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The association of Whole and Segmental Body Composition and Anaerobic Performance in Crossfit® athletes: sex differences and performance prediction

Asociación entre la composición corporal total y segmentaria y el rendimiento anaeróbico en atletas de Crossfit®: diferencias entre sexos y predicción del rendimiento

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Abstract. The main purpose of this study was to establish the association between total and segmental body composition (BC) variables and anaerobic performance and to create optimal models that best predict such performance in CrossFit® (CF) athletes. Fifty athletes, 25 males and 25 females (age: 33.26 ± 6.81 years; body mass: 72.57 ± 12.17 kg; height: 169.55 ± 8.71 cm; BMI: 25.06 ± 2.31 kg·m−2) were recruited to participate and underwent BC analysis using dual-energy X-ray absorptiometry (DXA) and an all-out laboratory test on a cycle ergometer (Wingate) to determine their anaerobic performance. The results show a significant correlation between BC values and performance, ranging from moderate ($r = -0.34$, $p = 0.015$) to near-perfect ($r = 0.96$, $p < 0.01$). Furthermore, the created performance prediction models exhibited predictive capacities ranging from 19% ($p = 0.017$) to 93% ($p < 0.001$). All prediction models were created using total or segmental lean mass variables, excluding others. The studied body composition and performance variables found significant differences between males and females. The findings demonstrate that body composition variables are crucial indicators of anaerobic performance in CF athletes. In this regard, it may be advisable for sports performance professionals to consider this information when monitoring athletes throughout the season or designing specific training programs. Similarly, the use of predictive equations could be a useful tool for estimating peak and mean power values.
Keywords: sports performance, anaerobic performance, body composition, athletes, CrossFit®, high-intensity functional training

Resumen. El objetivo principal del presente estudio fue establecer la asociación entre las variables de composición corporal (CC) total y segmentaria y el rendimiento anaeróbico, así como crear los modelos de regresión que mejor predigan dicho rendimiento en atletas de CrossFit® (CF). Cincuenta atletas, 25 hombres y 25 mujeres (edad: 33,26 ± 6,81 años; masa corporal: 72,57 ± 12,17 kg; estatura: 169,55 ± 8,71 cm; IMC: 25,06 ± 2,31 kg-m^{-2}) fueron reclutados para participar y se sometieron a un análisis de la CC mediante absorciometría de rayos X de energía dual (DXA) y a una prueba de laboratorio a máximo esfuerzo en un cicloergómetro (Wingate) para determinar su rendimiento anaeróbico. Los resultados muestran una correlación significativa entre los valores de CC y el rendimiento, que va de moderada ($r = -0{,}34$, $p = 0{,}015$) a casi perfecta ($r = 0{,}96$, $p < 0{,}01$). Además, los modelos de predicción del rendimiento creados mostraron capacidades predictivas que oscilaron entre el 19% ($p = 0{,}017$) y el 93% ($p < 0{,}001$). Todos los modelos de predicción se crearon utilizando variables de masa magra total o segmentaria, excluyendo otras. Las variables de composición corporal y rendimiento estudiadas encontraron diferencias significativas entre hombres y mujeres. Los resultados demuestran que las variables de composición corporal son indicadores cruciales del rendimiento anaeróbico en atletas de CF. En este sentido, sería recomendable que los profesionales responsables del rendimiento deportivo consideren esta información al momento de monitorizar a los atletas durante la temporada o al diseñar programas de entrenamiento específicos. Del mismo modo, el uso de ecuaciones de predicción podría resultar útil como herramienta para estimar los valores de potencia máxima y media.
Palabras clave: rendimiento deportivo, rendimiento anaeróbico, composición corporal, atletas, CrossFit®, entrenamiento funcional de alta intensidad.

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Introduction

Body composition (BC) refers to the ratio of the different components of the human body. One of the most widely used body composition models in research is the 2-compartment model. It divides the body into two main components: fat mass and fat-free mass, also known as Lean Body Mass (LBM), which includes everything that is not fat in the body, such as muscle, bone, organs, and water. Instead, fat mass refers to the amount of adipose tissue in the body. The proportion of each of these components varies according to an individual's age, gender, ethnicity, and physical activity level (Guo S et al., 1999; Kirchengast, 2010; Wulan et al., 2010). BC can be studied in total values (of the whole body) or segmentally (by regions). Segmental BC measures body composition, dividing the body into various anatomical regions, such as the arms, legs, trunk, and head. Segmental BC provides detailed information on body mass distribution and can help assess body asymmetry. The applications of BC are diverse and range from health evaluation to the design of personalized training and nutrition programs. Therefore, accurate measurement of BC can provide valuable information about health, fitness, and sports performance.

