with a SECA wall-mounted measuring rod (ref. 206). These assessments were performed while the athletes were barefoot and wearing sports shorts and a T-shirt.

Warm-up: To assess strength and power, the athletes performed a 10-minute warm-up, consisting of a 5-minute gentle run followed by 5 minutes of joint mobility and specific movements related to the tests. This protocol sought to guarantee the correct execution technique and neuromuscular activation.

Kicking power: It was evaluated using the Hykso device. This motion sensor records the power and speed of the kicking generated by the athlete, presenting the information visually through an application installed on a Samsung Galaxy S10 tablet. The device was attached to the ankle joint using micropore tape. The technique evaluated was the circular kick directed to the abdomen or chest (*bandal chagui*), considered one of the most representative in taekwondo combats. The athletes performed three kicks with each leg, with 15 seconds of rest between each attempt. The repetition with the highest recorded power was selected.

Explosive strength: It was determined by the Bosco test, including the squat jump (SJ), countermovement jump (CMJ) and Abalakov (ABK), the contractile contribution (CC%), elastic contribution (CE%), contribution of the coordinative component (CCC%), contribution of the use of the arms (CUB%) and the elasticity index (IE%) were calculated following Bosco's guidelines [6]. A BTS Bioengineering G-Sensor device – a wireless inertial sensor composed of a triaxial accelerometer, a magnetic sensor, and a triaxial gyroscope, was used to determine the height (cm) of the jumps. The jumps were performed barefoot on the *dojang*, a specific competition mat. Each athlete performed two attempts per type of jump, with 30 seconds of rest between them, and the best record of each jump was selected.

1RM: It was evaluated utilizing the half squat test (90° knee angle) with the free bar on the shoulders. An Eleiko Olympic barbell (Halmstad, Sweden) of 20 kg for men and 15 kg for women was used, together with Bulldog Olympic discs (Cali, Colombia). The 1RM was estimated through the mean propulsive velocity (MPV), measured with a Vitruve VBT linear encoder (Madrid, Spain). The initial load was 40% of each athlete's body weight, performing three repetitions with low loads (MPV > 1.10 m-s^{-1}) and two with medium loads. Subsequently, the load was increased in 10 kg intervals, with rest periods of 3-4 minutes between attempts. The test ended when the MPV recorded was equal to or less than 0.60 m/s, following the recommendations of previous studies [5, 30]. Athletes were encouraged to perform the hip and knee extension phase of the squat as quickly as possible.

Ethical considerations

After being informed about the purpose of the study and the physical assessments to be performed, the participants signed a written informed consent form before participating. The research was approved by the Bioethics and Scientific Integrity Committee of the Fundación Universitaria del Área Andina (Act 17_10/05/2024). It was carried out following the principles of the Declaration of Helsinki.

Data analysis

The data were collected using a Microsoft Excel online matrix. Subsequently, the normal distribution of the data was verified using the Shapiro–Wilk test, and the homogeneity of variances using the Levene's test ($p > 0.05$). Although most variables met the assumption of homogeneity of variances, some did not exhibit a normal distribution. Therefore, nonparametric statistical tests were chosen to ensure methodological consistency and appropriately address variables that did not meet the normality assumption. Subsequently, descriptive analyses were conducted using central tendency (median) and dispersion (interquartile range) measures. The Spearman's correlation test was used to analyze associations between variables, as it is robust against non-normality. The interpretation of the Spearman's correlation coefficients was performed according to the recommendations of Schober et al. [31]: ≤ 0.10: negligible correlation; 0.10-0.39: weak correlation; 0.40-0.69: moderate correlation; 0.70-0.89: strong correlation; ≥ 0.90: very strong correlation.

Additionally, multivariate analyses with an exploratory scope were carried out using machine learning methods, such as PCA and Spearman's correlation network analysis, to identify patterns and confirm relationships between variables. For the latter analyses, the guidelines were given by Aldás and Uriel [3] and Peres-Neto et al. [28]. In the PCA, most of the variance of the data is explained by the principal components, and the number of components retained is based on those that explain more than 80% of the variance [12]. Principal components with eigenvalues greater than 1 explain a greater amount of variance with respect to the original variable, and this procedure allowed the present study to identify four components with eigenvalues greater than 1.

All statistical analyses were performed in the RStudio programming environment (version 2024.12.12.0+467).

Results

The descriptive statistics of the variables analyzed are shown in Table 1. As seen in most variables, significant differences were found between men and women ($p < 0.05$).

