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Relationships between Anthropometric and Strength Profiles of Streetlifting Athletes

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Abstract: The aim of this study was to investigate the anthropometric characteristics of streetlifting athletes in the different body weight categories and to develop specific equations to predict the individual performance in the different exercises included in competitive programs (chin-up, dip, muscle-up and squat). A total of 79 athletes (60 men and 19 women; age: 26.1 ± 6.4 y; body mass: 72.7 ± 13.2 kg; height: 171.7 ± 8.9 cm) were tested in accordance with the Italian National championships. Athletes were tested for anthropometry and body composition before the competition, and the performance in each lift was registered. A partial correlation of 0.47 and 0.60 was detected between arm girth and chin-up and dip performance, respectively. On the contrary, body fat was negatively correlated with the same exercises (r = −0.42). Squat performance appeared mainly determined by fat-free mass and thigh cross-sectional area, while body fat did not affect the performance in this exercise. The prediction equations developed were based on anthropometric and body composition parameters and showed near-perfect correlations with the participants' competitive results (R^2 between 0.66 and 0.90). The normative data presented in this investigation and the prediction equations developed may help coaches and practitioners in athlete evaluation and comprehension of the key factor of streetlifting performance.

Keywords: somatotype; chin-up; muscle-up; squat; dip

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1. Introduction

Streetlifting is a recent strength and power sport in which athletes compete in specific weight categories in the attempt to lift as much external loads. The sum of the best attempts on each lift determines the final ranking. In particular, male streetlifting competitions include loaded chin-ups, dips, muscle-ups and barbell back squats, while female streetlifting programs until 2024 did not include loaded muscle-ups. Streetlifting competitions derivate by the evolution of street-workout training, in which practitioners were traditionally engaged in free-body exercises [1]. To date, streetlifting has been regulated worldwide by the International Streetlifting Federation, which determines the international technical rules and organizes competitions [2]. Eighteen national federations are currently recognized by the International Streetlifting Federation [2].

Anthropometric and body composition characteristics have been previously investigated in athletes competing in sports similar to streetlifting. In particular, these parameters were considered crucial for the performance in strength and power disciplines [3–5] and possibly useful for talent identification in powerlifting, gymnastics and weightlifting [6–8]. Keogh et al. [4], indeed, indicated that heavyweight powerlifters tend to be significantly taller and heavier and have a higher body fat percentage, larger girths and more endo-mesomorphy than their lighter counterparts. For that reason, body girths and body fat correlates with their final strength performance, parameters that can be predicted by specific equations [3]. In weightlifting, a relatively high body-mass-to-height ratio is considered positive for facilitating proper lifting technique and promoting large muscle cross-sectional areas to body mass ratios [5]. In gymnastics, a short stature and a low body mass may be considered positive because an elevated endomorphic component and fat mass may negatively impact performance [7]. Therefore, investigating the anthropometric profile of athletes competing in different sport disciplines, including streetlifting, may represent the key to understanding athletes' needs and to improve their performance [9].

To date, no research has investigated the anthropometric profile of streetlifting athletes included in the different body weight categories and the influence of different physical characteristics on specific types of strength performance. Thus, the aims of this study were to identify the anthropometric characteristics of streetlifting athletes of the different body weight categories and to investigate the relationships between anthropometric characteristics and strength performance. Another aim of the present study was to develop equations to predict the athlete's performance in each competitive exercise based on the most important components of each discipline included in the streetlifting competitive program.

2. Materials and Methods

2.1. Experimental Design

The present study consisted of anthropometric assessments performed in accordance with the Italian streetlifting Championships (30 April 2023; 13 May 2023; 18 June 2023). All the anthropometric assessments were performed before the warm-up. Each athlete was free to participate in this study and was assessed for anthropometric measurements and body composition. The competitive results of each participant were recorded and analyzed, and their correlations with anthropometric measures were studied.

2.2. Participants

Seventy-nine Italian streetlifting athletes volunteered to participate in the present study, which followed the format of the 2023 Italian streetlifting Championships. Individual variables such as age, sex, training experience and weekly training volume (training sessions per week x training duration in min) were collected using a questionnaire [10]. Athletes with a training experience shorter than 1 year and athletes under 18 years old were not considered for this study. Athletes participating in the present study were 60 men (age: 25.2 $\pm$ 4.7 y; body mass: 77.6 $\pm$ 11.0 kg; height: 175.3 $\pm$ 6.5 cm; training experience: 6.7 $\pm$ 3.7 y; average weekly training volume: 705.8 $\pm$ 208.2 min) and 19 females (age: 29.1 $\pm$ 9.6 y; body mass: 57.3 $\pm$ 5.6 kg; height: 160.3 $\pm$ 5.6 cm; experience: 3.1 $\pm$ 1.7 y; average weekly training volume: 544.73 $\pm$ 124.2 min). Male athletes were divided into five categories: −66 kg (n = 12), −74 kg (n = 13), −83 kg (n = 14), −93 kg (n = 16) and +93 kg (n = 5). Female athletes were divided into three weight categories: −57 kg (n = 8), −63 kg (n = 8) and −69 kg (n = 3). These weight categories have been determined according to the *Italian Streetlifting Technical Rules Book* [11]. All the participants were informed about the research procedures and gave their signed informed consent. This study was approved by the local bioethics committee (prot. n. 0025317; 1 February 2023).

