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Research article

Phase angle in recreationally active adults attending fitness centers: Independent contributions of demographic, training-related, behavioral, and body composition variables

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Abstract: *Background:* The phase angle (PhA), derived from bioelectrical impedance analysis, is used as a marker of cellular integrity and nutritional status. Although muscle mass is considered a primary determinant of the PhA, the contribution of behavioral and training-related factors remains unclear in recreationally active populations. *Objective:* To examine the independent associations between the PhA and demographic, lifestyle, training-related, and body composition variables in adults attending fitness centers. *Methods:* This cross-sectional study included 116 physically active adults from two fitness centers. Anthropometry, bioelectrical impedance analysis, and handgrip strength were assessed. Participants completed validated questionnaires evaluating sleep quality and eating-disorder risk. Hierarchical multiple linear regression was performed on 94 participants with complete and valid data. Predictors were entered in theory-driven blocks comprising demographic variables, behavioral and training-related factors, and Kerr-derived muscle mass. *Results:* Sex and age explained 34.7% of the variance in the PhA. The addition of behavioral and training-related variables significantly increased the explained variance by 13.8% ($p = 0.002$), while Kerr-derived muscle mass contributed 4.0% ($p = 0.009$). The final model explained 52.5% of the variance in the PhA (adjusted $R^2 = 0.474$; $p < 0.001$). Older age was independently associated with a lower PhA, whereas Kerr-derived muscle mass was positively associated with the PhA. Compared with strength training, aerobic and mixed training were associated with a lower PhA. Sex, SCOFF score, PSQI score, creatine use, and CrossFit/functional training were not independently associated with the PhA. Because the aerobic subgroup included only

five participants, this estimate should be interpreted cautiously; however, a sensitivity analysis excluding this subgroup yielded materially consistent findings. *Conclusions:* In recreationally active adults attending fitness centers, the PhA was independently associated with age, training modality, and Kerr-derived muscle mass. These findings support the interpretation of the PhA as a multidimensional physiological marker in recreational exercise settings, although modality-specific estimates require confirmation in larger and more balanced samples.

Keywords: phase angle; bioelectrical impedance analysis; Kerr-derived muscle mass; sleep quality; recreationally active adults; fitness centers; physiological monitoring

Abbreviations: PhA: Phase angle; BIA: Bioelectrical impedance analysis; PSQI: Pittsburgh Sleep Quality Index; SCOFF: Sick, Control, One stone, Fat, Food questionnaire; ISAK: International Society for the Advancement of Kinanthropometry; HGS: Handgrip strength; VIF: Variance inflation factor; UCAM: Universidad Católica San Antonio de Murcia

1. Introduction

Bioelectrical impedance analysis (BIA) is widely used in both clinical and sports settings as a practical and non-invasive method for assessing body composition. Beyond the estimation of fat mass and fat-free mass, raw impedance parameters provide physiological information that is independent of predictive equations. Among these parameters, the phase angle (PhA), derived from the relationship between resistance and reactance, has received increasing attention as a marker of cellular integrity, membrane functionality, and intracellular-extracellular fluid distribution [1–3].

Accumulating evidence indicates that the PhA reflects aspects of muscle quality and cellular health rather than body size alone. Higher PhA values have been associated with greater muscle mass, strength, and physical performance, whereas lower values have been linked to inflammation, malnutrition, sarcopenia, and adverse clinical outcomes [4–7]. In athletic populations, the PhA has been proposed as a marker capable of distinguishing between physiological phenotypes, with strength- and power-oriented athletes typically presenting higher values compared with endurance disciplines [8–11].

Previous evidence has shown that the PhA differs according to sex and age, with generally higher values in men than in women and a progressive decline across adulthood. In addition, the relationship between the BMI and PhA does not appear to be strictly linear across all weight categories, supporting the need to interpret the PhA in relation to demographic and body-size characteristics [12].

Training modality therefore represents a plausible determinant of the PhA. Resistance training promotes muscle hypertrophy, intracellular water expansion, and increased cell membrane capacitance, mechanisms that may elevate reactance and consequently the PhA [8,13]. In contrast, endurance-oriented training emphasizes oxidative efficiency and may be associated with lower absolute muscle mass despite high aerobic capacity [9–11]. Hybrid modalities, such as CrossFit, combine resistance and metabolic demands and may present intermediate cellular characteristics [14–16]. However, most available evidence derives from elite or competitive athletes, and relatively few studies have examined these relationships in recreationally active, gym-based populations [16].

