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Original Article

Unsupervised machine learning analysis of the anthropometric characteristics and maturity status of young Colombian athletes

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Abstract
Introduction: The study of anthropometry-based indicators of morphology and maturity status might contribute to the talent identification, sports specialization and early categorization of young athletes. The Urabá subregion is considered one of the geographical locations with the highest sport potential in Colombia; however, no study has evaluated young combat athletes. **Objective:** The aim of this study was to characterize for the first time morphology, body composition, and biological maturation status of pre-adolescent Olympic wrestling athletes from Urabá subregion (Antioquia, Colombia). **Materials and methods:** A STROBE-based cross-sectional study was carried out in forty-nine young Olympic wrestlers (20F: 29M; 13.3 ± 1.2 years; 154.0 ± 11.7 cm; 45.8 ± 10.8 kg; 19.0 ± 2.9 kg·m^{-2}) with previous experience in sports events and competing in the Urabá regional games. Anthropometry-based variables of morphology, body composition (five- and two-compartment models), and maturity status were analyzed. An unsupervised machine learning algorithm was used to identify similar data groups (clusters) and extract profile patterns. **Results:** Several morphological, body composition and maturity status differences were found between girls and boys ($p < 0.05$). We identified two significantly different phenotypes representing lighter, shorter, leaner, more biomechanically efficient, and in late maturing (Cluster 1) versus taller, heavier, more robust, less biomechanically efficient, and average matured (Cluster 2) young athletes. The matching analysis of the clusters revealed that maturity explained most of the variance in the data. **Conclusions:** Two clustering-based phenotypes were obtained to provide relevant information that might assist nutrition and exercise professionals when designing interventions. More research is needed to evaluate potential associations with physical performance and/or sport success.
Keywords: Anthropometry; **Body Composition; Somatotypes; Biological maturation; Youth sports; Sports medicine; Cluster Analysis.**

Introduction

Kinanthropometry (*kine*- movement, *anthropos*- men, *metron*- measure) is a discipline that allows the systematical evaluation of different aspects related to physical activity and health through the measurement of skinfolds, girths, breadths and lengths of the human body (Bonilla et al., 2021). Considering its advantages as a low-cost and field-applicable tool with moderate-high reliability, kinanthropometry is accepted by different international organizations to assess nutritional status, body composition and morphology in the sports population (i.e., International Olympic Committee, American College of Sports Medicine, National Strength and Conditioning Association) (Larson-Meyer, Woolf, & Burke, 2018). Hence, it is important to maintain the technical error of measurement within the range established by the International Society for the Advancement of Kinanthropometry (ISAK) (Esparza-Ros, Vaquero-Cristóbal, & Marfell-Jones, 2019).

Given that kinanthropometry provides a quantitative interface between the structure and function of the human body throughout life, its application also makes possible to estimate the biological maturation status of children and pre-adolescents (Patel, Nevill, Cloak, Smith, & Wyon, 2019; Sherar, Mirwald, Baxter-Jones, & Thomis, 2005; Söğüt et al., 2019). Structure refers to the measurable dimensions of the human body, such as stature, leg and arm lengths, width, girth and skinfold thickness. Therefore, the specific functions required for the different sports (e.g., categories by body mass) are expected to be associated with specific morphological advantages (i.e., stature, upper body length) or adaptations of body composition (i.e., higher musculoskeletal tissue, lower adiposity). This information becomes valuable for expert selectors and coaches in order to compare the status of their athletes with those from other regions or those entered in a given competition (with respect to morphological potential and performance results). On the other hand, maturation is a process that occurs in all tissues, organs and systems of the human body in a time- and biological-dependent manner (Bonilla et al., 2020).

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Understanding the maturity status and how it affects children and youth performance is highly valuable for exercise and sports professionals given that it plays an important role in neuromuscular development, physical conditioning and injury-risk (Beunen & Malina, 2007; Faigenbaum et al., 2009). Several methodologies are available to assess biological maturation; however, the search for simple, practical and non-invasive methodologies has always been a constant over the years (Malina, Rogol, Cumming, Coelho e Silva, & Figueiredo, 2015). The most commonly used indicators are secondary sexual characteristics, skeletal age and peak height velocity (PHV), considering that bone development is the most useful indicator of maturity (Rai, Saha, Yadav, Tripathi, & Grover, 2014). Interestingly, simple anthropometric measurements have been used to estimate PHV of children and adolescents (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002).

The Urabá sub-region (Antioquia, Colombia) is considered one of the geographical locations with the highest sport potential, as it contributes not only to the Antioquia delegation but also to the Colombian federations. This sub-region has been highly recognized by the "Talents Colombia" program within the framework of the "Land of Athletes" project of the Ministry of Sport, which seeks to promote the identification of young talents and sports specialization. In fact, Urabá accounts for approximately 60% of the medals in national championships and 20% of the medals in athletics, weightlifting and boxing in the Olympic Games (IOC, 2016) and Pan-American Games (Panam Sports, 2019), respectively. Although studies have been carried out in Colombia to characterize the anthropometric profile of young athletes in the Neiva wrestling league (Montealegre-Suárez & Vidarte-Claros, 2017) and U-17 soccer players from Envigado (Antioquia) (Muñoz, 2021), few projects have been developed with the necessary scientific rigor to evaluate young athletes from Urabá (Bonilla et al., 2020). Given we have demonstrated that unsupervised machine learning algorithms might strengthen the cross-sectional data analysis when the aim is to characterize populations (Cardozo et al., 2021), the aim of this study was to characterize for the first time morphology, body composition, and biological maturation status of pre-adolescent Olympic wrestling athletes from Urabá sub-region under the artificial intelligence paradigm.

