Anthropometric and morphological correlations of fat accumulation in active mesomorphic phenotypes: A cross-sectional observational study

Correlações antropométricas e morfológicas do acúmulo de gordura em fenótipos mesomórficos ativos: Estudo transversal observacional

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Abstract

Background: Although military personnel typically present lower BMI than civilians, significant body fat accumulation may still occur despite high levels of physical activity. The availability of tools for genome mapping has opened new perspectives on the study of body composition and polymorphisms. It has been shown that phenotypes studied for their differences, such as mesomorphy and endomorphy, share commonalities. This study investigated the relationship between body fat accumulation and the phenotypes defined by Heath-Carter somatotyping in active military personnel, aiming to understand the mechanisms driving the increasing prevalence of overweight and obesity in this workforce.

Methods: 130 military personnel who volunteered for this cross-sectional observational study were assessed for anthropometric measurements. The correlation between anthropometric variables and physical performance was analyzed using Principal Component Analysis. Statistical tests were performed using RStudio.

Results: The most common somatotype encountered was the endomorphic mesomorph (53.8%). Two distinct groups with different physical characteristics were identified. In the endomesomorphic group, body mass, body mass index, and % body fat values were 19%, 15%, and 83% higher than in the ectomesomorphic group. The ectomesomorphic group achieved 12% better V̇O2peak results and 7% better results in the 100m swimming tests. Principal Component 1 accounted for 69% of the variance in the data, with body mass index, endomorphy, mesomorphy, and % body fat showing strong positive correlations within this component.

Conclusion: The main finding was that mesomorphy, endomorphy, and body fat percentage were strongly correlated, despite these classic phenotypes being opposites. Observing individuals with extreme somatotype components, i.e., above 5.5 units for mesomorphy, may be an indicator of fat accumulation, even in groups undergoing constant training and high physical activity demands in their occupational activities.

Keywords: Anthropometry; Military; Obesity; Principal Components Analysis.

Resumo

Introdução: Militares que se exercitam diariamente têm um índice de massa corporal menor do que o da população civil, porém podem apresentar acúmulo significativo de gordura corporal, mesmo em idades fisicamente ativas. Ferramentas de mapeamento genético têm aberto novas perspectivas para estudar a composição e os polimorfismos. Assim, tem-se demonstrado que as diferenças encontradas entre os componentes somatotípicos, mesomórficos e endomórficos apresentam pontos em comum. Este estudo investigou a relação entre a acumulação de gordura corporal e os fenótipos definidos por Heath-Carter em militares da ativa, com o propósito de compreender os mecanismos responsáveis pela prevalência de obesidade e sobrepeso neste grupo.

Métodos: Medidas antropométricas foram realizadas em 130 militares e avaliadas em um estudo transversal observacional. As correlações entre variáveis antropométricas e o desempenho físico foram analisadas por meio da Análise de Componentes Principais. Os testes estatísticos foram realizados no RStudio.

Resultados: a categoria preponderante de somatotipia foi a endomesomorfia (53,8%). Neste trabalho, classificamos dois grupos fenotípicos com características antropométricas distintas: o endomesomórfico e o ectomesomórfico, sendo que o primeiro apresentou valores absolutos 19%, 15% e 83% maiores, respectivamente, na massa corporal, no índice de massa corporal e no percentual de gordura do que os do segundo grupo. Os ectomesomórficos apresentaram um V̇O2peak 12% maior e um desempenho 7% superior no teste de natação de 100 m. O primeiro componente principal (CP1) respondeu por 69% da variância dos dados, com o índice de massa corporal, a endomorfia, a mesomorfia e a porcentagem de gordura fortemente e positivamente correlacionados a este componente.

Conclusão: O principal achado deste trabalho foi a correlação forte e positiva entre o componente mesomorfia e a endomorfia e o percentual de gordura, visto que são fenótipos classicamente opostos. Acompanhar indivíduos com componentes somatotípicos extremos, ou seja, acima de 5,5 unidades, pode ser um indicador de acumulação de gordura, mesmo em grupos com alta demanda física em suas atividades diárias.

Palavras-Chave: Análise de Componentes Principais; Antropometria; Militares; Obesidade.

1. Introduction

Overweight and obesity have developed into a worldwide pandemic, and this concerns the military forces as a health issue (Knapik et al., 2023; Moura et al., 2017). These findings indicate a potential decline in physical readiness, a significant concern that could increase the economic burden on military personnel (Reyes-Guzman et al., 2015). Moreover, these tactical groups—namely military personnel, police officers, and firefighters—experience productivity losses due to excess weight, which restricts mobility and reduces operational effectiveness in daily missions (Lehnert et al., 2013).