Beyond structural adaptations, behavioral and recovery-related factors may also influence cellular health markers. Creatine supplementation, for example, enhances phosphocreatine storage and

intracellular hydration, potentially affecting reactance-derived parameters [17,18]. Similarly, sleep quality plays a critical role in muscle recovery, anabolic signaling, and inflammatory regulation [19–22], processes that may subtly influence cellular membrane integrity and fluid balance. In contrast, maladaptive eating-related behaviors, even at subclinical levels, may compromise nutritional adequacy and recovery despite apparently normal body composition [23–26].

Although individual associations between the PhA and muscle mass, physical performance, or selected lifestyle factors have been described [27], relatively few studies have evaluated their combined and independent contributions within a multivariable framework. In particular, it remains unclear whether the training modality and behavioral factors explain variability in the PhA beyond demographic characteristics and muscle mass in recreationally active adults.

A hierarchical modeling approach may help clarify these relationships by sequentially examining demographic structure, lifestyle and training characteristics, and body composition variables within the same analytical framework. This approach allows the incremental contribution of each domain to be quantified, providing a more nuanced understanding of the determinants of the PhA in fitness settings.

Therefore, the present cross-sectional study aims to examine the independent associations between the PhA and demographic variables (sex and age), training modality, creatine use, sleep quality, eating disorder risk, and Kerr-derived muscle mass in recreationally active adults attending fitness centers. We hypothesize that resistance-based training and higher muscle mass will be positively associated with the PhA, and that behavioral factors such as poorer sleep quality or elevated eating-disorder risk might be associated with lower PhA values. Hierarchical multiple linear regression was used to assess the incremental contribution of each block of variables.

2. Materials and methods

2.1. Study design and ethical considerations

A cross-sectional observational study was conducted in physically active adults recruited from two fitness facilities in Murcia, Spain (the UCAM Sports Center and IronSweat Muscle Center). The study protocol was approved by the Ethics Committee (CE012506) of the Universidad Católica San Antonio de Murcia (UCAM) and was conducted in accordance with the Declaration of Helsinki [28].

All participants received detailed information regarding the study procedures and provided written informed consent prior to participation. Confidentiality was ensured through anonymized data processing and secure data storage.

2.2. Participants and recruitment

Participants were recruited through voluntary response to informational announcements posted within the participating fitness centers. Adults aged ≥18 years who engaged in regular structured exercise training in a gym-based setting were eligible for inclusion. Regular physical activity was defined as consistent participation in structured exercise programs.

Exclusion criteria included diagnosed chronic diseases likely to substantially affect body composition or bioelectrical impedance measurements (e.g., renal, hepatic, cardiovascular, or metabolic disorders), clinically diagnosed sleep disorders, or the inability to complete the assessment protocol.

A total of 116 recreationally active adults were recruited and initially assessed. Of these, 94 participants had complete and valid data for all variables included in the hierarchical regression models and constituted the final analytical sample. The analytical sample comprised 45 women and 49 men, with a mean age of 32.43 ± 9.31 years, mean body mass of 70.25 ± 12.57 kg, and mean height of 169.25 ± 8.31 cm. Training experience was recorded as an ordinal categorical variable: 9 participants (9.6%) reported 0–3 months of experience, 6 (6.4%) reported 3–6 months, 6 (6.4%) reported 6–12 months, and 73 (77.7%) reported more than one year of training experience. Additional characteristics of the analytical sample are presented in Table 1.

2.3. Data-collection procedure

All measurements were performed during a single on-site assessment session at the fitness facilities following a standardized protocol. Participants attended under controlled conditions.

Anthropometric measurements, bioelectrical impedance assessment (BIA), and handgrip strength (HGS) testing were conducted on-site. Questionnaire-based information related to lifestyle factors, dietary habits, sleep quality, and eating-related behaviors was collected separately via online forms to reduce participant burden during the physical assessment.

2.3.1. Anthropometry and body composition assessment

Anthropometric measurements were performed by two Level 2 accredited anthropometrists of the International Society for the Advancement of Kinanthropometry (ISAK), following standardized ISAK procedures [29]. Measurements were obtained on the right side of the body with participants barefoot and wearing light clothing.

All variables were measured in duplicate or triplicate according to technical error of measurement criteria. When the difference between the first two measurements exceeded 5% for skinfold thicknesses or 1% for other anthropometric variables, a third measurement was obtained. The mean of the two closest values was used for analysis.

Body weight was measured to the nearest 0.1 kg using a calibrated TANITA BC-545N digital scale (Tanita Corporation, Tokyo, Japan), and standing height was measured to the nearest 0.1 cm using a SECA 220 stadiometer (seca GmbH & Co. KG, Hamburg, Germany), with participants barefoot and positioned in the Frankfurt plane. The body mass index (BMI) was calculated as weight divided by height squared (kg/m^2).