Methods

Study design

This was a cross-sectional study based on the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (Cuschieri, 2019). Study outcomes were measured following laboratory procedures reported in previous articles published by our research group (Bonilla et al., 2020). Non-probability sampling (convenience sampling) was implemented. After the call to participate in this study, only young athletes that fulfill all inclusion criteria were suitable for eligibility.

Setting

This study was conducted with the support of the Servicio Nacional de Aprendizaje – SENA (Apartadó, Colombia). The research activities were approved within the framework '*applied research projects in physical activity and sport training sciences*' of the SENNOVA Line 23: Technological Updating and Modernization Program of the Training Centres (valid until 2019), with a SIGPS verification code of submission: 981411626632015FD4F61A93C1F4A67C (confirmation number: 20155). All procedures were performed in accordance to the ethical guidelines of the Declaration of Helsinki. All the measurements were performed at the Combat Coliseum in Carepa, a municipality of the Urabá subregion (Antioquia, Colombia). Four folding screens were installed in the central training area for convenience (good lighting and ventilation). Moreover, two additional fans were available to mitigate the heat and avoid errors in the measurements (<22°C, <60% humidity). Anthropometric assessments were conducted between 9:00 and 13:00 hours (GMT-5).

Participants

Sixty young Olympic wrestlers (ranged from 8 to 14 years old) with previous experience in youth sports events (>1 competition) and registered to compete in the Urabá regional games were suitable for eligibility in this study (12.7 ± 1.4 years; 150.8 ± 18.3 cm; 46.5 ± 10.6 kg; 22.4 ± 4.9 $kg \cdot m^{-2}$). Athletes were born and resided in a municipality of the Urabá subregion (Carepa, Chigorodó, Necoclí, Apartadó, and Turbo) or two close municipalities in Antioquia (Itagüí and Sabaneta). Coaches and parents were asked to sign an informed consent to approve participation of the young athletes. In the consent, detailed information was given about the aim of the study, the measurements to be made, the conditions (comfortable clothing and features of the anthropometric assessment), and the approximate duration of the evaluation. Once the signed consents were checked, all participants were verbally confirmed to participate in this study.

Variables

The following anthropometric variables were measured: body mass (kg), stature (cm), sitting height (cm), wingspan (cm), skinfolds (mm), girths (cm) and breadths (cm). We derived several morphological indices and estimated body composition (five- and two-compartment models), maturity status and adult height prediction.

Anthropometry

All anthropometric measurements were carried out in accordance with the international standards for anthropometric assessment published by the ISAK (Esparza-Ros et al., 2019). The body mass was measured with a digital scale to the nearest 100-gram (Tanita BC-543, Amsterdam, Netherlands). A portable stadiometer with a 1-millimeter graduation was used to measure stature and wingspan (Seca 700, Medical Scales and Measuring Systems, Hamburg, Germany). A 50-cm high wooden anthropometric box was used to measure the sitting height. The skinfold thicknesses (triceps, subscapular, supraspinale, abdominal, front thigh and medial calf) were measured with a calibrated skinfold caliper (Gaucho Pro, Rosscraft SRL, Buenos Aires, Argentina). Girths (head, arm [relaxed], arm [flexed and tensed], forearm, thorax, chest [mesosternale], waist [minimum], gluteal [hips], thigh [1 cm gluteal], middle thigh and calf [maximum]) were measured with a non-extensible metal tape of 0.7 mm thickness (Rosscraft SRL, Buenos Aires, Argentina). The measurement of breadths was performed with a Campbell 10 (18 cm) small sliding calliper and a Campbell 20 (54 cm) wide sliding calliper with anterior-posterior branches (Rosscraft SRL, Buenos Aires, Argentina). Hand length and distal styloids were evaluated with a segmometer SEG4 (Rosscraft SRL, Buenos Aires, Argentina) according to the method established by Visnapuu and Jürimäe (Visnapuu & Jürimäe, 2007). For data analysis, averages of two measurements of each anthropometric variable were calculated and processed. To reduce the technical error of measurement, skinfold measurements were taken in triplicate if the difference between the first and second measurement was greater than 1.0 mm. The intra-observer technical error of measurement of the anthropometrists and research assistants was less than 7.5% for skinfolds and 1.5% for the other measurements, which is considered acceptable by the ISAK recommendations (Norton & Eston, 2018).