In sports, some BC components are used as a selection method, monitoring throughout the year, and predicting athletes' performance (Rudnev, 2020). In addition, athletes and coaches are aware of the importance of BC in sports performance and injury prevention (Lukaski & Raymond-Pope, 2021) since BC can significantly affect athletic performance by influencing an athlete's strength, power (Ben Mansour et al., 2021) and agility. Some authors have studied the relationship between some of the components of BC and performance in different physical tests in athletes (Corredor-Serrano et al., 2023; García-Chaves et al., 2023; Kim et al., 2011; Pearson et al., 2019). For example, excess fat mass has been shown to have a negative impact on physical performance (Lockie et al., 2021; Mangine et al., 2020; Vargas et al., 2018; Zeitz et al., 2020). Similarly, lean body mass (LBM) has been shown to be directly related to athletic performance (Maciejczyk et al., 2015; Stephenson et al., 2015; Zaras et al., 2020). Higher LBM is associated with greater muscle strength and power performance, which can improve performance in sports that require explosive strength, such as weightlifting (Zaras et al., 2020); soccer (Ishida et al., 2021; Triki et al., 2012), hockey (Chiarlitti et al., 2018) or water polo (Di Vincenzo et al., 2019). Thus, higher levels of LBM are associated with better anaerobic performance.

Anaerobic performance refers to the capacity of the human body to generate energy quickly and efficiently during high-intensity and short-duration activities, ranging from 1 second (e.g., maximum Olympic lift, 100-meter sprint) to 100 seconds (e.g., 400-meter sprint), predominantly through anaerobic metabolic pathways (ATP-phosphocreatine and anaerobic glycolysis). Even in short maximal efforts of 30 seconds, there is a contribution from aerobic systems of approximately 16-18% (Beneke et al., 2002; Smith & Hill, 1991). Anaerobic performance is characterized by two key aspects: power and capacity. Anaerobic power refers to the maximum peak power that an individual can generate during a short-duration maximal effort, typically observed within the exertion's first 5-10 seconds. On the other hand, anaerobic capacity is defined as the average power that can be sustained throughout the effort. These components of anaerobic performance are associated with the ability to perform explosive actions such as sprints, jumps, throws, or maximum lifts, as well as the capacity for rapid recovery between repeated efforts. They have been shown to be determining factors for performance in high-intensity sports and those with predominantly lower intensity but intermittent peaks of higher intensity. Therefore, improving anaerobic performance can be fundamental for competitive success in individual and team sports that demand intense and intermittent efforts (Bellar et al., 2015; Franchini, 2023; Gacesa et al., 2009; Hofman et al., 2017; Losnegard et al., 2012).

The prediction of performance through prediction equations has been addressed by several authors in different populations (Alvero-Cruz et al., 2019; Lara-Sánchez et al., 2011; Stickley et al., 2012). Equations have been developed for prediction of different expressions of performance such as peak vertical jump power through jump height (Lara-Sánchez et al., 2011), for estimation of trail running time through VO2 max and fat mass percentage (Alvero-Cruz et al., 2019), even for estimation of peak and mean power of the Wingate test (WG) through tests without subjecting participants to any physical exertion (Stickley et al., 2012). These prediction equations can be valuable tools for sports performance professionals to estimate specific performance parameters of athletes without subjecting them to maximal effort tests.

In recent years, one high-intensity sport that has experienced exponential growth and attracts an increasing number of participants each year is commercially known as CrossFit® (CF) (Feito et al., 2018). CF has become a trendy sport with thousands of affiliated centers worldwide and numerous competitions where athletes must demonstrate their physical capabilities in various unknown tests over a few days, typically a weekend. Its main characteristics lie in the multimodal nature of its training or competition events, combining exercises from gymnastics, Olympic weightlifting, running, jumping, and lifting or carrying of heavy objects performed at high intensities. This high-intensity component inherent in this sport necessitates athletes to exhibit good anaerobic performance (Bellar et al., 2015). Likewise, in other sports, BC can play a significant role in the performance of these athletes. Therefore, it would be essential to determine the optimal values that enhance their capacities and assist them in achieving the best results.

Several authors have attempted to determine the predictors of performance in official CF tests, also called WOD (from workout of the day) (Butcher et al., 2015; Mangine et al., 2020, 2022; Mangine & McDougle, 2022; Zeitz et al., 2020). However, significant heterogeneity in the investigated performance and BC variables makes formulating definitive and appropriate conclusions challenging. Therefore, the main objective of this study is to determine the total and segmental BC values associated with anaerobic performance, measured using a widely employed standard laboratory test (Wingate). Secondary objectives include developing prediction models that best explain the dependent performance variables and conducting comparison between sexes. We hypothesized that both total and segmental body composition would be associated with anaerobic performance, and sex differences would be present.