Skinfold thicknesses were assessed using a Holway caliper (precision 1.0 mm; Holway Tools, California, USA) at standardized anatomical sites. The sum of six skinfolds was calculated as an indicator of subcutaneous adiposity. Circumferences were measured with a non-extensible tape, and bone breadths and diameters were assessed using a Holway anthropometer (precision 0.1 cm; Holway Tools, California, USA), following ISAK landmark definitions.

Body composition was estimated using the five-component anthropometric model proposed by Kerr, partitioning total body mass into adipose, muscle, bone, residual, and skin mass [30]. This model was selected due to its suitability for recreationally active populations. In the regression analyses, muscle mass (kg) referred specifically to muscle mass estimated using the five-component anthropometric Kerr model.

2.3.2. Bioelectrical impedance analysis and the phase angle

Bioelectrical impedance assessment was performed using the BIVA/NUTRILAB™ platform (Akern S.r.l., Florence, Italy) at a single frequency of 50 kHz with a current of 400 μA. All measurements were conducted by trained personnel following standardized procedures.

Participants were assessed under controlled pre-measurement conditions, including ≥4 hours of fasting, avoidance of intense exercise during the previous 12 hours, abstention from alcohol and caffeine, and bladder emptying prior to measurement.

Measurements were performed with participants in a supine position after at least 5 minutes of rest, with limbs slightly abducted to avoid skin contact. Disposable electrodes were placed on the dorsum of the right hand and foot according to manufacturer recommendations [31].

Resistance and reactance values were recorded, and the PhA was calculated as arctan (Xc/R) × (180/π) [31]. The PhA was considered the primary indicator of cellular integrity.

2.3.3. Handgrip strength and muscle quality

HGS was measured using a calibrated Jamar® Hydraulic Hand Dynamometer (Performance Health, USA) following standardized procedures [32–34]. Participants were assessed in a standing position with the shoulder adducted and neutrally rotated, the elbow fully extended, and the wrist in a neutral position.

Two maximal voluntary contractions were performed with the dominant hand, separated by brief rest. The highest value (kg) was retained for analysis.

Muscle quality was estimated using the muscle quality index, calculated as HGS divided by skeletal muscle mass derived from bioelectrical impedance analysis [35].

BIA-derived skeletal muscle mass was used only for the calculation of the muscle quality index and was not included as an independent predictor in the hierarchical regression models.

2.3.4. Questionnaires and behavioral assessments

Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI), a validated instrument evaluating sleep patterns over the previous month [36]. Participants were classified as having optimal (≤5) or poor (>5) sleep quality.

Adherence to the Mediterranean diet was assessed using the 14-item PREDIMED questionnaire [37]. Scores ≥ 9 indicated high adherence.

Eating-disorder risk was screened using the SCOFF questionnaire (Sick, Control, One stone, Fat, Food questionnaire), with ≥2 affirmative responses indicating potential risk [26]. Orthorexic tendencies were assessed using the Spanish-validated ORTO-11 questionnaire [25].

Habitual supplement use, specifically creatine monohydrate and protein powder, was recorded using dichotomous (yes/no) responses.

2.3.5. Sport modality classification

Participants self-reported their primary training modality and were classified into one of four categories: strength training, CrossFit or functional training, aerobic modalities, or mixed training.

2.4. Statistical analysis

Statistical analyses were performed using SPSS Statistics version 31 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean ± standard deviation (SD), and categorical variables as frequencies and percentages. Prior to inferential analyses, data quality control procedures were conducted, including inspection of missing data patterns, plausibility checks for extreme or non-physiological values, and assessment of influential observations. Participants with incomplete data for the variables required in the hierarchical regression models were excluded from complete-case analyses.

To assess potential selection bias associated with complete-case analysis, participants included in the regression models were compared with those excluded because of missing or invalid data. Continuous characteristics were compared using Welch's t test or the Mann–Whitney U test, as appropriate, and sex distribution was compared using Pearson's chi-square test. Influential observations were examined using studentized deleted residuals, Cook's distance, leverage values, and Mahalanobis distance. Sensitivity analysis was conducted for a potentially influential observation. As excluding this observation did not materially alter the direction, magnitude, or statistical significance of the main regression coefficients, it was retained in the primary analysis. To evaluate the robustness of modality-specific estimates, the final hierarchical model was also repeated after excluding the five participants classified in the aerobic-training subgroup.

Bivariate associations between continuous variables were explored using Spearman's rank correlation coefficient.

To examine independent associations with the PhA, hierarchical multiple linear regression analysis was conducted with the PhA as the dependent variable. Predictors were entered in theory-driven blocks: (1) demographic variables (sex and age); (2) lifestyle and training-related variables (sport modality, creatine use, sleep quality score, and SCOFF score); and (3) Kerr-derived muscle mass (kg).