Morphology analysis

We reported the raw data obtained for each anthropometric variable (girths, breadths and skinfolds) and calculated the skinfold-corrected muscle girths according to the expression: girth - (π x skinfold) (Martin, Spenst, Drinkwater, & Clarys, 1990). Furthermore, we derived several anthropometric indices: i) cormic index, which provides an estimation of relative trunk length, calculated as sitting height/stature (Catikkas, Kurt, & Atalag, 2013); ii) the muscle-to-bone ratio, as the relationship between muscle mass and bone mass, both in kilograms (Holway & Garavaglia, 2009); iii) the adipose-to-muscle tissue ratio, as the ratio of adipose tissue to muscle mass, both in kilograms (Alastrue Vidal et al., 1988); iv) locomotive index, which describes a relationship between the load and musculoskeletal tissues to analyze the efficiency of the locomotor system, calculated as the ratio of the sum of adipose and residual tissues to the sum of muscle and bone mass (Galván-Fernández, Beas-Jara, & Urrutia-Zamudio, 2017). Finally, we calculated the somatotype according to Heath and Carter (1967) to identify the endomorphy (relative fatness), mesomorphy (musculoskeletal component), and ectomorphy (linearity) of the young Olympic wrestlers.

Body composition analysis

We estimated body composition using five- (Kerr, 1988) and two-compartment (Slaughter et al., 1988) models. These have been used in young Colombian populations due to the lack of a specific equation (Palma et al., 2021; Rodríguez-Arrieta, Montenegro-Arjona, & Petro, 2017). For convention, "%FM Slaughter_1" and "%FM Slaughter_2" represent the equations that used skinfolds of triceps + subscapular and triceps + calf, respectively, as input. We also reported the sum of six skinfolds (∑S6) as an absolute variable (expressed in millimeters) that no only gives information about local distribution of subcutaneous fat tissue but also indicates whole-body adiposity since it correlates with whole-body fat mass (Ballard, Dewanti, Sayuti, & Umar, 2014; Bonilla et al., 2021).

Maturity status

Biological maturation was estimated according to the practical recommendations reported by Sherar et al. (2005), which are based on the valid, non-invasive and simple method developed by Mirwald et al. (2002). In brief, this method estimates maturity offset (error of 1 year 95% of the time) according to the following formula:

In Boys (R = 0.94, R^2 = 0.891, and SEE = 0.592): -9.236 + 0.0002708 x (subisquial length x sitting height) - 0.001663 x (age x subisquial length) + 0.007216 x (age x sitting height) + 0.02292 x (body mass/stature).

In Girls (R = 0.94, R^2 = 0.890 and SEE = 0.569): -9.376 + 0.0001882 x (subisquial length x sitting height) + 0.0022 x (age x subisquial length) + 0.005841 x (age x sitting height) - 0.002658 x (age x body mass) + 0.07693 x (body mass/stature).

The age at PHV and prediction of adult stature were estimated according to Sherar et al. (2005), which allowed categorizing the young athletes as early, average or late maturing.

Basal metabolic rate

After a preliminary search, two sex- and age-specific equations were selected to report the estimated basal metabolic rate (BMR) of the young athletes who participated in this investigation. The approximate surface area was calculated with according to Du Bois (1916) and then BMR was estimated with the equations developed by Fleisch (1951) and Schofield (1985).

Statistical analysis

Descriptive statistics was expressed as mean and standard deviation (95% CI). Normality was assessed with the Shapiro-wilk test. The data were analyzed with the Mann-Whitney U and Kruskal-Wallis (Bonferroni *post hoc*) tests to determine differences between men and women and between municipalities of origin, respectively. In addition, participants were classified by groups using unsupervised machine learning in order to identify similar data groups (clusters) and extract profile patterns considering the collected 55 variables (including individual anthropometric measurements related to morphology along with estimations of body composition, basal metabolic rate and maturation status). The number of clusters was determined using the *fviz_nbclust* function (which include the "wss", "silhouette" and "gap_start" methods) and a loop script with the following methods: "kl", "ch", "hartigan", "mcclain", "gamma", "gplus", "tau", "dunn", "sdindex", "sdbw", "cindex", "ball", "ptbiserial", "gap", and "frey"). To avoid local minima, a bootstrapping of n=100 was performed and Euclidean distances were analyzed. Consequently, the partitioning around Medoids (PAM) algorithm, also known as k-Medoids clustering, was executed. The packages '*Factoextra*' was used to visualize clustering results. All tests (significance level of $p < 0.05$) were performed in the IBM SPSS v26 (IBM Corp., Armonk, NY, USA) and within the free software environment for statistical computing and graphics R v4.0.2 (R Core Team, 2017).

Results

All measures were obtained for 49 young athletes (20F, 29H) from the Urabá subregion (Apartadó=8, Carepa=17, Chigorodó=8, Necoclí 4, and Turbo=5) and the metropolitan area of the Aburrá Valley (Itagüí=2 and Sabaneta=5) that met the inclusion criteria for this study. The ethnic traits of the participants included black, indigenous, white, zambo, mulatto, and mestizo.