Materials and methods

Participants

Fifty CF athletes from various local centers were recruited to participate in the current study, 25 men (age: 33.32 ± 5.83 years; body mass: 82.76 ± 7.47 kg; height: 176.90 ± 4.16 cm; BMI: 26.43 ± 2.03 $kg \cdot m^{-2}$) and 25 women (age: 33.20 ± 7.78 years; body mass: 62.37 ± 5.50 kg; height: 162.20 ± 5.01 cm; BMI: 23.70 ± 1.70 $kg \cdot m^{-2}$). All participants voluntarily agreed to take part after responding to an advertisement posted at these centers. The primary inclusion criterion was a minimum of one year of CF practice. Individuals with any recent musculoskeletal injuries or medical conditions that could hinder their ability to perform the maximum effort test, such as cardiac issues, were excluded from the study.

Study Design

A cross-sectional study was conducted over four weeks, in which participants underwent three separate sessions with a minimum of 48 hours between each session. The first session involved a personal interview to provide volunteers with comprehensive information about all procedures, record sociodemographic data, obtain informed consent, and familiarize them with the performance test. The second session included anthropometric measurements and BC analysis, while the final session was dedicated to performing the maximum effort test. Participants were advised to refrain from engaging in strenuous physical activity within 24 hours before the all-out test. All procedures were conducted in accordance with the principles outlined in the Declaration of Helsinki and had received prior approval from the ethics committee at the University of Málaga (43-2018-H). Participants were fully informed beforehand and provided written consent. Figure 1 shows the algorithm of the study protocol.

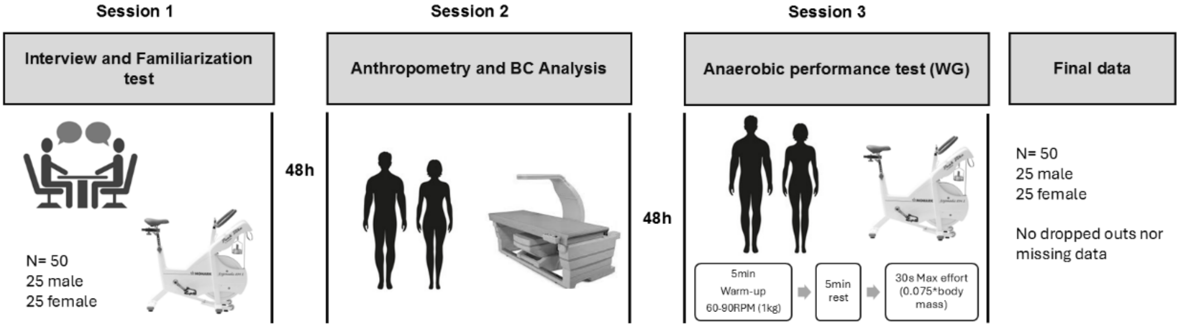

Figure 1. Study protocol.

Anthropometrics & Body Composition Analysis

During the second session, all participants were asked to come to the laboratory, where their height in cm was measured using a wall-mounted stadiometer with a precision of 1 mm (SECA® 206; SECA, Hamburg, Germany), and their body mass in kilograms was measured using a scale with a precision of 100 g (SECA® 803; SECA, Hamburg, Germany). Subsequently, body composition analysis was conducted using dual-energy X-ray absorptiometry (DXA) (Horizon A, Hologic Inc., Bedford, MA, USA). Data were processed using Hologic APEX software (version 4.6) integrated into the measuring instrument. Athletes were instructed to arrive at the laboratory fasting, having abstained from eating or drinking for at least 4 hours and consuming alcohol within the past 24 hours or diuretics within the previous week in accordance with Alvero-Cruz et al. (2010). Other authors have previously used this method of BC analysis in CF athletes (Carreker & Grosicki, 2020; Sauvé et al., 2024).

From the data provided by the system software, the variables of total lean body mass (WBLM), total fat mass (WBFM), and percentage of body fat (WBFMP) were extracted. Values of the trunk, upper limbs, and lower limbs were used for segmental body composition. Absolute values or the average of the percentages of both the right and left limbs were summed for the upper and lower limbs. Head values were excluded from the segmental analysis. Final segmental BC variables used were: trunk lean mass in kg (TRLM), trunk fat mass in kg (TRFM), percentage of trunk fat mass (TRFMP), upper extremity lean mass in kg (UELM), upper extremity fat mass in kg (UEFM), percentage of upper extremity fat (UEFMP), lower extremity lean mass in kg (LELM), lower extremity fat mass in kg (LEFM), and percentage of lower extremity fat (LEFMP). All values reported in grams by the software were converted to kilograms.