2.3. Anthropometric and Performance Assessments

A portable stadiometer (GPM, Zurich, Switzerland) and a scale (digital scale, Seca877; Seca, Leicester, UK) were used to measure the height and body mass of the athletes. As suggested by Lohman and Norton [12,13], six body girths (flexed and tensed arm, forearm, chest, hip, thigh and calf), five body breadths (humerus, femur, biacromial and bi-iliaocrestal) and four lengths (arm, forearm, tibia and femur) were measured using a flexible tape and a large and small sliding caliper (GPM calipers, Zurich, Switzerland), respectively. Flexed and tensed arm girth was assessed during maximum contraction at the point of maximum girth with the arm raised anteriorly to the horizontal and the elbow flexed at 90°. Forearm girth was measured at the point of maximum girth of the forearm with the subject holding the palm upwards and the arm muscles relaxed. Chest girth was measured at the midpoint of the articulation of the fourth rib with the sternum at the end of normal breathing. Hip girth was measured at the level of the iliac crest in the standing position.

Thigh girth was measured between the midpoint of the inguinal crease and the proximal edge of the patella. Calf girth was measured in sitting position at the widest point [13]. Biepicondylar humerus breadth was measured between the medial and lateral epicondyles of the humerus with the arm raised anteriorly to the horizontal and the elbow flexed at 90°. Biepicondylar femur breadth was assessed by measuring the distance between the medial and lateral epicondyles of the femur in a relaxed position. Biacromial breadth was measured between the two acromial processes with the participant standing in a relaxed position with the arms at the side of the body. Bi-iliocrestal breadth was measured between the most lateral points of the iliac tubercles crests [12]. Upper arm length was measured from the superolateral aspect of the acromion to the posterior surface of the olecranon process of the ulna. Forearm length was measured from the most posterior point above the olecranon to the most distal palpable point of the styloid process of the radius. Upper arm and forearm length were measured with the elbow bended at 90° and the forearm parallel to the ground. Femur length was measured from the inguinal ligament point to the proximal patella edge. Tibia length was measured from the most superior point on the medial border of the head of the tibia and the most superior point on the medial border of the head of the tibia [12]. Six skinfolds (triceps, abdominal, subscapular, supraspinale, medial calf and front thigh) were measured on the left side of the body, using a skinfold caliper (Cambridge Scientific Industries, Cambridge, MA, USA). The triceps skinfold was assessed on the posterior surface of the arm, at the mid-line between the most lateral part of the acromial border and the lateral border of the head of the radius. The abdominal skinfold was raised 3 cm on the left and 1 cm below the belly button. The subscapular skinfold was raised 2 cm below the inferior angle of the scapula. The supraspinale skinfold was assessed just above the iliac crestal site. The medial calf skinfold was assessed in sitting position on the most medial aspect of the calf at the level of the maximal girth. The thigh skinfold was taken in the midpoint of the distance between the inguinal ligament and the superior border of the patella [13]. Each assessment was repeated twice and the intra-operator measurements error was set to <5% for all skinfolds and <1% for girths, breadths and lengths, in accordance with the previous literature [14].

Only the maximum valid load lifted in each exercise during the competition was registered and used for the subsequent data analysis. Athletes had 3 attempts to lift the maximum weight possible during the competition with 10 min of rest between attempts. The order of the streetlifting exercises performed during the competition was as follows: muscle-up, chin-up, dip, and squat. For muscle-ups, the lift was considered valid if the athletes did not bend their legs during the concentric phase of the lift [2]. Chin-up attempts were considered valid if the arms were totally straight at the beginning of the movement and if the chin was above the level of the bar at the end of the pull phase [2]. In the dips exercise, attempts were considered valid if the athletes' arms were straight at the beginning of the movement, the elbow angle was 90 degrees at the end of the eccentric phase, and the elbows were straight again at the end of the concentric phase [2]. In the squat, athletes are asked to bend the knees and lower the body until the upper surface of the legs at the hip joint is lower than the upper surface of the knees at the end of the eccentric phase, before beginning the concentric phase and returning to the starting position with the legs fully extended [2].