Relationship between study variables

Table 2 presents only the significant and relevant Spearman's correlations between the study variables

Table 1. Descriptive statistics and comparison according to sex

	Sex	Me	Q1, Q3	IQR	CV	pSW	Min	Max	p	BRC
Age	Male	21.00	[19.00, 21.00]	2.00	0.22	0.06	18.00	30.00	0.95	−0.04
	Female	20.50	[20.00, 21.75]	1.75	0.17	0.001	18.00	31.00		
Height [cm]	Male	179.80	[179.50, 182.00]	2.50	0.02	0.18	173.30	182.60	0.04	0.96
	Female	161.00	[160.55, 166.38]	5.82	0.04	0.32	154.20	177.00		
BM [kg]	Male	72.30	[65.40, 73.20]	7.80	0.20	0.09	62.70	100.40	0.02	0.76
	Female	58.00	[49.88, 62.07]	12.20	0.17	0.97	42.50	75.20		
% fat	Male	16.00	[14.50, 16.80]	2.30	0.31	0.57	10.60	24.70	0.01	−0.88
	Female	28.40	[26.37, 31.53]	5.15	0.21	0.26	15.10	35.60		
% muscle	Male	42.70	[42.00, 44.20]	2.20	0.08	0.09	36.40	44.40	0.001	1.00
	Female	30.05	[28.90, 31.47]	2.57	0.08	0.97	25.80	33.40		
% visceral	Male	4.00	[4.00, 4.00]	0.00	0.69	0.03	2.00	11.00	0.48	0.24
	Female	3.50	[3.00, 4.00]	1.00	0.37	0.45	1.00	5.00		
BMI [m/kg^2]	Male	22.40	[21.70, 22.60]	0.90	0.18	0.18	18.80	30.30	0.62	0.18
	Female	21.20	[20.00, 23.33]	3.33	0.13	0.98	16.50	25.90		
RLPower	Male	17.00	[16.00, 18.00]	2.00	0.09	0.97	15.00	19.00	0.03	0.72
	Female	14.00	[12.50, 15.00]	2.50	0.25	0.23	8.00	19.00		
LLPower	Male	17.00	[16.00, 21.00]	5.00	0.22	0.39	15.00	25.00	0.02	0.76
	Female	14.00	[12.25, 14.75]	2.50	0.23	0.001	12.00	23.00		
SJ [cm]	Male	33.80	[31.30, 35.80]	4.50	0.15	0.95	25.90	39.10	0.04	0.70
	Female	27.35	[23.60, 28.80]	5.20	0.14	0.77	21.10	33.80		
CMJ [cm]	Male	37.80	[37.10, 42.70]	5.60	0.15	0.91	31.90	47.90	0.01	0.88
	Female	29.70	[26.62, 32.02]	5.40	0.13	0.79	24.30	35.80		
ABK [cm]	Male	43.40	[37.10, 47.10]	10.00	0.12	0.17	37.10	47.90	0.01	0.92
	Female	34.15	[30.78, 36.07]	5.30	0.14	0.29	24.80	38.40		
CC%	Male	75.00	[72.00, 83.00]	11.00	0.11	0.50	69.80	91.10	0.33	−0.34
	Female	80.65	[79.25, 84.70]	5.45	0.07	0.84	73.00	93.00		
CE%	Male	13.00	[10.80, 16.20]	5.40	0.45	0.58	8.00	25.00	0.11	0.54
	Female	9.40	[5.30, 11.38]	6.08	0.48	0.90	1.70	15.00		
CCC%	Male	9.00	[0.00, 14.00]	14.00	1.08	0.27	−1.90	15.00	0.50	−0.24
	Female	8.70	[4.05, 15.38]	11.32	0.67	0.15	2.00	17.90		

CUB%	Male	10.00	[0.00, 16.30]	16.30	1.07	0.24	−1.90	17.00	0.50	−0.24
	Female	9.50	[4.10, 18.18]	14.08	0.73	0.14	2.00	21.90		
IE%	Male	18.50	[11.80, 23.20]	11.40	0.51	0.73	9.20	33.80	0.11	0.54
	Female	11.85	[6.45, 14.92]	8.47	0.49	0.62	2.10	18.50		
1RM [kg]	Male	126.00	[125.00, 140.00]	15.00	0.09	0.59	113.0	143.00	0.001	1.00
	Female	85.50	[70.00, 91.75]	21.75	0.20	0.88	58.00	109.00		
RS	Male	1.80	[1.71, 1.93]	0.22	0.13	0.46	1.39	1.98	0.04	0.68
	Female	1.46	[1.25, 1.55]	0.29	0.16	0.53	1.18	1.89		