Sport modality was treated as a categorical variable and entered into the regression model using dummy coding (k-1). Strength training was used as the reference category, and three dummy variables were created representing CrossFit/functional training, aerobic modalities, and mixed training.

Model fit was evaluated using the coefficient of determination (R^2) and adjusted R^2. The incremental contribution of each block was assessed using ΔR^2 and the corresponding F-change statistic. Unstandardized coefficients (B), standard errors, 95% confidence intervals, standardized coefficients (β), and p values were reported. Overall model fit was described using the F statistic with its corresponding degrees of freedom and p value. Multicollinearity was examined using variance inflation factors (VIF), with values <5 considered acceptable.

Regression assumptions were assessed through visual inspection of residual plots. Normality of residuals was evaluated using histogram and normal probability (P-P) plots, homoscedasticity was examined using scatterplots of standardized residuals versus predicted values, and independence of errors was confirmed using the Durbin–Watson statistic. No major violations of regression assumptions were observed.

Statistical significance was set at $p < 0.05$.

3. Results

3.1. Participant characteristics

A total of 116 recreationally active adults were included in the study. Of these, 94 participants (81.0%) had complete and valid data for all variables required in the hierarchical regression models and constituted the final analytical sample. Twenty-two participants (19.0%) were excluded from the complete-case analysis because of missing or invalid values in one or more required variables. Missing data were identified for the SCOFF score (n = 11), PSQI score (n = 11), creatine use (n = 11), training modality (n = 12), and Kerr-derived muscle mass (n = 4). In addition, one participant had an invalid phase-angle value identified during plausibility checks, which was treated as missing. Missing values overlapped across participants and therefore do not sum to 22.

Table 1. General characteristics of the study population.

Variable	Total (n = 94)	Women (n = 45)	Men (n = 49)
Continuous variables			
Age (years)	32.43 ± 9.31	30.82 ± 8.68	33.90 ± 9.72
Height (cm)	169.25 ± 8.31	164.09 ± 6.12	173.99 ± 7.18
Body weight (kg)	70.25 ± 12.57	61.81 ± 8.92	78.00 ± 10.27
Body mass index (kg/m²)	24.39 ± 3.13	22.89 ± 2.45	25.77 ± 3.07
Handgrip strength (kg)	40.25 ± 10.54[1]	32.14 ± 4.90[2]	47.70 ± 8.66[3]
Phase angle (°)	6.82 ± 0.71	6.42 ± 0.60	7.18 ± 0.59
SCOFF score	1.12 ± 1.07	1.44 ± 1.18	0.82 ± 0.86
PSQI score	5.76 ± 2.73	5.71 ± 3.17	5.80 ± 2.28
PREDIMED score	8.39 ± 1.77	8.31 ± 1.82	8.47 ± 1.75
ORTO-11 score	26.66 ± 3.71	27.07 ± 3.29	26.29 ± 4.06
Sport modality, n (%)			
Strength training	30 (31.9)	12 (26.7)	18 (36.7)
CrossFit/functional training	26 (27.7)	15 (33.3)	11 (22.4)
Aerobic modalities	5 (5.3)	4 (8.9)	1 (2.0)
Mixed training	33 (35.1)	14 (31.1)	19 (38.8)
Habitual creatine use, n (%)			
No	48 (51.1)	29 (64.4)	19 (38.8)
Yes	46 (48.9)	16 (35.6)	30 (61.2)

Note: Data are expressed as mean ± standard deviation or n (%). Percentages for women and men are calculated within each sex. [1] n = 92; [2] n = 44; [3] n = 48. PhA: Phase angle; SCOFF: Sick, Control, One stone, Fat, Food questionnaire; PSQI: Pittsburgh Sleep Quality Index; PREDIMED: Prevención con Dieta Mediterránea questionnaire; ORTO-11: 11-item Orthorexia Nervosa questionnaire.

Participants excluded from the complete-case analysis were older than those included (median: 40 versus 31 years; Mann–Whitney U = 702.0, p = 0.019). No statistically significant differences were observed in sex distribution ($\chi^2(1) = 0.042$, p = 0.838), BMI (U = 856.0, p = 0.210), height (Welch's t = 0.929, p = 0.360), body weight (Welch's t = 1.376, p = 0.180), phase angle (Welch's t = −0.280, p =

0.781), or valid handgrip strength (U = 855.5, p = 0.261). Thus, the main detectable difference between included and excluded participants was age. Descriptive characteristics of the final analytical sample are presented in Table 1.