An epidemiological study conducted at a Brazilian Marine Corps Instruction Center to screen individuals' anthropometric and nutritional status found that the prevalence of overweight and obesity among military students was 47%. The anthropometric and health census conducted in the Brazilian general population during the same period revealed a higher prevalence of overweight and obesity among civilians: 62.5%. Although we observed a lower prevalence of excess weight among military personnel evaluated at this Training Center compared to the civilian population, key variables — including BMI (body mass index), body weight, percentage of body fat (%BF), and skinfold thickness — showed significant increases with age in the military population under study. The unexpected nature of these results for individuals with high physical demands and obligatory readiness to work, as observed by Gomes et al. (2022) in 2010/2011, was particularly intriguing.

A widespread tendency toward fat accumulation has led to increased interest in genetic polymorphisms that influence the mechanisms underlying this multifactorial condition (Hruby & Hu, 2015; Ibanez-Zamacona et al., 2019). Understanding these genetic variations can offer insights into individual predispositions to obesity, which may be reflected in body composition and morphology. The literature highlights the relationship between physical traits and genetics (Ibanez-Zamacona et al., 2019; Silventoinen et al., 2021; Silventoinen et al., 2023). Somatotype, comprising three components—endomorphy (fat content), mesomorphy (musculoskeletal development), and ectomorphy (body linearity)—provides a framework for assessing body composition (Carter & Heath, 1990). Lifestyle factors influence the Heath-Carter somatotype and do not indicate genetic determinism (Carter & Heath, 1990). However, heritability significantly shapes mesomorphy and endomorphy (Jelenkovic et al., 2010; Rebato et al., 2007; Saranga et al., 2008). It is well known that mesomorphy is associated with power production and inversely correlated with motor ability and cardiovascular endurance (Silventoinen et al., 2021). Despite growing evidence linking somatotype components to body composition, two key gaps remain. First, it is unclear whether active, mesomorph-dominant individuals who regularly engage in aerobic training remain susceptible to excess fat accumulation beyond what would be expected for their muscle mass. Second, the relationship between somatotype — particularly endomorphic and mesomorphic phenotypes — and metabolic risk has been primarily studied in sedentary or general populations, with limited data from military settings where physical demands are high. While endomorphy is traditionally associated with fat mass and adverse metabolic outcomes, mesomorphy may paradoxically confer risk when accompanied by centripetal fat patterning, even in fit individuals (Rosique et al., 1994; Ibanez-Zamacona et al., 2019). Clarifying this relationship is essential because military personnel with high mesomorphy and concurrent fat accumulation may present normal BMI yet harbor disproportionate metabolic risk.

This study examined the association between excess body weight and somatotype profiles among active military personnel. We hypothesized that phenotypes characterized by higher muscle mass are associated with a higher prevalence of excess body weight and fat deposition, including those who regularly engage in aerobic fitness training.

2. Methods

Brazilian marines with at least 4 years of experience who were participating in a specialization course or sergeant training were recruited for a cross-sectional observational study. The inclusion criteria were: (1) age between 18 and 33 years; (2) having performed initial physical tests this year, and (3) being a male Brazilian military. The exclusion criteria were: (1) engaging in any physical activity on the day of measurement; (2) being injured at the time of the measurements. Supplementary Figure 1 describes the recruitment flowchart for military personnel. Experimental protocols were approved by the Ethics Committee of Clementino Fraga Filho Hospital, Federal University of Rio de Janeiro (Protocol Number: 030/10) (Gomes et al., 2022). Informed consent was obtained from all participants.

Two experienced anthropometrists took eleven anthropometric measurements on the right side. The subjects wore minimal clothing to measure body mass (platform scale, Sanny, RJ, Brazil) to the nearest 0.01 kilogram. Stature (stadiometer Sanny, RJ, Brazil); bone breadths (small sliding caliper CESCORF, RS, Brazil); girths (flexible steel tape CESCORF, RS, Brazil) were measured to the nearest 0.1 cm. Skinfold thicknesses (skinfold caliper CESCORF, RS, Brazil) were measured to the nearest 0.1 mm. Bias and errors were minimized in anthropometric measurements, as stated: 1) measurements were performed in triplicate, non-consecutively, and the final result was obtained by calculating the mean; 2) the equipment was calibrated at the beginning of each data collection session; 3) only scientific-grade calipers were used; and 4) anthropometric measurements were conducted prior to the daily training session. Somatotype components were evaluated by calculating the endomorphy, mesomorphy, and ectomorphy indices. For the assessment of somatotype, anthropometric measurements were taken, including skinfold thickness (SF) at the triceps, subscapular, supraspinale, and medial calf; biepicondylar diameters of the humerus and femur; circumferences of the biceps and medial calf; and body weight and height (Carter & Heath, 1990). Somatotype was determined according to the Heath-Carter method. The endomorphy component was calculated using $\mathbf{Endo = 0.1451(Xc) - 0.00068(Xc)^2 + 0.0000014(Xc)^3 - 0.7182}$, where $\mathbf{Xc = \sum dc \times (170.18 / height)}$ is the sum of corrected skinfold thicknesses adjusted for height, with $\sum dc$ representing the sum of the triceps, subscapular, and suprailiac skinfold thicknesses (in mm), and height measured in centimeters (cm) (Carter & Heath, 1990, Equations 1 and 2).