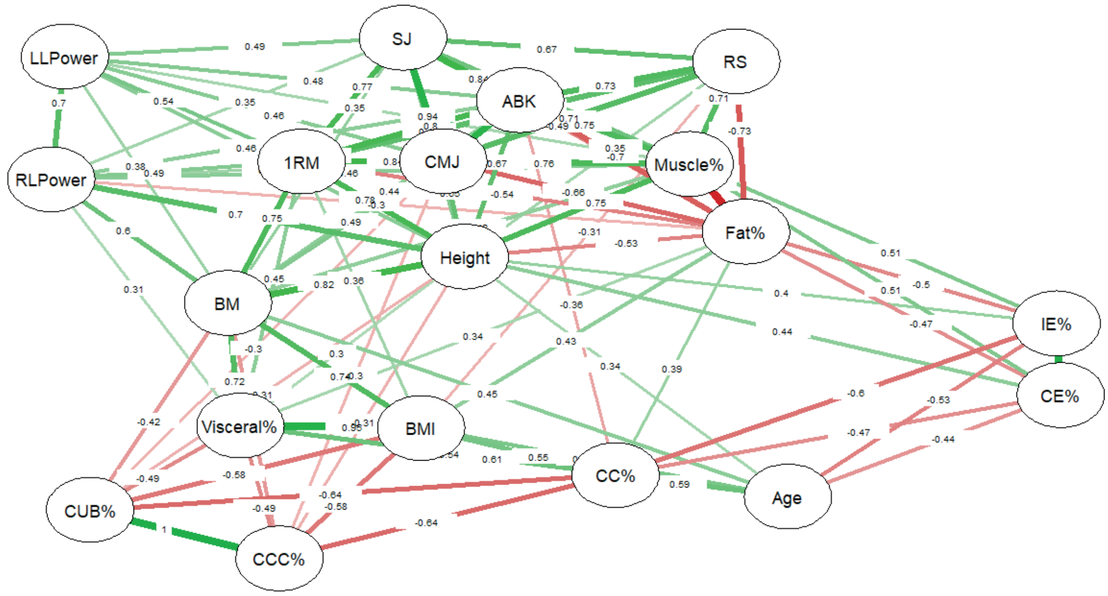
Note: Me – median, Q1, Q3 – the first quartile as the lower limit and the third quartile as the upper limit of the interquartile range, IQR – interquartile range, CV – coefficient of variation, pSW – p value obtained by the Shapiro–Wilk test, Min – minimum, Max – maximum, BM – body mass, % visceral – Visceral fat %, BMI – body mass index, RLPower – right leg power, LLPower – left leg power, SJ – squat jump, CMJ – countermovement jump, ABK – Abalakov, CC% – contractile contribution, CE% – elastic contribution, CCC% – contribution of the coordinative component, CUB% – contribution of the use of the arms, IE% – elasticity index, 1RM – 1 repetition maximum in the half squat exercise, RS – relative strength.
The magnitude of the effect is given by the biserial rank correlation (BRC).

($p < 0.05$). For its part, Figure 1 illustrates the Spearman's correlation networks between the variables evaluated. The Spearman's correlation network graph represents the relationships between the physical and sports performance variables, clearly and systematically visualizing their interactions.

Table 2. Spearman correlation analysis

Variables		Rho		p
Height [cm]	– Body mass [kg]	0.82	***	<º.001
Height [cm]	– % fat	-0.53	*	0.044
Height [cm]	– % muscle	0.75	**	0.001
Height [cm]	– RLPower	0.70	**	0.004
Height [cm]	– CMJ	0.65	**	0.009
Height [cm]	– ABK	0.67	**	0.006
Height [cm]	– 1RM squat [kg]	0.78	***	<º.001
Body mass [kg]	– % visceral fat	0.72	**	0.002
Body mass [kg]	– BMI [m/kg2]	0.74	**	0.002
Body mass [kg]	– RLPower	0.60	*	0.017
Body mass [kg]	– 1RM squat [kg]	0.75	**	0.002
% fat	– % muscle	-0.93	***	<º.001
% fat	– CMJ [cm]	-0.66	**	0.010
% fat	– ABK [cm]	-0.70	**	0.004
% fat	– 1RM squat [kg]	-0.54	*	0.042
% fat	– Relative strenght	-0.73	**	0.003
% muscle	– SJ [cm]	0.59	*	0.021
% muscle	– CMJ [cm]	0.76	**	0.002
% muscle	– ABK [cm]	0.75	**	0.001
% muscle	– 1RM squat [kg]	0.72	**	0.003
% muscle	– Relative strenght	0.71	**	0.004
% visceral fat	– BMI [m/kg2]	0.95	***	<º.001
LLPower	– 1RM squat [kg]	0.54	*	0.040
SJ [cm]	– 1RM squat [kg]	0.77	***	<º.001
SJ [cm]	– Relative strenght	0.67	**	0.006
CMJ [cm]	– 1RM squat [kg]	0.84	***	<º.001
CMJ [cm]	– Relative strenght	0.71	**	0.004
ABK [cm]	– 1RM squat [kg]	0.80	***	<º.001
ABK [cm]	– Relative strenght	0.73	**	0.002
CC %	– CCC %	-0.64	**	0.010
CC %	– CUB %	-0.64	**	0.010
CC %	– IE %	-0.60	*	0.019
CE %	– IE %	0.98	***	<º.001
CCC %	– CUB %	1.00	***	<º.001
1RM squat [kg]	– Relative strenght	0.67	**	0.007

Rho: Spearman correlation.
BMI – body mass index, RLPower – right leg power, LLPower – left leg power, SJ – squat jump, CMJ – countermovement jump, ABK – Abalakov, CC% – contractile contribution, CE% – elastic contribution, CCC% – contribution of the coordinative component, CUB% – contribution of the use of the arms, IE% – elasticity index, 1RM – 1 repetition maximum in the half squat exercise
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$



BM – body mass, Visceral% – Visceral fat %, BMI – body mass index, RLPower – right leg power, LLPower – left leg power, SJ – squat jump, CMJ – countermovement jump, ABK – Abalakov, CC% – contractile contribution, CE% – elastic contribution, CCC% – contribution of the coordinative component, CUB% – contribution of the use of the arms, IE% – elasticity index, 1RM – 1 repetition maximum in the half squat exercise, RS – relative strength.

Figure 1. Spearman's correlation network between the study variables.