3.2. Body composition and cellular health indicators

Complete data for all five components of the anthropometric Kerr model were available for 93 participants (44 women and 49 men; Table 2). In this subgroup, mean Kerr-derived muscle mass was 32.08 ± 8.37 kg, mean fat mass was 19.53 ± 4.86 kg, and the mean sum of six skinfolds was 83.68 ± 28.19 mm.

Men showed higher mean values of muscle, bone, residual, and skin mass, whereas women showed higher mean values of fat mass and the sum of six skinfolds. Kerr-derived muscle mass, the body-composition variable entered in the regression models, was available for all 94 participants in the final analytical sample.

Table 2. Body composition parameters.

Variable	All (n = 93)	Women (n = 44)	Men (n = 49)
Kerr-derived muscle mass (kg)	32.08 ± 8.37	25.25 ± 3.96	38.40 ± 5.89
Fat mass (kg)	19.53 ± 4.86	20.37 ± 5.16	18.91 ± 4.59
Bone mass (kg)	7.62 ± 1.29	6.70 ± 0.77	8.48 ± 1.08
Residual mass (kg)	7.37 ± 1.92	5.90 ± 1.12	8.70 ± 1.51
Skin mass (kg)	3.74 ± 0.49	3.60 ± 0.30	3.88 ± 0.59
Sum of six skinfolds (mm)	83.68 ± 28.19	92.88 ± 28.23	75.82 ± 26.42

Note: Data are expressed as mean ± standard deviation. Table 2 includes participants with complete data for all five Kerr components (n = 93); Kerr-derived muscle mass was available for all 94 participants included in the regression analysis. Muscle mass refers to Kerr-derived anthropometric muscle mass.

Table 3. Spearman correlations among continuous study variables in the final analytical sample (n = 94).

Variable	1	2	3	4	5	6
1. Phase angle	—					
2.Age	−0.106	—				
3.PSQI score	−0.188	0.026	—			
4.PREDIMED score	0.010	−0.132	−0.158	—		
5.SCOFF score	−0.249*	−0.138	0.185	−0.100	—	
6.Kerr-derived muscle mass (kg)	0.613***	0.004	−0.045	0.017	−0.118	—

Note: Values are Spearman's rho coefficients. *p < 0.05; ***p < 0.001. PSQI: Pittsburgh Sleep Quality Index.

3.3. Bivariate analyses

Spearman correlation analyses were conducted among continuous study variables and are presented in Table 3. The PhA was positively correlated with Kerr-derived muscle mass (ρ = 0.613, p < 0.001) and negatively correlated with the SCOFF score (ρ = −0.249, p = 0.016). No statistically

significant correlations were observed between the PhA and age, PSQI score, or PREDIMED score. Sport modality was treated as a categorical variable and was therefore not included in the Spearman correlation matrix; its association with the PhA was examined in the hierarchical regression models using dummy coding.

3.4. Hierarchical regression analyses

Hierarchical multiple linear regression was conducted to examine the independent contributions of demographic, behavioral, training-related, and body-composition variables to the PhA (Table 4).

In Model 1, sex and age explained 34.7% of the variance in the PhA ($R^2 = 0.347$; adjusted $R^2 = 0.333$; ($F(2, 91) = 24.206$, $p < 0.001$). Men had higher PhA values than women (B = 0.818; 95% CI: 0.578 to 1.058; $\beta = 0.581$; $p < 0.001$), whereas age was inversely associated with the PhA (B = −0.018; 95% CI: −0.031 to −0.005; $\beta = -0.233$; $p = 0.008$).

The addition of behavioral and training-related variables in Model 2 significantly increased the explained variance by 13.8% ($\Delta R^2 = 0.138$; F-change(6, 85) = 3.791; $p = 0.002$), yielding a total R^2 of 0.485. Sex and age remained independently associated with the PhA. Compared with strength training, aerobic training (B = −0.707; 95% CI: −1.230 to −0.184; $p = 0.009$) and mixed training (B = −0.342; 95% CI: −0.623 to −0.060; $p = 0.018$) were associated with a lower PhA, whereas CrossFit/functional training, creatine use, the PSQI score, and the SCOFF score were not independently associated with the PhA.