The mesomorphy component was calculated using $\mathbf{Meso = 4.50 + (U) + 0.601(F) + 0.188(adjustedPBT) + 0.161(adjustedPPM) - 0.131(height)}$, where U is the biepicondylar diameter of the humerus (cm), F is the biepicondylar diameter of the femur (cm), adjustedPBT is the adjusted circumference of the flexed and tensed arm (cm), adjustedPPM is the adjusted circumference of the medial calf (cm), and height is expressed in cm (Carter & Heath, 1990, Equation 3).

The ectomorphy component was calculated using the ponderal index: **IP = height / $\sqrt[3]{}$(body weight)**. Depending on the IP value: if IP ≥ 40.75, then **Ecto = (IP × 0.732) − 28.58**; if 38.25 < IP < 40.75, then **Ecto = (IP × 0.463) − 17.63**; or if IP ≤ 38.25, then **Ecto = 0.1** (Carter & Heath, 1990, Equations 4, 5a, 5b, and 5c).

The Cartesian coordinates for the somatoplot were calculated as **x = (ectomorphy − endomorphy)** and **y = [(mesomorphy × 2) − (endomorphy + ectomorphy)]** (Carter & Heath, 1990, Equations 6a and 6b).

Somatotype components are classified as low (<2.5 units), average (3–5 units), high (5.5–7 units), and very high (>7.5 units); values exceeding 5 units are regarded as extreme (Carter & Heath, 1990). Individual somatotypes were presented on a somatochart and related to somatotype categories in Supplementary Figure 2 (Carter & Heath, 1990). Body density was calculated as the sum of chest, triceps, and subscapular skinfold thicknesses (Jackson & Pollock, 1985), and %BF was calculated using Siri's equation (Siri, 1961).

Nutritional status was assigned according to body weight/height^2 (BMI), classified as underweight (<18.5 kg/m2), normal range (18.5–24.9 kg/m2), overweight (25.0–29.9 kg/m^2), obese class 1 (30.0–34.9 kg/m^2), obese class 2 (35.0–39.9 kg/m^2), obese class 3 (>40.0 kg/m^2) (Madden & Smith, 2016). Chances of occurrence of overweight/obesity and %BF were analyzed against the values of extreme and non-extreme somatotypes for mesomorphy (exposure status). Thus, groups with extreme somatotypes between 5.0 to 5.49 units, high or very high extreme somatotypes above 5.5 units, and somatotypes below 5.0 units (non-extreme) were compared against the outcome conditions of individuals with BMI ≥ 25.0 (overweight/obesity) and BMI 18.5–24.9 (normal), as well as outcomes for body fat indices ≥ 18.0% and < 18.0 %. The correlation between body type, %BF, BMI, and $\dot{V}O_{2peak}$ was evaluated using Principal Components Analysis (PCA) to reduce anthropometric and performance data to a minimum number of orthogonal variables (Savegnago et al., 2011). The Kaiser criterion selected the principal components (PC) that account for a significant data variance. This method included values with eigenvalues greater than 1 (Fraga et al., 2016).

RStudio v2024.04.01 (Positiv Software, PBC). Intraclass correlations for anthropometric measurements ranged from 0.89 (medial calf) to 1.0 (body weight). The Shapiro-Wilk test assessed normality of the data distribution. Kruskal-Wallis tests were used to compare differences among sample groups. PCA was performed using R FactoMinerR for multivariate analysis (Lê et al., 2008). Descriptive analyses of anthropometric and aerobic performance data are presented as the median with interquartile range [IQR] [25th percentile – 75th percentile]. Odds ratios (ORs) are reported with 95% confidence intervals (CIs). Statistical significance was set at $p<0.05$. This research was conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (von Elm et al., 2007).