The nodes represent the variables studied, and the edges (lines) indicate the strength and direction of the Spearman's correlations. Thicker and shorter lines reflect stronger Spearman's correlations, while thinner and longer lines represent weaker correlations. The color of the edges differentiates the type of Spearman's correlation: green for positive correlations and red for negative ones.

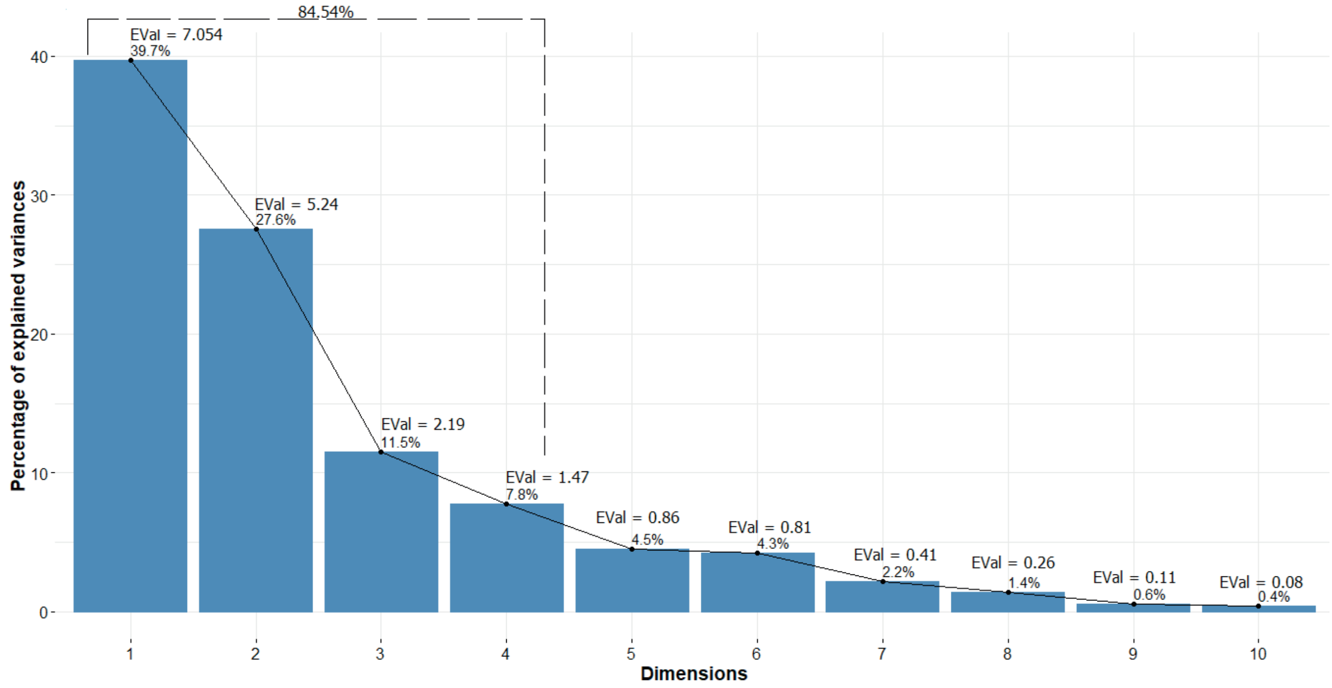
Principal component analysis (PCA)

The PCA analysis with exploratory scope indicates the most relevant aspects of the decomposition, specifically

Table 3. Eigenvectors and their contribution to the principal component

Eigenvectors	PC1	PC2	PC3	PC4
Age	0.05	−0.36	0.06	−0.13
Height	0.32	0.01	−0.04	−0.24
Body mass	0.27	−0.25	0.01	−0.22
Fat %	−0.22	−0.27	0.04	−0.07
Muscle %	0.31	0.17	−0.01	−0.03
Visceral fat %	0.16	−0.35	0.08	−0.12
BMI	0.14	−0.36	0.03	−0.16
1RM	0.34	−0.03	0.15	0.00
Relative strength	0.21	0.24	0.24	0.29
RLPower	0.23	−0.03	−0.05	−0.33
LLPower	0.20	−0.13	0.11	−0.28
SJ	0.29	0.01	0.30	0.27
CMJ	0.33	0.08	0.08	0.20
ABK	0.29	0.19	0.22	0.07
CC%	−0.01	−0.37	0.09	0.38
CE%	0.19	0.14	−0.52	−0.05
CCC%	−0.14	0.27	0.34	−0.37
CUB%	−0.15	0.26	0.34	−0.38
IE%	0.18	0.19	−0.48	−0.09
Cumulative	2.97†	−0.61	0.99	−1.24†