The addition of Kerr-derived muscle mass in Model 3 explained a further 4.0% of the variance ($\Delta R^2 = 0.040$; F-change(1, 84) = 7.133; $p = 0.009$). The final model explained 52.5% of the variance in the PhA (adjusted $R^2 = 0.474$; $F(9, 84) = 10.330$; $p < 0.001$). Older age remained associated with a lower PhA (B = −0.014; 95% CI: −0.026 to −0.002; $\beta = -0.188$; $p = 0.022$), while Kerr-derived muscle mass was positively associated with the PhA (B = 0.030; 95% CI: 0.008 to 0.053; $\beta = 0.351$; $p = 0.009$). Aerobic training (B = −0.660; 95% CI: −1.166 to −0.154; $p = 0.011$) and mixed training (B = −0.378; 95% CI: −0.651 to −0.104; $p = 0.007$) remained associated with a lower PhA compared with strength training. Sex, SCOFF score, PSQI score, creatine use, and CrossFit/functional training were not independently associated with the PhA.

In the sensitivity analysis excluding the five participants in the aerobic subgroup, the final model included 89 participants and explained 50.1% of the variance in the PhA (adjusted $R^2 = 0.451$; $F(8, 80) = 10.030$; $p < 0.001$). Age remained inversely associated with the PhA (B = −0.015; 95% CI: −0.028 to −0.003; $\beta = -0.206$; $p = 0.017$), mixed training remained associated with a lower PhA compared with strength training (B = −0.374; 95% CI: −0.649 to −0.099; $\beta = -0.262$; $p = 0.008$), and Kerr-derived muscle mass remained positively associated with the PhA (B = 0.030; 95% CI: 0.008 to 0.053; $\beta = 0.361$; $p = 0.010$). Thus, the direction and magnitude of the principal associations were materially unchanged.

Multicollinearity diagnostics indicated acceptable variance inflation factors (all VIF < 3.3). Residual diagnostics showed no major violations of normality or homoscedasticity, and the Durbin–Watson statistic for the final model was 1.843, supporting independence of errors.

Table 4. Hierarchical multiple linear regression predicting phase angle (n = 94).

Hierarchical multiple linear regression predicting phase angle (n = 94)											
Panel A. Model fit											
Model	Predictors added	R^2	Adjusted R^2	ΔR^2	F change	df1	df2	p change	Overall F (df)	Overall p	SEE
1	Sex, age,	0.347	0.333	0.347	24.206	2	91	<.001	24.206 (2, 91)	<0.001	0.5773
2	SCOFF, PSQI, creatine, sport modality	0.485	0.437	0.138	3.791	6	85	0.002	10.008 (8, 85)	<0.001	0.5305
3	Kerr-derived muscle mass	0.525	0.474	0.040	7.133	1	84	0.009	10.330 (9, 84)	<0.001	0.5124
Panel B. Model 1 coefficients											
Predictor	B	SE	95% CI for B	β	p						
Constant	6.147	0.263	5.625 to 6.669	—	<0.001						
Sex (men vs. women)	0.818	0.121	0.578 to 1.058	0.581	<0.001						
Age (years)	−0.018	0.007	−0.031 to −0.005	−0.233	0.008						
Panel C. Model 2 coefficients											
Predictor	B	SE	95% CI for B	β	p						
Constant	6.576	0.301	5.978 to 7.173	—	<0.001						
Sex (men vs. women)	0.733	0.123	0.490 to 0.977	0.521	<0.001						
Age (years)	−0.018	0.006	−0.030 to −0.006	−0.238	0.004						
SCOFF score	−0.020	0.059	−0.137 to 0.097	−0.031	0.732						
PSQI score	−0.032	0.021	−0.074 to 0.010	−0.123	0.138						
Creatine use (yes vs. no)	0.185	0.117	−0.047 to 0.417	0.131	0.117						
CrossFit/functional vs. strength	−0.057	0.146	−0.347 to 0.233	−0.036	0.696						
Aerobic vs. strength	−0.707	0.263	−1.230 to −0.184	−0.226	0.009						
Mixed vs. strength	−0.342	0.142	−0.623 to −0.060	−0.232	0.018						

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Hierarchical multiple linear regression predicting phase angle (n = 94)					
Panel D. Model 3 coefficients					
Predictor	B	SE	95% CI for B	β	p
Constant	6.125	0.336	5.457 to 6.793	—	<.001
Sex (men vs. women)	0.327	0.193	−0.057 to 0.710	0.232	0.094
Age (years)	−0.014	0.006	−0.026 to −0.002	−0.188	0.022
SCOFF score	−0.053	0.058	−0.169 to 0.063	−0.080	0.363
PSQI score	−0.020	0.021	−0.062 to 0.022	−0.077	0.341
Creatine use (yes vs. no)	0.144	0.114	−0.082 to 0.371	0.103	0.208
CrossFit/functional vs. strength	−0.114	0.142	−0.397 to 0.169	−0.072	0.426
Aerobic vs. strength	−0.660	0.254	−1.166 to −0.154	−0.211	0.011
Mixed vs. strength	−0.378	0.137	−0.651 to −0.104	−0.256	0.007
Kerr-derived muscle mass (kg)	0.030	0.011	0.008 to 0.053	0.351	0.009

Note: B: unstandardized coefficient; SE: standard error; CI: confidence interval; β: standardized coefficient; SEE: standard error of the estimate; PSQI: Pittsburgh Sleep Quality Index. Sex: 1 = women, 2 = men; creatine: 0 = no, 1 = yes. Strength training was the sport-modality reference category. The Durbin–Watson statistic for the final model = 1.843.