Descriptive data

The characteristics of the participants grouped by sex are shown in Table 1. Significant differences were found between sexes in the biepicondylar diameter of humerus and femur biepicondylar (greater in boys). Several anthropometry-based calculations revealed significant morphological differences; in this regard, girls had significant higher values than boys in cormic index (girls vs. boys; 0.51 vs. 0.50), adipose-to-muscle ratio (0.93 vs 0.74), locomotive index (0.98 vs. 0.84), and endomorphy (3.50 vs. 2.68). Boys only showed higher mesomorphy than girls (3.32 vs. 4.44). No differences were found in girths although skinfolds values were significantly higher in girls in comparison to the boys (excepting for the medial calf). In this sense, the male participants had significantly lower values than girls in adipose tissue mass (16.00 vs. 13.39 kg), body fat percentage (20.36 vs. 15.54%, estimated by %FM Slaughter_1), and sum of six skinfolds (57.20 vs. 72.45 mm). Significant difference was also found in BMR (1304.54 vs. 1465.08 kcal, estimated by the Schofield's equation). Regarding maturity status, significant differences were detected in maturity offset (0.77 vs. -1.22), age at PHV (12.56 vs. 14.54 years), predicted adult height (162.92 vs. 177.66 cm) and distance left to grow (9.00 vs. 23.52 cm). No significant differences were found between the municipalities for the variables analyzed in this study (Supplementary Table S1).

Table 1. Characteristics of the young athletes by sex (n=49)

Variable	Girls (*n*=20)	95% CI (min, max)	Boys (*n*=29)	95% CI (min, max)	*p*-value
Age (years)	13.34 (0.94)	12.90, 13.78	13.28 (1.50)	12.71, 13.86	0.502
Body mass (kg)	46.35 (10.10)	41.61, 51.08	45.48 (11.49)	41.11, 49.85	0.535
Stature (cm)	153.92 (11.91)	148.34, 159.49	154.14 (11.75)	148.34, 159.49	0.684
BMI ($kg \cdot m^{-2}$)	19.41 (2.93)	18.04, 20.78	18.87 (2.93)	17.75, 19.99	0.387
Sitting height (cm)	79.30 (4.56)	77.16, 81.43	77.33 (7.33)	74.54, 80.12	0.339
B. biacromial	29.46 (2.28)	28.39, 30.52	29.29 (2.82)	28.22, 30.37	0.984
B. biiliocristal	22.64 (2.52)	24.46, 23.82	22.43 (2.84)	21.35, 23.51	0.427
B. transverse chest	23.15 (2.17)	22.13, 24.16	23.90 (2.39)	22.98, 24.81	0.276
B. A-P chest depth	15.34 (2.77)	14.04, 16.64	17.35 (6.34)	14.94, 19.77	0.393
B. humerus	5.76 (0.49)	5.53, 5.99	6.38 (0.66)	6.13, 6.64	<0.001
B. femur	8.12 (0.45)	7.90, 8.33	8.71 (0.57)	8.49, 8.92	<0.001
G. head	54.35 (1.96)	53.43, 55.26	53.72 (1.43)	53.17, 54.26	0.169
G. arm (relaxed)	24.09 (3.07)	22.65, 25.52	23.98 (3.01)	22.83, 25.13	0.831
G. arm (flexed and tensed)	24.97 (2.74)	23.69, 26.25	25.82 (3.33)	24.56, 27.09	0.445
G. corrected arm	20.17 (2.75)	18.88, 21.46	21.02 (2.79)	19.96, 22.09	0.349
G. forearm	22.35 (2.19)	21.32, 23.37	23.23 (2.51)	22.28, 24.19	0.242
G. chest	77.43 (7.04)	74.13, 80.72	77.48 (7.78)	74.52, 80.44	0.959
G. corrected chest	74.50 (6.34)	71.52, 77.47	75.05 (7.19)	72.32, 77.79	0.839
G. waist	64.04 (5.92)	61.26, 66.81	66.37 (7.75)	63.42, 69.33	0.376
G. corrected waist	60.33 (5.34)	57.82, 62.84	63.41 (6.76)	60.84, 65.98	0.143
G. gluteal (hips)	84.77 (8.11)	80.97, 88.57	80.79 (8.71)	77.47, 84.10	0.113
G. thigh (1 cm gluteal)	50.39 (5.78)	47.68, 53.09	47.91 (6.41)	45.47, 50.35	0.078
G. middle thigh	43.09 (5.44)	40.54, 45.63	42.85 (5.80)	40.64, 45.06	0.807
G. corrected thigh	37.86 (4.72)	35.64, 40.07	38.82 (5.41)	36.77, 40.88	0.528
G. calf	30.44 (3.33)	28.88, 31.99	30.47 (3.03)	29.31, 31.62	0.959
G. corrected calf	26.49 (3.17)	25.00, 27.97	27.21 (2.58)	26.22, 28.19	0.458
S. triceps	12.45 (3.60)	10.76, 14.13	9.41 (3.48)	8.08, 10.74	0.005
S. subescapular	9.32 (3.34)	7.76, 10.88	7.72 (3.22)	6.49, 8.95	0.029
S. supraespinale	9.65 (4.00)	7.77, 11.52	7.41 (3.98)	5.89, 8.93	0.029
S. abdominal	11.80 (4.42)	9.73, 11.72	9.44 (4.14)	7.87, 11.02	0.029
S. front thigh	16.65 (6.11)	13.78, 19.51	12.82 (6.12)	10.49, 15.15	0.021
S. medial calf	12.57 (4.33)	10.54, 14.60	10.37 (3.64)	8.99, 11.76	0.074
Cormic index	0.51 (0.02)	0.50, 0.52	0.50 (0.03)	0.48, 0.51	0.045