3. Results

This study was conducted on a sample of 130 military personnel with at least 4 years of experience in the Brazilian Marine Corps (age: 25.0 [24.0, 30.0] years; BMI: 24.8 [22.5, 27.1] kg/m^2; %BF: 11.5 [8.5, 16.1]; $\dot{V}$O2peak: 53.1 [49.6, 56.8] ml/kg*min; median [IQRs]) at a Marine Corps Training Center (Table 1). Somatotype components indicated mesomorphy (5.4 [4.6, 6.3], median [IQRs]) as the dominant component, with endomorphy (3.6 [2.6, 4.5], median [IQRs]) as the second-largest component (Table 1).

Table 1: Descriptive characteristics of the study sample (N = 130)*.

Variable	Min	Values	Max
Age (years)	21.0	**25.0** [24.0-30.0]	33.0
Weight (kg)	58.0	**77.4** [68.4-88.5]	120.0
Height (cm)	1.62	**1.76** [171.0-182.0]	1.93
BMI (kg/m^2)	19.8	**24.8** [22.5-27.1]	38.1
%BF	2.8	**11.5** [8.5-16.1]	29.8
$\dot{V}O_{2peak}$ (ml/kg*min)	35.2	**53.1** [49.6-56.8]	64.1
Endomorphy	1.6	**3.6** [2.6-4.5]	9.3
Mesomorphy	2.9	**5.4** [4.6-6.3]	11.2
Ectomorphy	0.1	**1.9** [1.1-2.6]	4.2

* Non-normal data shown as median [Q1 – Q3]. BMI: body mass index;
%BF: percentage of body fat; $\dot{V}O_2$peak: peak oxygen consumption.

The sample consisted of 44 non-extreme individuals (somatotype units < 5.0); 62 individuals were extreme mesomorphs only; 3 individuals were extreme endomorphs only; and 16 individuals were both extreme mesomorphs and endomorphs (Table 2). The somatopoint distribution on the somatochart (Supplementary Figure 2) indicates a predominance of endomorphy and mesomorphy in the upper-left region. Of the 36 somatopoints outside the triangle's limits, 11 were classified as extreme mesomorphs with 18.0–20.9% body fat, while 10 exhibited over 21.0% body fat and extreme mesomorphic and endomorphic traits (Supplementary Figure 2). The group of military personnel with mesomorphy ranging from 5.0 to 5.49 units had an OR (CI) of 1.61 (0.46–5.47; p=0.53), while the group with mesomorphy ≥ 5.5 exhibited an OR (CI) of 25.45 (9.45–77.83; p<0.0001), both compared to individuals with BMI ≥ 25.0. The OR (CI) for the association of military personnel with body fat ≥ 18.0% was calculated as 0.69 (0.02–6.36; p=0.76) for the group with mesomorphy from 5.0 to 5.49 units, and for the group with mesomorphy ≥ 5.5, an OR (CI) of 7.66 (2.37-35.83; p<0.0001) was calculated.

Table 2 presents the distribution of eight somatotype categories. Endomorphic mesomorphs were the largest group (53.8%). To assess the concentration of extreme morphotypes, we defined extreme mesomorphy and extreme endomorphy as ≥5.0 units (Andreenko & Mladenova, 2015). Among individuals meeting either criterion, 79% fell into three categories: endomorphic mesomorph, mesomorphic endomorph, and mesomorph-endomorph (Table 2). In these three categories, the dominant component alternates between endomorphy and mesomorphy. The remaining categories show alternating dominance of mesomorphy and ectomorphy (ectomorphic mesomorph, mesomorph-ectomorph, mesomorphic ectomorph, balanced mesomorph, and central) (Table 2). In this analysis, two distinct groups emerged: the first group had higher body mass and greater fat accumulation (Table 3), and the second group was lean and exhibited better aerobic output (Table 3). The predominance of endomorphy and mesomorphy clusters in endomesomorphism (endomorphic mesomorph, mesomorphic endomorph, and mesomorph-endomorph) (Tables 2 and 3), in opposition to ectomesomorphism (ectomorphic mesomorph, mesomorphic ectomorph, mesomorph-ectomorph, balanced mesomorph, and central) (Tables 2 and 3), which indicates mesomorphy and ectomorphy (Table 3). Body weight and BMI were 19% and 15% higher, respectively, than in the ectomesomorphic group (both with p<0.001, n = 130) (Table 3). BF% (83%, p<0.001, n = 130) and skinfold thickness of the chest, triceps, subscapular, suprailiac, and medial calf followed an increasing pattern for the endomesomorphic group, with increases of 103%, 67%, 66%, 90%, and 161%, respectively, all with p<0.001, n = 130 (Table 3). Ectomesomorphism outperformed endomesomorphism in physical tests, with $\dot{V}O2$peak 12% higher (p < 0.0001, n = 130) and 100m freestyle times 7% faster (p < 0.05, n = 130).