Anaerobic Performance

Anaerobic performance was measured using the Wingate Anaerobic Test (WG) with a resistance of 0.075 kp per kg body mass (Bar-Or, 1987). This test was chosen because it has been shown to have a significant relationship with performance in various official CF events (Butcher et al., 2015; Menargues-Ramírez et al., 2022). The test was conducted using a Monark 894E cycle ergometer (Monark Exercise AB, Vansbro, Sweden). To determine peak (WGPP), mean (WGXP), and minimum power output (WGMP), power values were recorded every 5 seconds. A first familiarization test was carried out during the study's first session.

Statistical Analysis

The statistical package for the social sciences (SPSS 26, IBM Corp., Armonk, NY, USA) and the statistical software MedCalc (MedCalc 18.6, MedCalc Software Ltd., Ostend, Belgium) were used for statistical analyses. Descriptive statistics (mean and standard deviation) were calculated for all variables. Normality of the variables was assessed using the Shapiro-Wilk test. As some variables did not meet the assumption of normality, the relationships between all independent variables and anaerobic performance were quantified by calculating Spearman's Rho correlation coefficients. The strength of the observed relationships was interpreted using the following criteria: trivial (<0.10), small (0.10–0.29), moderate (0.30–0.49), high (0.50–0.69), very high (0.70–0.90), or nearly-perfect (>0.90) (Alsamir Tibana et al., 2019). Independent samples t-tests were conducted to assess differences between male and female athletes. Effect sizes for sex comparisons were calculated using Cohen's d (d). According to Cohen (1988), effect size values were interpreted as small (d = 0.2), medium (d = 0.5), or large (d = 0.8). The statistical significance level for all tests was set at p <0.05. Finally, stepwise multiple regression analyses were performed to determine the relationship between the independent and dependent variables and to create models that best explained the variance of the anaerobic performance variables. A stepwise multiple linear regression analysis was conducted for each dependent variable (WGPP, WGXP and WGMP) using total or segmental body composition data. The significant variables selected by the statistical software were used to create a predictive model for the performance variables.

Results

Table 1 presents descriptive statistics for the entire group and for males and females, along with the comparison between sexes and the effect size of all study variables. Table 2 presents correlation data between all variables.

Table 1.
Descriptive data of the variables, sex comparison and effect size.

	Group (n=50)			Male (n=25)			Female (n=25)				
	Mean	SD	SEM	Mean	SD	SEM	Mean	SD	SEM	t	*d*
Age (years)	33.26	6.81	0.96	33.32	5.84	1.17	33.20	7.78	1.56	0.951	0.02
Body Mass (kg)	72.57	12.17	1.72	82.76	7.47	1.49	62.37	5.50	1.10	0.000	3.11
Height (cm)	169.55	8.71	1.23	176.90	4.16	0.83	162.20	5.01	1.00	0.000	3.20
BMI ($kg \cdot m^{-2}$)	25.06	2.31	0.33	26.43	2.03	0.41	23.70	1.70	0.34	0.000	1.46
WBLM (kg)	58.20	12.15	1.72	69.01	6.15	1.23	47.39	4.46	0.89	0.000	4.02
WBFM (kg)	15.49	3.14	0.44	15.15	3.25	0.65	15.82	3.05	0.61	0.459	0.21
WBFM (%)	21.45	4.95	0.70	17.95	3.09	0.62	24.96	3.86	0.77	0.000	2.01
TRLM (kg)	27.24	5.49	0.78	32.14	2.77	0.55	22.35	2.00	0.40	0.000	4.06
TRFM (kg)	6.26	1.77	0.25	6.72	1.94	0.39	5.79	1.47	0.29	0.062	0.54
TRFM (%)	18.80	4.46	0.63	17.14	3.91	0.78	20.47	4.42	0.88	0.007	0.80
UELM (kg)	7.02	2.19	0.31	8.99	1.13	0.23	5.05	0.65	0.13	0.000	4.27
UEFM (kg)	1.68	0.38	0.05	1.69	0.38	0.08	1.67	0.39	0.08	0.855	0.05
UEFM (%)	20.25	5.94	0.84	15.73	2.51	0.51	24.77	4.82	0.96	0.000	2.35
LELM (kg)	20.45	4.28	0.61	24.10	2.44	0.49	16.80	1.91	0.38	0.000	3.33
LEFM (kg)	6.46	1.57	0.22	5.55	1.18	0.24	7.37	1.38	0.28	0.000	1.41
LEFM (%)	24.55	7.04	1.00	18.67	3.32	0.66	30.42	4.29	0.86	0.000	3.06
WGPP (W)	700.93	224.08	31.69	895.41	135.75	27.15	506.45	72.75	14.55	0.000	3.57
WGXP (W)	511.58	160.89	22.75	653.11	91.80	18.36	370.06	51.92	10.38	0.000	3.80
WGMP (W)	311.27	112.64	15.93	387.99	101.22	20.24	234.55	58.28	11.66	0.000	1.86
WGFI (%)	54.84	10.31	1.46	56.59	9.24	1.85	53.09	11.20	2.24	0.235	0.34