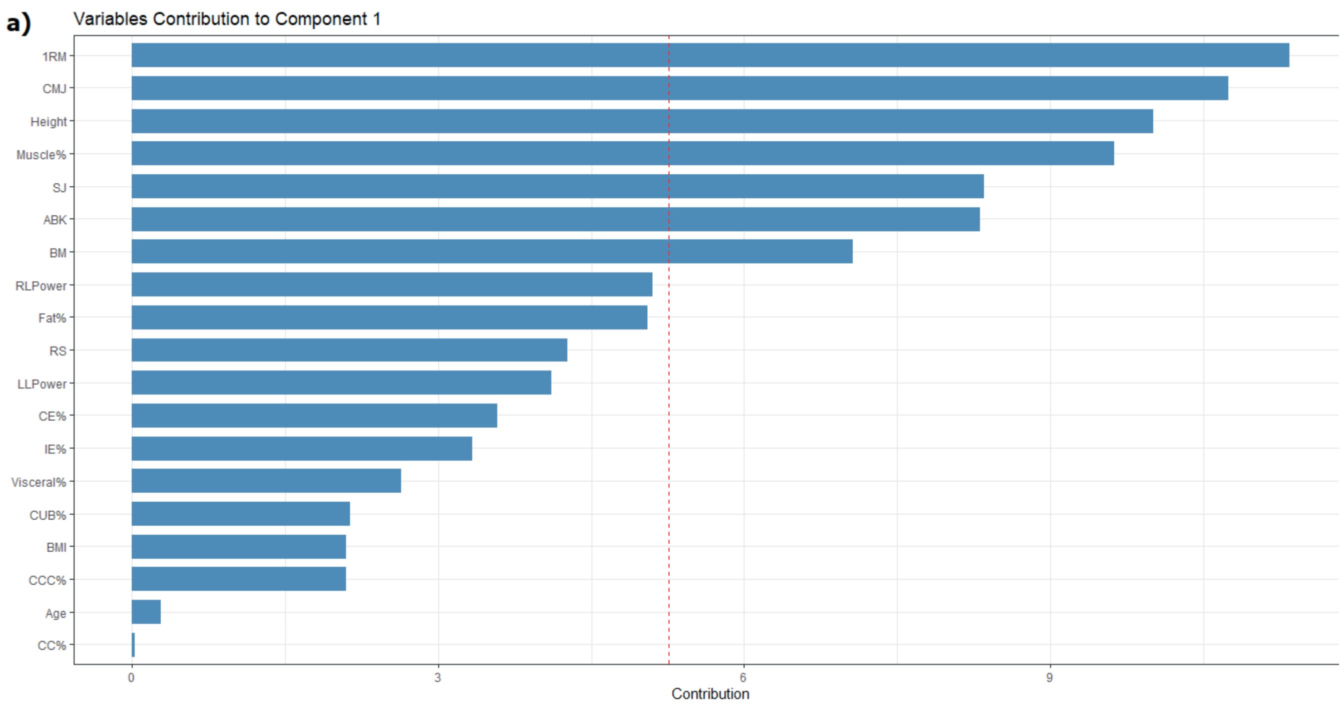
PC: principal component, †: meets the minimum values suggested in the literature. BMI – body mass index, RLPower – right leg power, LLPower – left leg power, SJ – squat jump, CMJ – countermovement jump, ABK – Abalakov, CC% – contractile contribution, CE% – elastic contribution, CCC% – contribution of the coordinative component, CUB% – contribution of the use of the arms, IE% – elasticity index, 1RM – 1 repetition maximum in the half squat exercise