Table 2: Distribution of somatotype categories by BMI and extreme component classification (N = 130).

			normal	overweight	obese 1	obese 2	mesomorphy*				Endomorphy*#		
			BMI:18.50-24.9kg/m²	BMI:25.0-29.9 kg/m²	BMI:30.0-34.9 kg/m²	BMI:35.0-40.0 kg/m²	**non-extreme**	extreme	high extreme	very high extreme	extreme	high extreme	very high extreme
somatotype	**N**	**%**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
endomorphic mesomorph	**70**	**53.8**	**23**	**41**	**5**	**1**	**12**	**14**	**35**	**9**	**8**	**3**	**1**
mesomorphic endomorph	**8**	**6.9**	**1**	**4**	**3**	**---**	**1**	**1**	**1**	**3**	**---**	**4**	**3**
mesomorph-endomorph	**10**	**7.7**	**4**	**5**	**1**	**---**	**5**	**3**	**---**	**1**	**4**	**---**	**1**
ectomorphic mesomorph	**11**	**8.5**	**10**	**1**	**---**	**---**	**8**	**2**	**1**	**---**	**---**	**---**	**---**
mesomorphic ectomorph	**1**	**0.8**	**1**	**---**	**---**	**---**	**1**	**---**	**---**	**---**	**---**	**---**	**---**
mesomorph-ectomorph	**4**	**3.0**	**4**	**---**	**---**	**---**	**4**	**---**	**---**	**---**	**---**	**---**	**---**
balanced mesomorph	**25**	**19.2**	**22**	**3**	**---**	**---**	**12**	**7**	**6**	**---**	**---**	**---**	**---**
central	**1**	**0.8**	**1**	**---**	**---**	**---**	**1**	**---**	**---**	**---**	**---**	**---**	**---**

Mesomorphy and encomorphy cut-off values: non-extreme (<5.0); extreme (5.0–5.49); high-extreme (5.5–7.49); very high-extreme (≥7.5).* Sixteen individuals presented extreme values for both mesomorphy and endomorphy. # Three individuals were only extreme endomorphs.

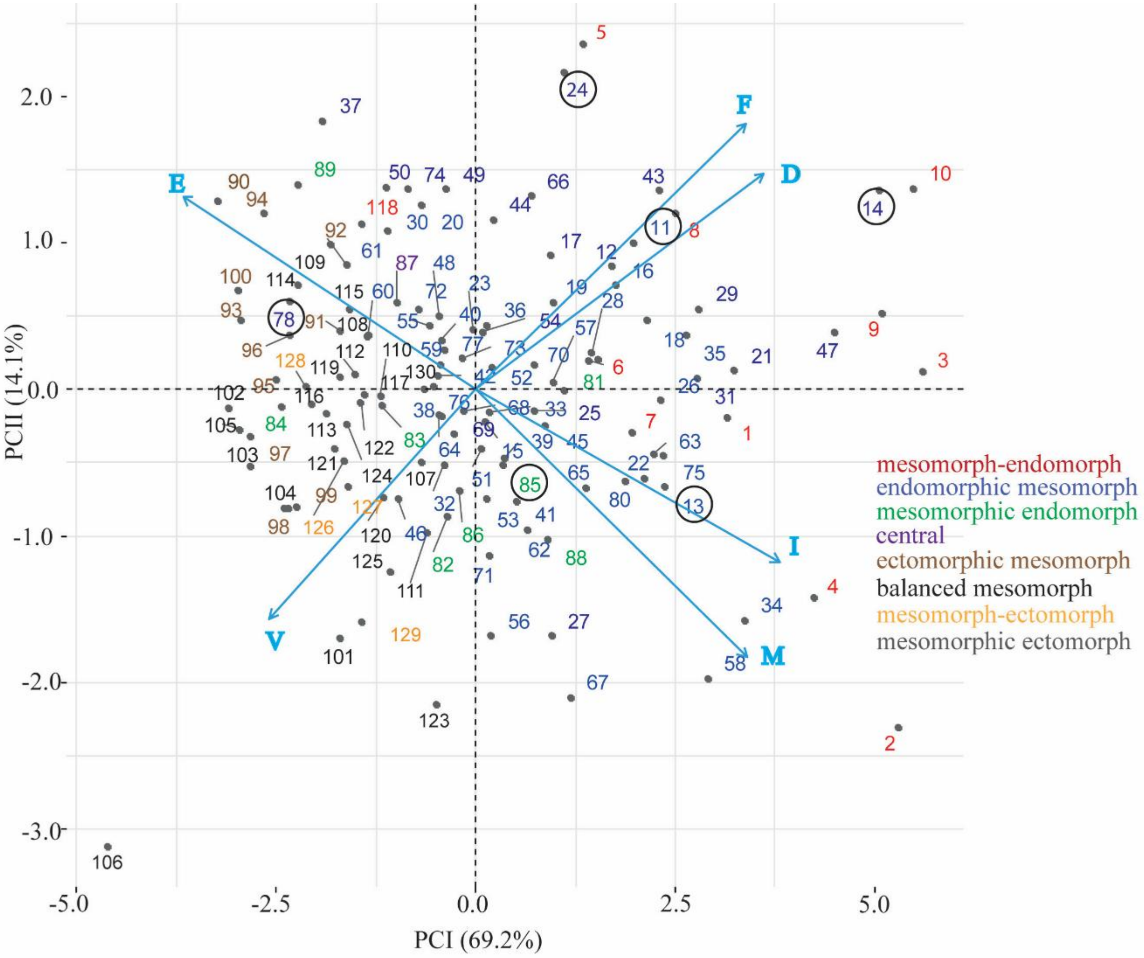
Table 3: Comparison of anthropometric, body composition, and aerobic performance between endomesomorphic (n = 86) and ectomesomorphic (n = 44) groups.