SD: standard deviation; SEM: standard error of the mean; t: significance of t-student analysis; *d*: Cohen d effect size; BMI: body mass index; WBLM: whole body lean mass in kg; WBFM: whole body fat mass in kg; WBFMP: whole body fat mass as percentage; TRLM: trunk lean mass in kg; TRFM: trunk fat mass in kg; TRFMP: trunk fat mass percentage; UELM: upper extremity lean mass in kg; UEFM: upper extremity fat mass in kg; UEFMP: upper extremity fat mass as percentage; LELM: lower extremity lean mass in kg; LEFM: lower extremity fat mass in kg; LEFMP: lower extremity fat mass as percentage; WGPP: peak power in watts; WGXP: mean power in watts; WGMP: minimal power in watts; WGFI: fatigue index.

Correlations

Table 2 shows the correlations of the group variables and the sample split by sex. Total lean mass (WBLM) and segmental lean mass of the trunk (TRLM), upper extremity (UELM), and lower extremity (LELM) showed significant positive correlations with all anaerobic performance variables (WGPP, WGXP and WGMP) in both the total and sex-separated samples. Likewise, significant negative correlations were found between total fat mass percentage (WBFMP) and segmental fat mass percentage of the trunk (TRLMP), upper extremity (UELMP) and lower extremity (LELMP) with all performance variables (WGPP, WGXP and WGMP) only when the sample was considered as a single group. Furthermore, lower extremity fat mass in kilograms (LELM) showed significant negative correlations with all performance variables in the pooled sample.

Table 2.
Spearman's correlation coefficient between total and segmental body composition and the anaerobic power values in the whole group, male and female athletes.

	Group (n=50)			Male (n=25)			Female (n=25)		
	WGPP	WGXP	WGMP	WGPP	WGXP	WGMP	WGPP	WGXP	WGMP
WBLM (kg)	0.93**	0.96**	0.82**	0.72**	0.83**	0.59**	0.69**	0.82**	0.59**
WBFM (kg)	-0.03	-0.02	-0.1	0.32	0.3	0.11	0.01	0.06	-0.1
WBFMP (%)	-0.68**	-0.68**	-0.64**	0.01	-0.05	-0.13	-0.26	-0.26	-0.3
TRLM (kg)	0.91**	0.94**	0.81**	0.69**	0.79**	0.54**	0.56**	0.74**	0.63**
TRFM (kg)	0.25	0.27	0.19	0.23	0.26	0.12	0.01	0.06	-0.08
TRFMP (%)	-0.34*	-0.35*	-0.35*	0.04	0.02	-0.1	-015	-0.16	-0.26
UELM (kg)	0.91**	0.94**	0.81**	0.57**	0.71**	0.52**	0.67**	0.80**	0.57**
UEFM (kg)	0.06	0.11	0.06	0.38	0.45*	0.23	-0.11	0.04	-0.01
UEFMP (%)	-0.73**	-0.72**	-0.64**	0.08	0.03	-0.04	-0.39	-0.29	-0.23
LELM (kg)	0.93**	0.95**	0.80**	0.77**	0.83**	0.59**	0.69**	0.74**	0.46*
LEFM (kg)	-0.47**	-0.48**	-0.50**	0.21	0.15	0.01	0.01	0.08	-0.05
LEFMP (%)	-0.79**	-0.79**	-0.71**	-0.09	-0.16	-0.21	-0.34	-0.33	-0.29

WBLM: whole body lean mass in kg; WBFM: whole body fat mass in kg; WBFMP: whole body fat mass as percentage; TRLM: trunk lean mass in kg; TRFM: trunk fat mass in kg; TRFMP: trunk fat mass percentage; UELM: upper extremity lean mass in kg; UEFM: upper extremity fat mass in kg; UEFMP: upper extremity fat mass as percentage; LELM: lower extremity lean mass in kg; LEFM: lower extremity fat mass in kg; LEFMP: lower extremity fat mass as percentage; WGPP: peak power in watts; WGXP: mean power in watts; WGMP: minimum power in watts; *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 evel (2-tailed).