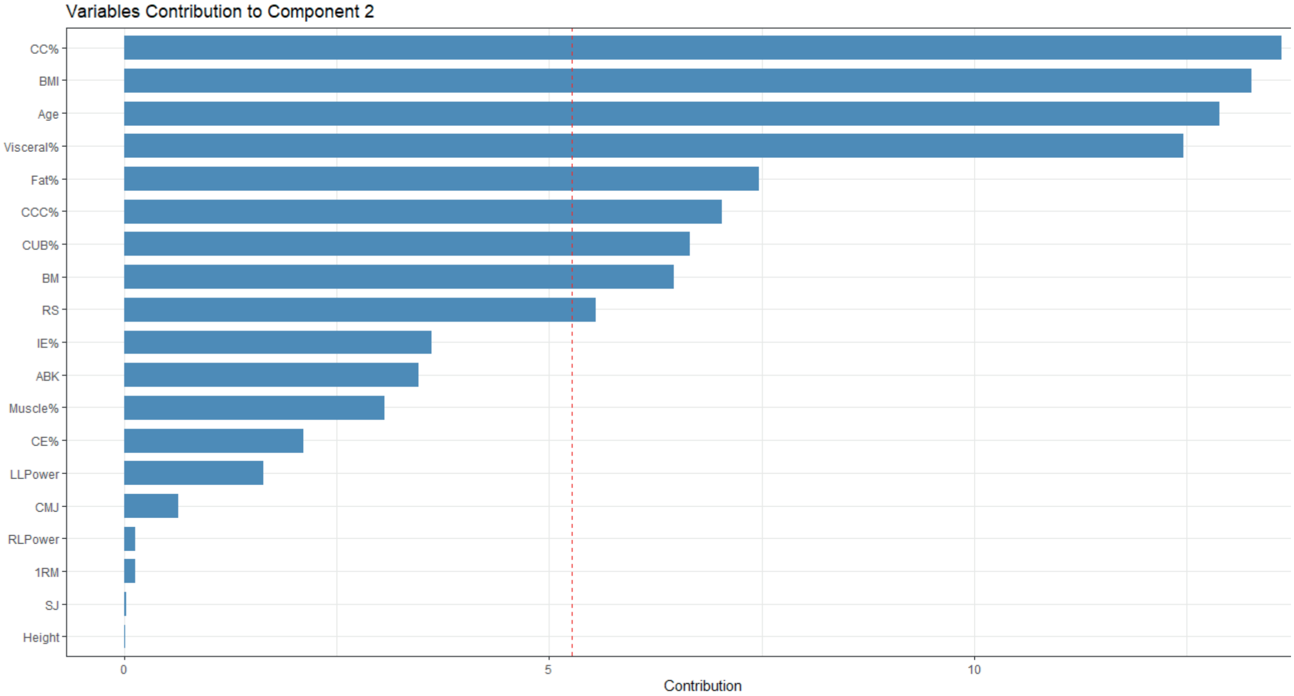
EVal – eigenvalue > 1

Figure 2. Sedimentation and dimension reduction plot of the original data set

the variance explained by each component and the loadings (eigenvectors) of each variable on the principal components. First, the study variables are grouped in a higher proportion in two components, as shown in Figure 2. Second, the eigenvectors represent the directions in feature space that maximize the variance of the projected data in the principal components (Figure 3c). In Table 3, each column indicates the loading of that variable on a principal component (PC1, PC2, PC3, PC4).



b)


Variables Contribution to Component 2
CC%
BMI
Age
Visceral%
Fat%
CCC%
CUB%
BM
RS
IE%
ABK
Muscle%
CE%
LLPower
CMJ
RLPower
1RM
SJ
Height
0
5
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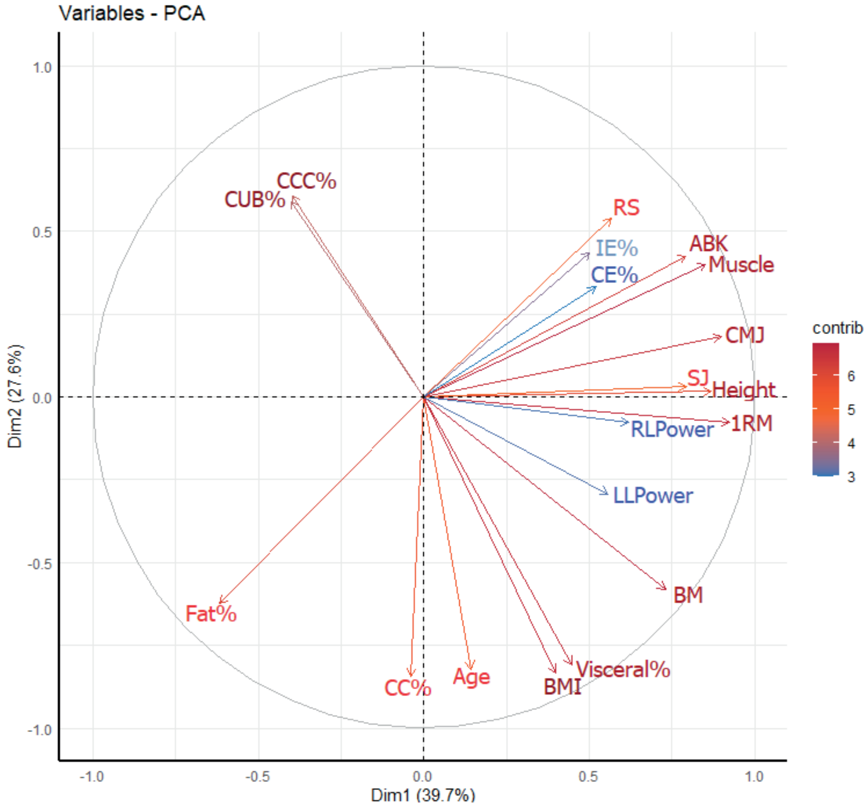
Contribution

c)