Description	endomesomorphism	ectomesomorphism	p-value
	n= 86	n= 44	
age (years)	25.0 [24.0 – 30.0]	24.0 [23.0 – 25.0]	$p<0.05$
height (m)	1.77 [1.71 – 1.82]	1.76 [1.72 – 1.81]	NS
weight (kg)	82.1 [73.4 – 91.5]	68.8 [65.9 – 75.0]	$p<0.001$
BMI (kg/m^2)	25.8 [24.4 – 27.9]	22.4 [21.4 – 23.3]	$p<0.001$
%BF	14.1 [11.1 – 18.1]	7.7 [5.92 – 8.9]	$p<0.001$
chest SF (mm)	6.5 [3.8 – 13.0]	3.2 [2.65 – 4.15]	$p<0.001$
triceps SF (mm)	12.2 [9.8 – 15.3]	7.4 [5.12 – 8.6]	$p<0.001$
subscapular SF (mm)	16.1 [13.5 – 19.8]	9.7 [8.3 – 11.3]	$p<0.001$
suprailiac SF (mm)	14.1 [11.6 – 17.6]	7.4 [6.2 – 8.5]	$p<0.001$
calf SF (mm)	5.5 [2.2 – 11.0]	2.1 [1.4 – 5.5]	$p<0.001$
BD humerus (cm)	7.1 [6.7 – 7.3]	7.0 [6.6 – 7.2]	NS
BD femur (cm)	10.0 [9.5 – 10.7]	9.6 [9.2 – 10.0]	$p<0.001$
arm girth (cm)	35.0 [32.7 – 37.0]	32.4 [30.7 – 35.2]	$p<0.001$
calf girth (cm)	39.0 [36.5 – 41.0]	35.8 [34.9 – 37.8]	$p<0.001$
VO_{2peak} (ml*kg*min)	51.6 [46.9 – 54.7]	57.9 [54.0 – 61.7]	$p<0.001$
swim test (min)	1.80 [1.63 – 2.01]	1.68 [1.48 – 1.88]	$p<0.05$

SF: skinfold thickness; BD: biepicondylar breadth; NS: not significant ($p > 0.05$). Non-normally distributed data are presented as median [Q1 – Q3]. Swim test time is expressed in minutes and hundredths of a minute (e.g., 1.80 min = 1 min and 48 s).

Principal component analysis (PCA) was used to understand the correlation between anthropometric parameters. PC1 accounted for 69% of the data variance, with $\lambda = 4.14$, and showed strong positive correlations with BMI, endomorphy, mesomorphy, and %BF, as indicated by vector lengths in the biplot (Supplementary table 2, figure 1). Figure 1 presents a biplot in which the vector lengths indicate their correlations with PC1. Vectors with acute angles indicate variables that are correlated with each other, as observed in the following pairs: mesomorphy and endomorphy; fat percentage and BMI; fat percentage and mesomorphy; fat percentage and mesomorphy; and ectomorphy and $\dot{V}O_{2peak}$. The vector orientations indicate that %BF, BMI, endomorphy, and mesomorphy are positively correlated with PC1 (Figure 1; Supplementary Table 2). Variables in opposite quadrants are inversely correlated with PC1, such as ectomorphy and $\dot{V}O_{2peak,}$ whereas the other variables are not (Figure 1, Supplementary Table 2). The proximity of the numbers on the biplot indicates individuals with similar characteristics, and their proximity to a vector reflects their relationship with the respective variable, as shown in Supplementary Table 1.