Table 3.
Multiple regression models of the whole group using whole and segmental body composition

Dependent variable	Independent variable	Coefficient	Std. Error	P	VIF	R^2	R^2-ajusted
Whole Body Composition							
WGPP	Constant	-277.109				0.90	0.90
	WBLM	16.726	0.815	<0.001	1		
WGXP	Constant	-229.002				0.94	0.93
	WBLM	12.699	0.483	<0.001	1		
WGMP	Constant	-98.142				0.64	0.63
	WBLM	7.000	0.763	<0.001	1		
Segmental Body Composition							
WGPP	Constant	-268.458				0.89	0.88
	LELM	47.173	2.449	<0.001	1		
WGXP	Constant	-218.682				0.91	0.91
	LELM	35.628	1.588	<0.001	1		
WGMP (model 1)	Constant	-91.794				0.62	0.61
	LELM	19.610	2.216	<0.001	1		
WGMP (model 2)	Constant	38.810				0.63	0.62
	UELM	38.540	4.288	<0.001	1		

WGPP: peak power in watts; WGXP: mean power in watts; WGMP: minimal power in watts; WBLM: whole body lean mass in kg; LELM: lower extremity lean mass in kg; UELM: upper extremity lean mass in kg; VIF: variance inflation factor

Multiple Regression Analysis

Table 3 presents the multiple regression models developed based on total and segmental BC using data from the entire group. The results demonstrate that the strongest predictor of total BC variables is WBLM, explaining 90% ($F(1,48) = 421.066$, $p < 0.001$), 93% ($F(1,48) = 692.025$, $p < 0.001$), and 63% ($F(1,48) = 84.261$, $p < 0.001$) of the variance in WGPP, WGXP, and WGMP values, respectively. Regarding segmental BC, a model for WGPP is generated through LELM, accounting for 88% ($F(1,48) = 371.044$, $p < 0.001$) of the variance. For WGXP, a model explained by LELM is developed with a predictive capacity of 91% ($F(1,48) = 503.624$, $p < 0.001$). Finally, for WGMP, two different models are developed, model 1 explained by LELM, with a prediction capacity of 61% of its variance ($F(1,48) = 78.299$, $p < 0.001$) and model 2 using UELM, accounting for 62% of its variance ($F(1,48) = 80.764$, $p < 0.001$).

Table 4 presents regression models for the dependent variables, classified by sex. Prediction models based on WBLM were developed based on total body composition. These models explain 57% ($F(1,23) = 32.253$, $p < 0.001$) and 42% ($F(1,23) = 18.456$, $p < 0.001$) of the variance in WGPP, 72% ($F(1,23) = 63.222$, $p < 0.001$) and 65% ($F(1,23) = 46.432$, $p < 0.001$) of the variance in WGXP, and 27% ($F(1,23) = 9.743$, $p = 0.005$) and 19% ($F(1,23) = 6.668$, $p = 0.017$) of the variance in WGMP for males and females, respectively.

When considering segmental body composition, prediction models were developed for both sexes, revealing a significant contribution from LELM. In the case of WGPP, LELM accounts for 59% ($F(1,23) = 35.848$, $p < 0.001$) and 47% ($F(1,23) = 22.219$, $p < 0.001$) of the variance in males and females, respectively.

Similarly, for WGXP, LELM contributes to 70% ($F(1,23) = 56.030$, $p < 0.001$) and 60% ($F(1,23) = 37.615$, $p < 0.001$) of the variance in males and females, respectively.

For WGMP in males, LELM was also selected as an independent variable, explaining 28% ($F(1,23) = 10.558$, $p = 0.004$) of the variance. Conversely, in the case of females, the independent variable TRLM was chosen for model creation, explaining 23% ($F(1,23) = 8.278$, $p = 0.009$) of its variance.

Table 4.
Multiple regression models of by sex using whole and segmental body composition,

Dependent variable	Independent variable	Coefficient	Std. Error	P	VIF	R^2	R^2-ajusted
Whole Body Composition							
WGPP (male)	Constant	-109.973				0.58	0.57
	WBLM	14.435	2.542	<0.001	1		
WGPP (female)	Constant	-8.726				0.44	0.42
	WBLM	10,872	2.531	<0.001	1		
WGXP (male)	Constant	-234.243				0.73	0.72
	WBLM	12.812	1.611	<0.001	1		
WGXP (female)	Constant	-80.568				0.67	0.65
	WBLM	9.510	1.396	<0.001	1		
WGMP (male)	Constant	-168.543				0.30	0.27
	WBLM	8.007	2.565	0.005	1		
WGMP (female)	Constant	-58.676				0.23	0.19
	WBLM	6.188	2.396	0.017	1		
Segmental Body Composition							
WGPP (male)	Constant	-8.697				0.61	0.59
	LELM	37.131	6.202	<0.001	1		
WGPP (female)	Constant	57.947				0.49	0.47
	LELM	26.693	5.663	<0.001	1		
WGXP (male)	Constant	-114.627				0.71	0.70
	LELM	31.721	4.238	<0.001	1		
WGXP (female)	Constant	10.341				0.62	0.60
	LELM	21.409	3.491	<0.001	1		
WGMP (male)	Constant	-115.630				0.31	0.28
	LELM	20.730	6.380	0.004	1		
WGMP (female)	Constant	-99.744				0.27	0.23
	TRLM	14.960	5.199	0.009	1		

WGPP: peak power in watts; WGXP: mean power in watts; WGMP: minimal power in watts; WBLM: whole body lean mass in kg; LELM: lower extremity lean mass in kg; TRLM: trunk lean mass in kg; VIF: variance inflation factor.