Variables - PCA
CCC%
CUB%
RS
IE%
ABK
Muscle
CE%
CMJ
SJ
Height
RLPower
1RM
LLPower
BM
Fat%
CC%
Age
BMI
Visceral%
contrib
6
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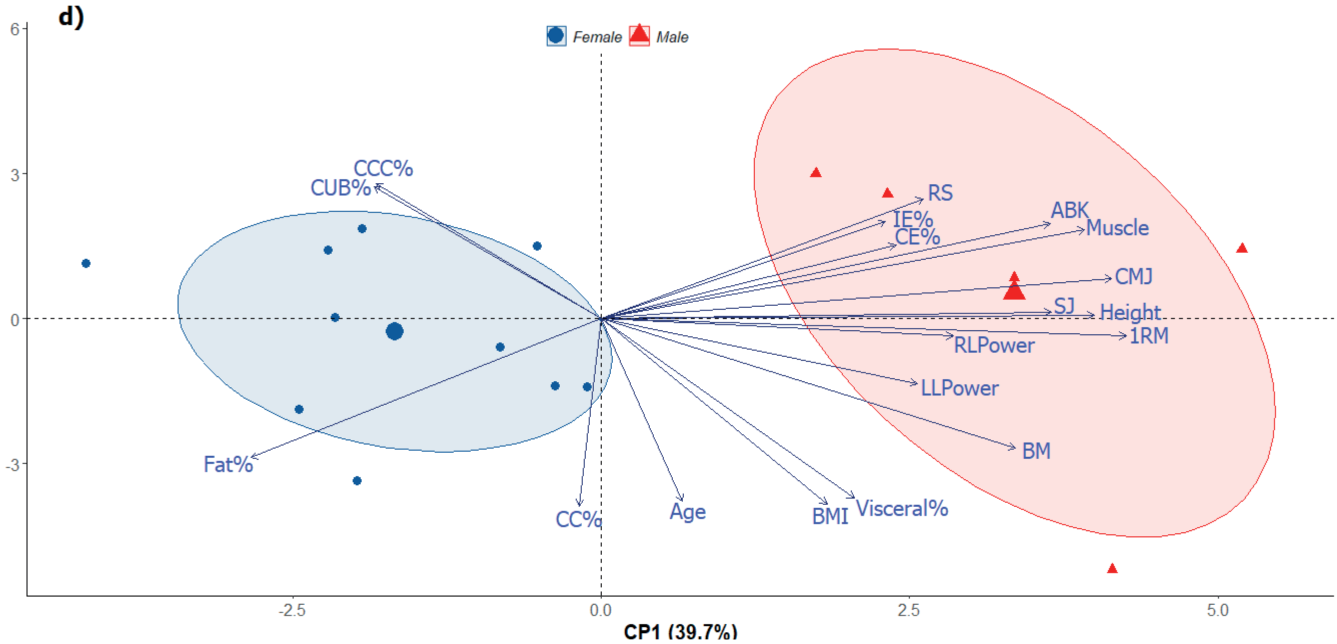
4
3
Dim2 (27.6%)
Dim1 (39.7%)
1.0
0.5
0.0
-0.5
-1.0



BMI – body mass index, RLPower – right leg power, LLPower – left leg power, RS – relative strenght, SJ – squat jump, CMJ – countermovement jump, ABK – Abalakov, BM – body mass, CC% – contractile contribution, CE% – elastic contribution, CCC% – contribution of the coordinative component, CUB% – contribution of the use of the arms, IE% – elasticity index, Visceral% – Visceral fat %, 1RM – 1 repetition maximum in the half squat exercise

Figure 3. Representation of the study variables in the components

a., b. Contribution of the variables to each principal component (PC1 and PC2). The variables that exceed the dotted red line generate the most significant contribution in creating the component, c. The variables with warmer colors (yellow or orange) significantly contribute to the variance explained by these dimensions. In comparison, the variables with cooler colors (blue) have a more minor contribution. This allows us to identify which variables are the most influential in the overall structure of the data and how they relate to each other in the principal components space, d. Clear separation between the groups regarding the principal components, suggesting that men and women differ significantly in terms of the variables analyzed in this model.

These loadings reflect each variable's contribution to each component's formation. Only the four principal components are shown for their contribution to the variance explained. The two principal components (PC) that contribute most to the explained variance and the contribution of the variables to these can be seen in Figures 3a, 3b, and 3d.

Figure 3 shows how much each variable contributes to each principal component, which is helpful for understanding which variables have the greatest weight in creating each component.

Discussion

This study aimed to explore the dimensionality of body composition and muscle strength variables in elite taekwondo athletes and to evaluate the associations between these variables. Overall, significant differences were observed between men and women in most of the variables analyzed, both body composition and muscle strength (e.g., 1RM, SJ, CMJ, ABK). These differences reflect the typical distinctions between genders in taekwondo athletes that have been observed at different performance levels [10], findings that are consistent with previous studies in taekwondo and other combat sports that evaluated morphofunctional parameters, such as bone diameters, perimeters, limb lengths, somatotypes, muscle percentage, and fat percentage, among others, in a sample comprised of 101 women and 105 men [26]. On the other hand, the values of fat percentage found in the present study are superior to international-level athletes belonging to different national teams [10], international medalists and non-medalists of the Turkish national team [1].

However, some variables, such as body mass index (BMI) and visceral fat percentage, did not show significant differences. The particular characteristics of taekwondo could explain this as a combat sport, where body weight categories force athletes to maintain a low body weight to meet competitive demands, thus reducing variations in these parameters [18]. In addition, BMI is not an adequate indicator of body composition in taekwondo athletes, as it does not differentiate between lean mass and body fat, which could generate misinterpretations about physical condition, especially in athletes with high levels of muscle mass or low-fat percentage [15]. These results suggest that some specific variables may not present significant gender differences. For example, in a study conducted on combat sports athletes, including taekwondo, boxing, wrestling, and karate, no gender differences were found in the contribution of the glycolytic and oxidative systems during two types of training [34].

On the other hand, regarding the significant Spearman's correlations found, there is a significant negative Spearman's correlation between body fat percentage and muscle percentage, reflecting the inverse relationship between muscle mass and body fat. In addition, measures of strength and power are strongly correlated. For example, CMJ shows a strong correlation with 1RM in squat and with relative strength; similar correlations were found with the other jumps evaluated and muscle mass. Specific training programs in these physical abilities have seen significant improvements in the performance of taekwondo and other combat sports athletes [9, 24]. This suggests that jumping skills and the ability to perform one repetition maximum in squats are closely related, indicating that performance in explosive activities is influenced by muscle strength. In contrast, no or moderate associations have been observed when strength has been assessed through other types of tests, such as the long jump or digital dynamometer test for isometric contraction in taekwondo athletes [7].