Muscle-to-bone ratio	4.35 (0.82)	3.96, 4.75	4.19 (0.83)	3.96, 4.75	0.476
Adipose-to-muscle ratio	0.93 (0.27)	0.80, 1.06	0.74 (0.20)	0.66, 0.81	0.011
Locomotive index	0.98 (0.21)	0.87, 1.08	0.84 (0.19)	0.76, 0.91	0.034
Endomorphy	3.50 (1.09)	2.99, 4.01	2.68 (1.07)	2.27, 3.09	0.011
Mesomorphy	3.32 (1.33)	2.69, 3.94	4.44 (1.17)	3.99, 4.88	0.002
Ectomorphy	3.01 (1.68)	2.23, 3.80	3.32 (1.38)	2.80, 3.85	0.319
Adipose tissue (kg)	16.00 (4.19)	14.04, 17.97	13.39 (4.15)	11.81, 14.97	0.020
Muscle tissue (kg)	17.77 (4.86)	15.49, 20.05	18.75 (5.80)	16.55, 20.96	0.729
Residual mass (kg)	4.99 (1.31)	4.37, 5.60	5.60 (1.56)	5.01, 6.20	0.207
Bone tissue (kg)	4.09 (0.87)	3.68, 4.50	4.48 (1.10)	4.06, 4.90	0.193
Skin mass (kg)	3.24 (0.45)	3.03, 3.45	3.10 (0.56)	2.89, 3.32	0.502
Structured mass 5C	42.36 (10.09)	37.63, 47.09	42.78 (11.63)	38.35, 47.20	0.903
%FM Slaughter_1	20.36 (4.43)	18.28, 22.44	15.54 (4.97)	13.65, 17.44	<0.001
%FM Slaughter_2	17.31 (4.20)	15.34, 19.28	15.33 (5.80)	13.12, 17.53	0.080
Sum of six skinfolds	72.45 (22.13)	62.08, 82.81	57.20 (21.12)	49.17, 65.24	0.016
Schofield's equation (kcal)	1304.54 (130.05)	1243.67, 1365.41	1465.08 (201.85)	1388.29, 1541.86	0.004
Fleisch's equation (kcal)	1374.38 (181.15)	1289.60, 1459.17	1419.94 (197.91)	1344.66, 1495,22	0.452
Maturity offset	0.77 (0.98)	0.31, 1.23	-1.22 (1.37)	-1.74, -0.70	<0.01
Age at PHV	12.56 (0.61)	12.28, 12.85	14.51 (1.07)	14.10, 14.92	<0.001
Predicted adult height (cm)	162.92 (8.95)	158.73, 167.11	177.66 (7.23)	174.91, 180.47	<0.001
Distance left to grow (cm)	9.00 (5.34)	6.50, 11.50	23.52 (8.68)	20.21, 26.82	<0.001

Note: Data are expressed as media (SD) with the respective 95% confidence interval (CI). B: breadths (in centimeters); G: girths (in centimeters); S: skinfolds (in millimeters); 5C: five-compartment; %FM Slaughter_1: percentage of body fat calculated with the Slaughter equation using triceps and subscapularis skinfolds as input variables; %FM Slaughter_2: percentage of body fat calculated with the Slaughter equation using triceps and calf skinfolds as input variables; PHV: peak high velocity. p-value for the Mann–Whitney U test. **Source**: Authors

Main results

PAM clustering analysis resulted more appropriated to cluster our data as it was revealed in a preliminary exploration with the '*clValid()'* function. After determining the number of clusters, the PAM clustering was executed with k = 2. Two clusters were identified: n = 22 (cluster 1) and n = 27 (cluster 2), as can be seen in Figure 1. Almost all female participants were classified in Cluster 2 (15/20) but this cluster also contain a 41.3% of males (12/29). No relevant matching was found for the municipality of origin. Regarding maturity status, Cluster 1 encompassed 85.7% of those participants classified on late in maturation (12/14) while Cluster 2 comprised a 72.7% of young average maturing (24/33). The matching analysis of the identified clusters is shown in Table 2.