Sex differences

Table 1 displays the sex differences observed among male and female athletes. The t-Test results indicated statistically significant differences between sexes for most of the variables examined ($p < 0.05$). Conversely, a few variables did not exhibit statistically significant differences ($p > 0.05$), namely age, WBFM, TRFM, and UEFM. The most notable differences were the significantly higher correlations in men than in women. Conversely, the total and segmental body fat percentage was higher in women than men, especially in the lower extremities. Likewise, the prediction models developed show a more significant predictive capacity in men than women.

Discussion

The main purpose of this study was to determine the relationship between body composition values and anaerobic performance in CF athletes. The results of our work reveal a significant positive correlation between WBLM, TRLM, UELM and LELM with all studied anaerobic performance variables (WGPP, WGXP, and WGMP). The percentages of total or segmental fat mass in all segments (WBFMP, TRFMP, UEFMP, and LEFMP), as well as LEFM, showed a significant negative correlation with WGPP, WGXP, and WGMP when the sample was considered as a single group.

Concerning lean body mass, these results are consistent with those published by other authors in studies conducted on different populations. Maciejczyk et al. (2015) found a positive correlation between lean mass and peak and mean power in a 20-second maximal effort cycling test in a sample of physically active men. Similarly, Stephenson et al. (2015) demonstrated a significant correlation between total and segmental lower limb lean mass values and performance in vertical jump, in 102 non-athlete adults. Furthermore, a study conducted on motorcycle racing riders found a significant positive correlation between lean mass and WGPP (Michalik et al., 2022). Other findings, such as those of Collins et al., (2022) showed a significant positive correlation between lean mass and maximum power, vertical jump, and medicine ball throw in law enforcement officer recruits.

In CF athletes, Mangine et al. (2022) found a significant negative correlation between lean mass and the completion time of a standard WOD called "Fran," which involves performing a specified task as fast as possible. Therefore, athletes with higher lean mass values completed the WOD in less time. Menargues-Ramírez et al. (2022) found a relationship between muscle mass determined through skinfold measurements and the total weight lifted in another standard workout. These findings support the idea that lean mass is positively related to anaerobic performance in different populations and sporting contexts.

Regarding fat mass, our results show a negative effect on performance, agreeing with those shown in other works that report a significant positive correlation between the WBFMP and skating times in male and female hockey players indicating that lower fat percentage is associated with faster times (Czeck et al., 2021) and a significant negative correlation between the values of total and segmental fat mass and anaerobic performance in female handball players (Kale & Akdoğan, 2020) or performance variables in other physical tests in recruits for law enforcement (Collins et al., 2022). Similarly, other studies conducted on CF athletes show similar results in which the percentage of fat mass negatively affects performance in different standard CF WODs, such as the "Open 19.1", described in the study conducted by Zeitz et al. (2020), all the events from the 2018 Open (Mangine et al., 2020), the time of the workout called "Fran" (Mangine et al., 2022), as well as the performance in another well-known WOD called "Murph" in which the subjects with the lowest percentage of fat showed better performance achieving the event in less time (Carreker & Grosicki, 2020). Like lean mass, these results highlight the relevance of the role of fat mass in athletic performance, emphasizing its significant influence on athletes' ability to achieve optimal levels of power and endurance.

The results presented in our work show that the absolute values of lean mass accurately predict anaerobic performance among CF athletes. The goodness of fit of the prediction models developed in this study ranges from 61% to 93% (for minimum and peak power, respectively) by the WBLM values of the pooled sample (men and women together). The prediction equations obtained were WGPP = -277.109 + 16.726*WBLM (R^2= 0.90); WGXP = -229.002 + 12.699*WBLM (R^2= 0.93); WGMP = -98.142 + 7*WBLM (R^2 = 0.63).