The importance of optimal muscle development in taekwondo athletes is supported by the moderate to strong Spearman's correlations between muscle mass, all evaluated jumps, 1RM, and relative strength. Previous studies have found that those athletes with higher levels of explosive strength than their counterparts can generate efficient attacks over long and safe distances [25]. The Spearman's correlation between fat percentage and physical performance is also relevant, showing that as body fat percentage increases, CMJ, ABK, and 1RM test scores decrease, suggesting that higher body fat could negatively affect physical performance. This same inverse relationship has been found with other parameters of physical performance, such as with cardiovascular capacity in young athletes [32]. On the other hand, the punching power, especially of the right leg, evidenced a moderate positive correlation with the height and body mass of the athletes, contrary to what was exposed in another research where they found no relationship between height and length of the extremities with the speed of execution of spinning kicks [36].

PCA allowed the identification of underlying patterns in the physical evaluation variables of taekwondo athletes. The retention of four principal components explained 86.54% of the total variance, exceeding the 80% threshold recommended in the literature [3]. This indicates that the model is suitable for dimensionality reduction, preserving most of the relevant information [28].

The first component (PC1), which explains 39.70% of the variance, is dominated by variables related to maximum strength (1RM squat), jumping power (CMJ, SJ, ABK), and anthropometric characteristics (height and muscle mass). This component reflects a comprehensive physical-muscular profile that is key to taekwondo performance, particularly in executing explosive techniques and fast movements, which are fundamental in combat situations. These findings are consistent with previous studies highlighting the importance of strength and power as key predictors of success in combat sports [8, 11]. The second component (PC2), which explains an additional 27.58% of the variance, suggests an inverse relationship between age and physical performance, with greater emphasis on relative strength and body composition. In this sample, younger athletes tend to show better strength values and lower body mass, which could reflect a trend toward losing physical performance with age, even in a physically active population [2, 18]. This result emphasizes the need for specific training programs to mitigate these effects in older athletes, a relevant area for future research [35].

In turn, the third component (PC3), which explains 11.51% of the variance, is mainly influenced by energy efficiency parameters, such as IE% and CE%. These indicators reflect the ability of athletes to efficiently exploit muscle elasticity during movements, a crucial factor in high-intensity sports such as taekwondo [11]. Although their contribution to the total variance is minor, it highlights the importance of optimizing technical aspects directly impacting competitive performance. Finally, dimension 4 (PC4), which contributes 7.76% to the total variance, is characterized by variables related to coordination and elasticity, such as the contribution of the coordinative component, the contribution of the use of the arms, and right and left leg power (lower limb power). These variables reflect specific aspects of jumping biomechanics and the ability of athletes to coordinate complex movements, essential in combat situations [11, 16, 37]. Although its explained variance is the lowest, dimension 4 highlights the importance of specific components of technical performance. For example, higher negative loadings on variables such as CUB% (−0.38) and CCC% (−0.37) indicate that athletes with lower arms use efficiency and coordination present reduced overall performance, while positive values on CC% (0.38) and SJ (0.27) highlight the impact of jumping and coordinative contribution on performance [6]. This component could be beneficial to identify technical weaknesses that personalized training can address.

Limitations of the study and further research

The present study is not without limitations, among which are the small sample size and the possibility of human error during the data collection process. Future research should include additional variables, such as indicators of cardiovascular capacity, muscle recovery, psychological factors, and nutritional assessments, which could influence the overall performance of taekwondo athletes. In addition, it would be pertinent to perform a longitudinal analysis to evaluate how these components evolve throughout the sports career or at different points in the competitive calendar.

Conclusions

The results suggest that differences in body composition and physical performance between men and women are evident, with men showing advantages in terms of muscle mass and performance in strength and power. In addition, physical variables such as body mass, fat percentage, and muscle percentage directly influence performance capabilities, highlighting the importance of these variables for coaches and athletes in the design of training and evaluation programs. Spearman's correlation analysis reinforces the idea that higher muscle mass and lower body fat percentage are strongly associated with better performance in physical tests, which could have implications for both training and nutrition in sports contexts. The PCA reveals areas relevant to the sports performance of taekwondo athletes, an aspect that coaches should consider.

Practical applications

The findings of the present study have direct implications for the planning and optimization of sports training in taekwondo combat athletes. For coaches, the identification of an integral physical-muscular profile (PC1) highlights the importance of designing programs that prioritize the development of maximum strength and explosive power, critical variables for success in combat. In addition, the components related to energy efficiency (PC3) and biomechanical coordination (PC4) underline the need to incorporate specific exercises that improve muscular elasticity and motor coordination, factors that can be addressed through techniques such as plyometric training and the practice of taekwondo-specific movements. On the other hand, the inverse relationship between age and physical performance observed in PC2 offers researchers a basis for exploring training and recovery strategies designed to mitigate performance loss in older athletes.

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Conflict of Interest

The authors declare the existence of a potential conflict of interest. Authors Gino Salcedo-Goméz and Martín A. Suárez declare receiving fees for their services as national coaches in taekwondo clubs. The remaining authors declare no conflicts of interest.

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