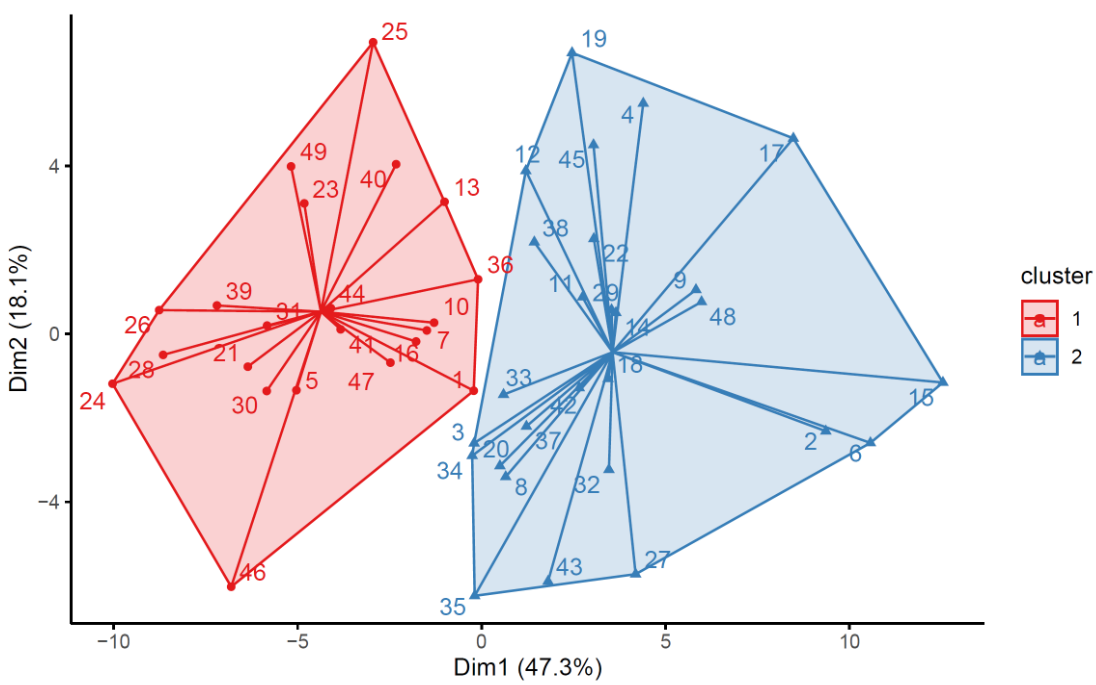

Figure 1. Results from the partitioning around Medoids clustering algorithm. Red solid circles represent participants classified in the cluster 1 (*n*=22) while the blue solid triangles are participants of the cluster 2 (*n*=27). **Source:** Authors

Table 2. Matching analysis of the clusters with categorical variables

PAM Clustering	Sex		Maturity categorization		
	Girls	Boys	Early	Average	Late
Cluster 1 $n = 22$	5	17	1	9	12
Cluster 1 $n = 27$	15	12	1	24	2

Note: PAM: partitioning around Medoids (PAM) algorithm. **Source**: Authors

From the 55 input variables to cluster the data, all were significantly different except for humerus biepicondylar diameter, femur biepicondylar diameter, adipose-to-muscle ratio, locomotive index, mesomorphy, and predicted adult height. Table 3 shows the characteristics and differences between clusters.