4. Discussion

The present study examined the independent contributions of demographic, lifestyle, training-related, and body composition variables to the PhA in recreationally active adults attending fitness centers. The final hierarchical model explained 52.5% of the variance in the PhA. Older age, aerobic and mixed training compared with strength training, and Kerr-derived muscle mass were independently associated with the PhA. In contrast, sex, sleep quality, eating-disorder risk, creatine use, and CrossFit/functional training were not independently associated with the PhA in the fully adjusted model. A sensitivity analysis excluding the small aerobic subgroup yielded materially consistent findings for age, mixed training, and Kerr-derived muscle mass.

In the hierarchical model, demographic variables alone explained 34.7% of the variance in the PhA. Sex was strongly associated with the PhA in the first two models, with men presenting higher values than women; however, this association was attenuated and was no longer statistically significant after Kerr-derived muscle mass was introduced into the final model. This attenuation suggests that a substantial proportion of the sex-related difference in the PhA may be explained by differences in muscle mass and body cell composition. This interpretation is consistent with population reference data showing higher PhA values in men, which have been attributed to differences in body cell mass, intracellular water distribution, and muscle composition [8,12,14,38]. In the fully adjusted model, the confidence interval for sex included zero and the estimate remained imprecise; therefore, this association should not be interpreted as independent of muscle mass.

Age remained independently and inversely associated with the PhA in the fully adjusted model. Each additional year of age was associated with a small reduction in the PhA, even after controlling for sex, behavioral characteristics, training modality, and Kerr-derived muscle mass. This finding is consistent with previous evidence indicating a progressive decline in the PhA across adulthood, potentially reflecting age-related changes in cellular integrity, membrane function, and intracellular-to-extracellular water distribution [12,14]. Although the sample was relatively young and physically active, the association suggests that age should remain an important consideration when interpreting the PhA in recreational exercise settings.

The addition of behavioral and training-related variables significantly improved model fit, although the interpretation of sport-modality contrasts requires caution. Compared with strength training, both aerobic and mixed training were independently associated with a lower PhA in the final model, whereas CrossFit/functional training was not. These findings may reflect differences in muscle development, cellular mass, hydration patterns, and physiological adaptations across training modalities [8–11,15]. However, the aerobic subgroup included only five participants, which substantially limits the precision of the aerobic-versus-strength estimate. Importantly, a sensitivity analysis excluding this subgroup produced coefficients of similar magnitude and direction for age, mixed training, and Kerr-derived muscle mass. Therefore, the mixed-versus-strength association appears comparatively robust, whereas the aerobic estimate should be interpreted cautiously and confirmed in larger and more balanced samples.

Sleep quality was not independently associated with the PhA in the fully adjusted model. Although the bivariate coefficient suggested a modest inverse relationship, the association was not statistically significant and was further attenuated after multivariable adjustment. Therefore, the present results do not provide sufficient evidence that the PSQI score independently contributes to PhA

variability in recreationally active adults. Sleep-related mechanisms involving anabolic signaling, inflammation, recovery, and fluid regulation remain physiologically plausible [19–22,39], but longitudinal studies using more detailed or objective sleep assessments are needed to determine whether changes in sleep influence the PhA over time.

Kerr-derived muscle mass contributed a significant incremental increase in explained variance in the final model, explaining an additional 4.0% of the variance in the PhA. Greater muscle mass was independently associated with a higher PhA and showed the largest standardized coefficient among the significant predictors in the fully adjusted model. This finding supports the well-established positive relationship between muscle quantity, body cell mass, intracellular water, and PhA in both athletic and clinical populations [38,40,41]. Nevertheless, muscle mass accounted for only part of the observed variability, indicating that the PhA should not be interpreted exclusively as a proxy for muscle quantity.

Creatine use and eating-disorder risk were not independently associated with the PhA in the multivariable model. Although the SCOFF score was negatively correlated with the PhA in the bivariate analysis, this association was attenuated after adjustment for demographic, training-related, and body composition variables. The absence of an independent association with creatine may reflect heterogeneity in supplementation dose, duration, adherence, and training practices [17,42,43]. Similarly, the SCOFF is a screening instrument rather than a clinical diagnostic measure, and the behavioral risk identified in this sample may not have been sufficiently severe to produce detectable alterations in bioelectrical parameters [26,44].