Figure 1: Mesomorphy and endomorphy are positively correlated with PC1.



Biplot illustrating the variables D (endomorphy), E (ectomorphy), M (mesomorphy), F (%BF), I (BMI), and V ($\dot{V}O_{2peak}$). Long vectors indicate high correlations with PC1. Acute angles represent strong correlations between variables, while obtuse angles indicate weak correlations.

4. Discussion

The classification of somatotype components is determined using different equations. Endomorphy assesses subcutaneous fat by summing skinfold measurements at the triceps, subscapular, and suprailiac sites; mesomorphy assesses muscular robustness using bone diameters and circumferences; and ectomorphy evaluates the height-to-weight ratio (Carter & Heath, 1990). Although these indices are derived differently, endomorphy and mesomorphy can correlate in individuals with centripetal fat accumulation (Rosique et al., 1994). This finding suggests that the muscular strength component was positively correlated with endomorphy and increased %BF (Figure 1, Supplementary Table 2). These results are consistent with the hypothesis that phenotypes characterized by greater muscle mass may contribute to an increased prevalence of excess body weight and fat deposition, even among individuals routinely engaged in aerobic fitness training.

In the present data, as in Andreenko and Mladenova (2015) and Simenko (2018), the dominant somatotype category was endomorphic mesomorph (Table 2). The prevalence of mesomorphy (81.5% of the sample, including endomorphic, balanced, and ectomorphic mesomorphs) aligns with observations in special military forces. Figure 1 shows that endomorphic mesomorphs are dispersed throughout the biplot, with their characteristics reflected in different vectors, as exemplified by individuals 11 (high %BF and BMI, and low $\dot{V}O_{2peak}$) and 78 (low %BF and BMI, and high $\dot{V}O_{2peak}$) (Supplementary table 1). Mesomorphy was associated with a profile capable of performing tasks requiring strength and muscular endurance, physical attributes essential for completing basic military tasks such as carrying loads, transporting injured personnel, and handling equipment

(Araujo et al., 2019; Moura et al., 2017). Consistent with Araujo et al. (2019), who evaluated special operations military personnel and found a positive correlation between mesomorphy and explosive strength, maximal strength, and muscular endurance in both upper and lower limbs.

Eight somatotype categories (Carter & Heath, 1990) were observed and distributed into two groups, characterized by either muscle mass and body fat accumulation or dominant traits of body linearity and muscle mass (Table 2). Both groups exhibited excellent aerobic power (Kaminsky et al., 2022) as indicated by $\dot{V}O_{2peak}$ values (51.6 ± 9.1 and 57.9 ± 10.4 ml*kg*min) and short times in the 100 m swimming test (1.80 ± 0.40 and 1.67 ± 0.43 min, respectively) (Table 3), corresponding to endomesomorphism and ectomesomorphism. Despite comparable cardiorespiratory fitness, the endomesomorphic group tended toward fat accumulation (Tables 2 and 3), as represented in Supplementary Table 1 by individuals 13, 14, 24, and 85, who exhibited higher fat-accumulation parameters and lower oxygen consumption rates. Rosique et al. (1994) and Rebato et al. (2007) previously noted that individuals with centralized fat distribution showed strong correlations with mesomorphy and inverse correlations with ectomorphy. They suggested that endomorphy and mesomorphy are more sensitive to variations in body composition, with mesomorphy associated with a greater tendency toward fat accumulation.

Andreenko and Mladenova (2015) stated that extreme morphotypes (≥5.0) exhibit strong characteristics of one of the somatotype components and are rare in the population. In this cohort, despite a normal median BMI (24.8 ± 3.3 kg/m²) (Table 1), 45% of the sample showed endomorphy, mesomorphy, or both morphotypes, ranging from high to very high levels (5.50 to 11.24 units) (Supplementary figure 2 and examples in Supplementary table 1). Notably, individuals with mesomorphy ≥ 5.5 had 25.4 times higher odds of being classified as overweight or obese (ORs: (CI, 9.45–77.83; p<0.0001). Gomes et al. (2022) reported that BMI and %BF significantly increased with age among 1,144 military cadets from this Training Center between 2010 and 2011. However, in the current study, no significant differences were observed between age groups among the 130 cadets evaluated in the 2011 class. Nonetheless, 23 individuals aged 22 to 33 had body fat over 18% and exhibited extreme somatotypes (Supplementary Figure 2 and examples in Supplementary Table 1). It is worth noting that body fat values above 18% exceed the anthropometric standards established by the U.S. Marine Corps (Potter et al., 2022). Among the evaluated individuals, a %BF higher than 18% occurred 7.6 times more frequently in extreme mesomorphs above 5.5 units (ORs: CI, 2.37-35.83; p<0.0001).