Table 3. Characteristics of the identified clusters

Variable	Cluster 1 (*n*=22)	95% CI (min, max)	Cluster 2 (*n*=27)	95% CI (min, max)	*p*-value
Age (years)	12.73 (1.53)	12.05, 13.41	13.78 (0.81)	13.45, 14.10	0.007
Body mass (kg)	39.49 (5.46)	34.07, 38.91	53.44 (7.68)	50.40, 56.48	<0.001
Stature (cm)	146.44 (9.26)	142.33, 150.54	160.25 (9.71)	156.41, 164.09	<0.001
BMI ($kg \cdot m^{-2}$)	16.95 (1.45)	16.30, 17.59	20.83 (2.64)	19.79, 21.88	<0.001
Sitting height (cm)	72.97 (5.20)	70.66, 75.27	82.34 (3.48)	80.96, 83.72	<0.001
B. biacromial	27.72 (2.42)	26.65, 28.80	30.69 (1.89)	29.94, 31.44	<0.001
B. biiliocristal	20.75 (1.94)	19.82, 21.62	23.95 (2.36)	23.01, 24.88	<0.001
B. transverse chest	22.11 (1.83)	21.30, 22.92	24.80 (1.94)	24.02, 25.57	<0.001
B. A-P chest depth	15.82 (6.22)	13.06, 18.58	17.11 (4.32)	15.40, 18.82	<0.001
B. humerus	5.98 (0.64)	5.69, 6.27	6.25 (0.67)	5.98, 6.52	0.247
B. femur	8.37 (0.61)	8.10, 8.64	8.54 (0.58)	8.31, 8.77	0.493
G. head	53.01 (1.53)	52.33, 53.70	54.75 (1.37)	54.21, 55.30	<0.001
G. arm (relaxed)	21.56 (1.96)	20.69, 22.43	26.02 (2.08)	25.20, 26.85	<0.001
G. arm (flexed and tensed)	23.15 (2.38)	22.09, 24.21	27.37 (2.20)	26.50, 28.24	<0.001
G. corrected arm	18.72 (2.02)	17.82, 19.62	22.27 (2.26)	21.37, 23.16	<0.001
G. forearm	21.17 (1.94)	20.31, 22.04	24.25 (1.78)	23.55, 24.96	<0.001
G. chest	71.27 (4.18)	69.42, 73.13	82.50 (5.35)	80.38, 84.61	<0.001
G. corrected chest	69.28 (3.99)	67.51, 71.05	79.34 (5.01)	77.36, 81.33	<0.001
G. waist	61.35 (5.24)	59.03, 63.68	68.73 (6.73)	66.07, 71.40	<0.001
G. corrected waist	58.86 (4.78)	56.74, 60.98	64.83 (6.27)	62.35, 67.32	<0.001
G. gluteal (hips)	74.73 (5.22)	72.41, 77.04	88.68 (4.93)	86.72, 90.63	<0.001
G. thigh (1 cm gluteal)	44.34 (5.30)	41.99, 46.69	52.65 (4.07)	51.04, 54.47	<0.001
G. middle thigh	38.96 (4.63)	36.91, 41.02	46.20 (4.02)	44.60, 47.79	<0.001
G. corrected thigh	35.41 (4.67)	33.34, 37.48	40.89 (4.07)	39.28, 42.50	<0.001
G. calf	28.52 (2.00)	27.63, 29.41	32.03 (3.00)	30.84, 33.22	<0.001
G. corrected calf	25.64 (1.87)	24.81, 26.47	27.95 (3.07)	26.74, 29.17	<0.001
S. triceps	9.04 (3.15)	7.64, 10.44	11.96 (3.84)	10.44, 13.48	0.007
S. subescapular	6.34 (1.53)	5.65, 7.02	10.03 (3.50)	8.65, 11.42	<0.001
S. supraespinale	5.63 (1.86)	4.80, 6.46	10.51 (4.14)	8.87, 12.15	<0.001
S. abdominal	7.95 (2.83)	6.69, 9.21	12.40 (4.42)	10.65, 14.15	<0.001
S. front thigh	11.31 (3.74)	9.65, 12.97	16.88 (6.96)	14.13, 19.64	0.008
S. medial calf	9.18 (2.75)	7.96, 10.40	12.98 (4.17)	11.32, 14.63	0.001
Cormic index	0.50 (0.04)	0.48, 0.51	0.51 (0.02)	0.50, 0.52	0.091
Muscle-to-bone ratio	3.85 (0.76)	3.51, 4.19	4.59 (0.74)	4.29, 4.88	0.001
Adipose-to-muscle ratio	0.78 (0.26)	0.68, 0.91	0.83 (0.24)	0.73, 0.93	0.360
Locomotive index	0.88 (0.22)	0.78, 0.98	0.91 (0.20)	0.82, 0.99	0.482
Endomorphy	2.42 (0.80)	2.07, 278	3.50 (1.17)	3.03, 3.96	0.001
Mesomorphy	4.11 (1.16)	3.59, 4.63	3.87 (1.49)	3.28, 4.47	0.666
Ectomorphy	3.81 (1.13)	3.31, 4.32	2.70 (1.60)	2.06, 3.33	0.002
Adipose tissue (kg)	10.99 (2.48)	9.89, 12.09	17.28 (3.34)	15.96, 18.60	<0.001
Muscle tissue (kg)	14.27 (2.87)	13.00, 15.55	21.68 (4.66)	19.83, 23.52	<0.001
Residual mass (kg)	4.46 (0.90)	4.06, 4.87	6.07 (1.48)	5.49, 6.66	<0.001
Bone tissue (kg)	3.78 (0.84)	3.40, 4.15	4.76 (0.96)	4.38, 5.15	0.001

Skin mass (kg)	2.81 (0.51)	2.58, 3.04	3.44 (0.32)	3.31, 3.57	<0.001
Structured mass 5C	33.58 (6.00)	30.92, 36.25	49.96 (8.13)	46.74, 53.17	<0.001
%FM Slaughter_1	14.81 (3.94)	13.06, 16.56	19.71 (5.27)	17.62, 21.80	0.002
%FM Slaughter_2	14.35 (4.25)	12.46, 16.24	17.59 (5.61)	15.37, 19.81	0.053
Sum of six skinfolds	49.47 (13.68)	43.41, 55.54	74.79 (22.23)	66.00, 83.59	<0.001
Schofield's equation (kcal)	1284.34 (125.46)	1228.72, 1339.97	1493.43 (186.75)	1419. 55, 1567.31	<0.001
Fleisch's equation (kcal)	1252.06 (118.10)	1199.70, 1304.43	1522.98 (147.04)	1464.82, 1581.15	<0.001
Maturity offset	-1.69 (1.21)	-2.23, -1.15	0.64 (0.91)	0.27, 1.00	<0.001
Age at PHV	14.42 (1.35)	13.83, 15.02	13.14 (0.99)	12.74, 13.53	<0.001
Predicted adult height (cm)	171.81 (10.33)	167.22, 176.39	171.51 (11.29)	167.04, 175.98	0.794
Distance left to grow (cm)	25.37 (8.78)	21.47, 29.26	11.25 (6.54)	8.66, 13.84	<0.001