For developing the prediction models of the whole group based on the segmental BC, the absolute values of LELM are included for three of the four models elaborated. As the only predictor of the WGPP and WGXP explaining 88% and 91% of their variances, respectively. Equations for these models are WGPP = -268.458 + 47.173*LELM (R^2 = 0.88) and WGXP = -218.682 + 35.628*LELM (R^2 = 0.91). For the prediction of the WGMP, two different models were obtained: model 1 by LELM, which explains 61% of its variance and model 2, explained by UELM, providing a goodness of fit of 62%. Developed equations are WGMP (model 1) = -91.794 + 19.610*LELM (R^2 = 0.61) and WGMP (model 2) = 38.810 + 38.540*UELM (R^2 = 0.62).

When the sample is divided by sex, the prediction models substantially decrease their predictive capacities, varying between 21% in men and 19% in women of the prediction model created for the WGMP and 67% in men and 65% in women for the WGXP, both created through the WBLM. In the same way as for the whole group, using the segmental body composition values, almost all the models were created by the LELM, except for the prediction of the WGMP in women executed through the TRLM. The goodness of fit of these models ranges from 23% to 66%. An interesting aspect to consider is the improvement in the predictive capacity of the models made with the segmental BC variables compared to those of the total body when the sample is split by gender. This variation could be explained by the differences between men and women in the amount and distribution of lean mass or the contribution of other variables not recorded in the present study. Finally, in the sex comparison of our study, significant differences were found in all performance variables. These differences have been previously published by some authors such as Maud & Shultz (1986), who found significant differences between sexes in the absolute power values in the Wingate test, or Collins et al. (2022), who found significant differences between men and women in all performance variables except for maximum repetitions of push-up and the multi-station fitness test. In addition, statistically significant differences were found in all BC variables except for WBFM, TRFM, and UEFM. However, significant differences were found between sexes when expressing these same variables as a percentage (WBFMP, TRFMP and UEFMP). This discrepancy can be attributed to the use of the percentage value since it provides a more individually standardized parameter instead of a simple absolute value in kg. Likewise, the significant difference observed in the LELM value between both sexes could be associated with a greater amount of lean mass and a lower amount of segmental fat in the lower limbs of male athletes compared to their female counterparts. In addition, our results are consistent with those published by Collins et al. (2022), who found significant differences in the WBLM, as well as TRLM, UELM, and LELM, but found no differences in the variables of total or segmental fat mass between male and female law enforcement recruits. Using DXA as a method of analysis, Sanfilippo et al. (2019) also found significant differences between sexes in different sports, where men showed a higher lean mass and lower fat mass.

The present study has several limitations that need to be considered. Firstly, the timing of the menstrual cycle in female athletes was neither considered nor recorded, nor was the use of contraceptive pills during the study and their potential effects on the results of BC analysis or performance in the maximal effort test. Also, the prediction models' low predictive capacity in women could raise doubts about the sample size used in this group. Second, dietary habits or food intake were not recorded in the days leading up to and during the study duration. This information could be important for better understanding the influence of nutrition on the obtained results. Third, the fatigue state before the max effort tests was not recorded, which might impact the results of these assessments.

Furthermore, it is essential to acknowledge that using laboratory tests in a controlled environment does not fully simulate the real competitive situations that athletes face in this sport. The absence of external factors and the lack of competitive pressure may limit the results' applicability under actual conditions.

Lastly, this study was cross-sectional, without establishing a cause-effect relationship between body composition values and anaerobic performance. Future intervention studies are needed to identify the effects of changes in lean mass and fat values on power and anaerobic capacity and identify other factors contributing to a more comprehensive explanation of these effects.

The findings of this research suggests that leaner CF athletes demonstrate superior performance, implying that an increase in lean mass could substantially improve their performance. These results provide valuable information for CF coaches to consider the possibility of focusing their training programs on increasing lean mass and reducing fat mass to enhance these athletes' performance. However, future research should aim to determine the optimal balance between lean and fat mass, avoiding excessive lean mass gains or extreme reductions in fat mass that may surpass the optimal levels and become counterproductive or detrimental to health.

Furthermore, the prediction equations developed in this study for body composition show a high predictive capacity. They could be used for estimating power and anaerobic capacity in CF athletes at specific time points or monitoring these parameters throughout the season. Thus, body composition assessment can be a valid tool, providing healthcare professionals, coaches, and fitness practitioners with an alternative method of evaluating anaerobic performance without exposing athletes to maximal effort tests.

Conclusions

We can conclude that our findings show a moderate to nearly-perfect relationship between lean body mass and total and segmental body fat percentage with anaerobic performance in CF athletes. Furthermore, considering the high goodness of fit of the prediction models developed in this study, we can report that total and segmental lean mass values are strong predictors of maximum and mean power determined in the Wingate test. However, due to the multiple factors that can contribute to performance, the specific predictive value of the regression models developed in this study should be interpreted with caution. The mentioned parameters can be reliable and cost-effective tools to aid in identifying athletes' potential and monitoring their fitness levels throughout the season.

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