Heritability accounts for 80% to 93% of somatotype variation in young individuals, and the Heath-Carter somatotype method considers each somatotype component the product of an interaction between genetic predisposition and environmental factors (Silventoinen et al., 2021). In principle, dietary habits and physical training can modulate the phenotype within the limits of the genotype (Guedes & Guedes, 2006; Saranga et al., 2008). This may be associated with higher aerobic performance in specific groups within a population, such as ectomorphic mesomorphs in Supplementary Table 1, who exhibit higher aerobic power. Bolonchuk et al. (2000) and Araujo et al. (2019) previously showed that individuals with lower endomorphic components demonstrate improved performance in response to aerobic power training. Another example of genetics' role in somatotyping is variation in obesity susceptibility, ranging from 40% to 70% (Loos & Yeo, 2014). In the military population from this Training Center, studied between 2010 and 2011, a prevalence of 40% for overweight and 7% for obesity was observed (Gomes et al., 2022).

Ibanez et al. (2019) reported that the FTO rs9939609 gene polymorphism was negatively associated with ectomorphy and positively associated with mesomorphy and severe obesity. Here, the ectomesomorphic group displayed distinct characteristics of ectomorphy and mesomorphy, with higher $\dot{V}O_{2peak}$ and ectomorphy than other groups, despite all individuals being subjected to the same diet and training routine. The literature supports the relationship between lifestyle and obesity risk factors (Andreenko & Mladenova, 2015; Loos & Yeo, 2014). In the evaluated group, somatotype categories (Table 2) within the same phenotypic spectrum, related to endomesomorphism (Table 3), were located near diagonally opposing vectors in the biplot, indicating inversely correlated variables (Figure 1, Supplementary Table 1 examples 11 and 78). Consistent with this pattern, the data suggested two subpopulations of endomorphic mesomorph, mesomorphic endomorph, and mesomorph endomorph were suggested by the data: one prone to fat accumulation and obesity and another with normal nutritional status (Figure 1). While the environmental role is undeniable, the literature underscores the significance of the genotype factor (Andreenko & Mladenova, 2015; Loos & Yeo, 2014). Various genes have been linked to obesity (Lu & Loos, 2013), including the TT allele of the FTO gene, which is associated with increased post-exercise appetite, and the AT allele, which is linked to lower fat oxidation rates during physical activity (Ponce-Gonzalez et al., 2023). Some limitations were observed here. First, the dietary intake was not recorded. Finally, their daily energy expenditure was not assessed. This information would explain how the subjects in endomesomorphic and ectomesomorphic clusters balance their energy expenditure and food intake. From a research perspective, it is crucial to map genetic polymorphisms to somatotype profiles, particularly extreme mesomorphy and the endomesomorphic cluster associated with fat accumulation. Individuals in this group face high energy demands yet are prone to being overweight and obese. Future studies should examine how specific genotypes (e.g., FTO rs9939609) affect body composition, appetite regulation, and substrate oxidation during exercise. This understanding may help clarify whether certain somatotypes are associated with fat gain despite regular cardiovascular activity and could inform future interventions.

5. Conclusion

This work highlights the association between mesomorphy and endomorphy, particularly regarding fat accumulation. Among these individuals, 59 morphotypes were classified as exhibiting extreme mesomorphy (>5.5), whereas only eight fell into the ectomesomorphic category. These findings reinforce the potential of somatotype analysis to indicate overweight and obesity, providing valuable insights for tailoring diet and exercise interventions. Additionally, the integration of anthropometric variable analysis and performance assessment using principal component analysis (PCA), with graphical representation through vectors and individuals, proved to be an effective method for characterizing somatotypes in large populations, particularly in identifying mesomorphic phenotypes prone to fat accumulation despite regular physical activity. In practical terms, somatotype assessment should be incorporated into periodic military health screenings to detect extreme mesomorphs (≥5.5) at risk of excess fat deposition. For these individuals, targeted nutritional counseling—focusing on energy balance and fat oxidation—alongside monitored concurrent training, may help prevent obesity while preserving operational fitness.

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Declaração Ética

Revisão por Pares: Dupla-cega.

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