Collectively, the hierarchical modeling approach indicates that the PhA in recreationally active adults reflects the combined influence of demographic characteristics, training modality, and muscle mass. The findings do not support an independent contribution of sleep quality, eating-disorder risk, creatine use, or CrossFit/functional training after multivariable adjustment. The PhA should therefore be interpreted as a multidimensional physiological marker, but the dimensions supported by the present data are principally age, training modality, and Kerr-derived muscle mass [8,38].

From a practical perspective, the PhA assessment may provide complementary information on physiological status in fitness-center settings. Its interpretation should account for age, Kerr-derived muscle mass, and the participant's primary training modality rather than relying on a single universal reference or treating the PhA exclusively as a marker of muscle quantity. Modality-specific interpretation should remain cautious until the present findings are replicated in larger and more balanced samples.

A key strength of this study is the hierarchical modeling approach, which enabled the independent contribution of demographic, behavioral, training-related, and body composition variables to be evaluated within the same analytical framework.

Several limitations should be acknowledged. First, the cross-sectional design precludes causal inference. Although regression assumptions were evaluated and no major violations were observed, residual confounding cannot be excluded. Second, the regression analysis was based on complete cases, and excluded participants were older than those included, indicating the possibility of selection bias related primarily to age. Third, the aerobic subgroup included only five participants, limiting the precision and stability of the aerobic-versus-strength estimate, although the sensitivity analysis excluding this subgroup supported the robustness of the remaining principal findings. Fourth, behavioral characteristics and supplement use were self-reported and may have been affected by recall or classification error. The SCOFF and ORTO-11 instruments identify potential risk but do not provide clinical diagnoses [25,26]. Finally, training experience was collected using broad ordinal categories

rather than as a continuous variable, limiting the ability to examine dose–response relationships and to characterize long-term training exposure.

Future longitudinal and interventional studies are warranted to determine whether changes in training exposure, muscle mass, and other physiological or behavioral characteristics are accompanied by corresponding changes in the PhA, and to clarify the mechanisms underlying these associations.

5. Conclusions

This cross-sectional study suggests that the PhA in recreationally active adults attending fitness centers was independently associated with age, training modality, and Kerr-derived muscle mass. Older age and participation in aerobic or mixed training modalities, compared with strength training, were associated with a lower PhA, whereas greater Kerr-derived muscle mass was associated with a higher PhA. The aerobic-modality estimate should be interpreted cautiously because this subgroup included only five participants.

Sex, sleep quality, eating-disorder risk, creatine use, and CrossFit/functional training were not independently associated with the PhA in the fully adjusted model. The PhA may provide complementary information in recreational exercise and fitness-center settings when interpreted alongside age, training modality, and body composition, rather than solely as a proxy for muscle quantity.

6. The limitations of this study

Several limitations should be acknowledged. First, the cross-sectional design precludes causal inference. Although regression assumptions were evaluated and no major violations were observed, residual confounding cannot be excluded. Second, the regression analysis was based on complete cases, and excluded participants were older than those included, indicating the possibility of selection bias related primarily to age. Third, the aerobic subgroup included only five participants, limiting the precision and stability of the aerobic-versus-strength estimate, although the sensitivity analysis excluding this subgroup supported the robustness of the remaining principal findings. Fourth, behavioral characteristics and supplement use were self-reported and may have been affected by recall or classification error. The SCOFF and ORTO-11 instruments identify potential risk but do not provide clinical diagnoses [25,26]. Finally, training experience was collected using broad ordinal categories rather than as a continuous variable, limiting the ability to examine dose–response relationships and to characterize long-term training exposure.

Use of AI tools declaration

The authors used ChatGPT (OpenAI) solely to support language editing and consistency checks during manuscript revision. The authors independently verified all scientific content, statistical results, interpretations, references, and final wording; and take full responsibility for the article.

Authors' contributions

Conceptualization: D.V.-M., P.B.-P.; Methodology: D.V.-M., P.B.-P., M.T.M.-R., C.L.-A.; Formal analysis: P.B.-P., A.M.G.-M.; Investigation: D.V.-M., M.T.M.-R., C.L.-A., T.B.-L., M.B.B.-B., and

M.C.V.-C.; Data curation: D.V.-M., P.B.-P.; Writing – original draft: D.V.-M., P.B.-P.; Writing – review and editing: D.V.-M., A.M.G.-M., M.T.M.-R., and C.L.-A.; Supervision: D.V.-M., P.B.-P., M.T.M.-R., and C.L.-A. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflicts of interest.

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