Note: Data are expressed as media (SD) with the respective 95% confidence interval (CI). B: breadths (in centimeters); G: girths (in centimeters); S: skinfolds (in millimeters); 5C: five-compartment; %FM Slaughter_1: percentage of body fat calculated with the Slaughter equation using triceps and subscapularis skinfolds as input variables; %FM Slaughter_2: percentage of body fat calculated with the Slaughter equation using triceps and calf skinfolds as input variables; PHV: peak high velocity. **Source**: Authors

Discussion

The study of anthropometry-based indicators of morphology and maturity status might contribute to the talent identification, sports specialization and early categorization of young athletes (Cumming, Lloyd, Oliver, Eisenmann, & Malina, 2017; Malina, Coelho E Silva, Figueiredo, Carling, & Beunen, 2012). In fact, current research have reinforced the utility of the anthropometric assessment to distinguish morphological and performance characteristics of young combat athletes (Toselli et al., 2021) besides reporting significant associations (Giudicelli et al., 2021) that help nutrition and exercise professionals to monitor and design intervention programs. With this in mind, the aim of this study was to characterize for the first time the morphological characteristics, body composition, and biological maturation status of young Olympic wrestling athletes from Urabá sub-region. This sub-region has been a source of athletes with Olympic projection for the sports Colombian federations. In addition, we performed an unsupervised machine learning analysis to identify similar data points (natural groupings) and extract profile patterns which complement traditional statistical approaches.

Similar to previous studies (Albaladejo-Saura, Vaquero-Cristóbal, González-Gálvez, & Esparza-Ros, 2021; Boullosa et al., 2020; Oliveira et al., 2020), we found several morphological and body composition differences between girls and boys which is probably due to biological features of the sexual dimorphism. In comparison to young male participants, female athletes had a higher cormic index (short trunk and long legs), adipose-to-muscle ratio, locomotive index (lower biomechanical efficiency than men), and relative adiposity (balanced endomorphy and greater sum of six skinfolds and body fat percentage). The analysis of the characteristics by municipality showed that there were no significant differences in any of the studied variables which might be due to the insufficient sample in some municipalities and thereby warrants further research.

As expected, we evidenced significant differences in most variables related to maturity status which obey to the higher maturation rate of females compared to males. Previous research has demonstrated that sexual maturity may have a greater influence on boy's performance (Jones, Hitchen, & Stratton, 2009). Interestingly, the obtained clusters were significantly different between them in regards to maturity categorization (Cluster 1: 4.5% - 40.9% - 86.3% vs. Cluster 2: 3.7% - 88.8% - 7.40% for early, average and late maturing, respectively), which explained most of the variance in the data (Table 2). Thus, Cluster 2 were young athletes significantly taller, heavier, more robust, less biomechanically efficient, and more matured compared with young athletes of the Cluster 1. Although further research is needed to associate these morphological features, the body composition and maturity status of the Urabá young athletes with sports performance, these results provide relevant information to sports nutritionists and coaches/trainers when addressing preparation to competitions.

This study has several limitations that should be highlighted. Firstly, albeit relatively homogeneity between number of boys and girls, next studies should analyze more young athletes and include a higher number of participants from the different municipalities to examine geographical changes. Secondly, several variables indicative of sport performance should be also evaluated to associate with morphology, body composition and maturity status. Thirdly, authors are aware of the implicit flaws of the Mirwald's method and encourage researchers to develop and validate equations/methods with young Colombian athletes from the Urabá sub-region. Finally, we not only reported relevant anthropometry-based data from this youth population with high Olympic projection but also contributed with methodological procedures to analyze/interpret datasets under the machine learning paradigm.

Conclusion

The evaluation of anthropometry-based variables of morphology, body composition and maturity status in young Olympic wrestling athletes from the Urabá sub-region revealed significant sex-dependent differences. In general, girls showed higher cormic index, adipose-to-muscle ratio, locomotive index, and upper-body adiposity than boys. Furthermore, two phenotypes were obtained from our PAM clustering analysis (Cluster 2 were young athletes significantly taller, heavier, more robust, less biomechanically efficient, and more matured compared with young athletes of the Cluster 1) which provides relevant information about the particular differences in terms of maturity status and might assist nutrition and exercise professionals when designing interventions. Applying unsupervised machine learning to characterize young athletes contributes to the identification of patterns besides providing a reproducible and a fast tool to analyze data. More research is needed to evaluate potential associations with physical performance and sport success.

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Ethical approval: The study was conducted in accordance with the declaration of Helsinki and the protocol was approved within the framework '*applied research projects in physical activity and sport training sciences*' of the SENNOVA Line 23: Technological Updating and Modernization Program of the Training Centres (valid until 2019), with a SIGPS verification code of submission: 981411626632015FD4F61A93C1F4A67C (confirmation number: 20155).

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Conflict de interests: D.A.B. is a certified Level Three Anthropometrist (Instructor) by the International Society for the Advancement of Kinanthropometry (ISAK), has conducted academic-sponsored research on anthropometry, and has received honoraria for selling anthropometric equipment and speaking about anthropometry at international conferences/private courses. The other authors declare no conflicts of interest. All authors are responsible for the content of this article.

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