2.4. Data Analysis

Relative proportion as arm length/height index (AL/H), brachial index (forearm/upper arm lengths), Brugsch's index (chest girth/height), crural index (tibia/femur lengths) and acromio-iliac index (bi-iliocristal/bi-acromial breadth), expressed in percentages, were calculated [4]. Body fat percentage (%Body fat) was estimated using Evan's three skinfolds equation [15]: $\%\text{Body fat} = 8.997 + 0.24658 \times (3\text{SKF}) - 6.343 \times (\text{sex}) - 1.998 \times (\text{race})$, where 3SKF was the sum of triceps, abdominal and thigh skinfolds in millimeters with the sex coded as 0 = women and 1 = men and race coded as 0 = white and 1 = black. Fat-free mass (FFM) was then calculated for each athlete by subtracting the fat mass from the body mass.

Estimations of the mid-arm muscle area (AMA) and total thigh muscle cross-sectional area (tCSA) were calculated using the equations previously published by Heymsfield and Housh [16,17]:

$$AMA = \frac{arm\ girth\ in\ cm - (\pi * triceps\ skinfold\ in\ cm)^2}{4 * \ \pi} - (10\ for\ males; 6.5\ for\ females)$$

$$tCSA = \left(4.68 * \ thigh\ girth\ in\ cm - (2.09 * thigh\ skinfold\ in\ mm)^2 - 80.99\right)$$

The characteristics of the athletes' somatotypes were calculated as suggested by Carter [18].

Relative strength was calculated in each exercise by dividing the load lifted by the athlete's body mass. In addition, the total load lifted by athletes in each competition exercises were corrected by adding the athlete's body mass to the external load lifted (corrected performance).

2.5. Statistical Analysis

The Shapiro–Wilk test and Q-Q plots were used to check the normal distribution of the data. Pearson partial correlations accounted for sex and body weight categories was used to study the relationships between the independent variables and the corrected performance. According to Hopkins [19], the strength of the correlation coefficient was considered small (0.00–0.30), moderate (0.31–0.49), large (0.50–0.69), very large (0.70–0.89) or near perfect (0.90–1.00). Investigative analyses using forward linear regression were used (1) to understand the influence of variables on the competitive exercises; (2) to quantify the contribution of each exercise on the total final performance; and (3) to develop an equation to predict the performance in each exercise. Anthropometric and body composition parameters that were more correlated with the competitive performance were included in the linear regression models. Variables that showed significant correlations with performance but no contribution to the predicting model were not included in the prediction equation. Adjusted coefficients of determination (R^2) and root-mean-square error (RMSE) were used to represent the goodness of the prediction model [20]. The correspondence between measured vs. predicted performance for each lift was tested using paired sample *t*-test analysis and Pearson correlations. Significance was set at $p \leq 0.05$ for the sample *t*-test. SPSS software (version 28.0, SPSS Inc., Chicago, IL, USA) was used for all the data analyses.

3. Results

3.1. Anthropometric Characteristics and Body Composition

Individual variables, anthropometric, body composition data and strength performance are reported in Tables 1 and 2. In male categories, mesomorphy was dominant (5.8–6.5) while endomorphy was greater than ectomorphy (3.4–5.6 and 0.8–1.9 for endomorphy and ectomorphy, respectively) in every body weight category. In female categories, endomorphy was dominant (5.1–6.2) and mesomorphy was more common than ectomorphy (4.1–5.4 and 0.9–1.9 for mesomorphy and ectomorphy, respectively). Figure 1 shows the somatoplots for the male and female streetlifters of the different body weight categories.

3.2. Relationships between Anthropometrics, Body Composition and Streetlifting Performance

Significant positive correlations were detected between the chin-up performance and flexed and tensed arm girth (r = 0.470; $p < 0.001$), forearm girth (r = 0.35; $p = 0.002$) chest girth (r = 0.40; $p < 0.001$), fat-free mass (r = 0.42; $p < 0.001$), AMA (r = 0.52; $p < 0.001$) and Brugsch's index (r = 0.25; $p = 0.029$). Negative correlations were found between the chin-up performance and calf girth (r = −0.23; $p = 0.039$), %bodyfat (r = −0.42; $p < 0.001$) and endomorphy (r = −0.32; $p = 0.004$). The dip performance was correlated with flexed and tensed arm (r = 0.60; $p < 0.001$), forearm (r = 0.54; $p < 0.001$), chest girth (r = 0.41; $p < 0.001$), fat-free mass (r = 0.37; $p < 0.001$), AMA (r = 0.64; $p < 0.001$), mesomorphy (r = 0.26; $p = 0.022$) and Brugsch's index (r = 0.38; $p < 0.001$). Low and moderate negative correlations were found between dip performance and thigh girth (r = −0.28; p = 0.046), calf girth (r = −0.33; p = 0.003), femur length (r = −0.34; p = 0.002), tibial length (r = −0.31; p = 0.006), %body fat (r = −0.42; p < 0.001) and endomorphy (r = −0.28; p = 0.013). Muscle-up performance correlated with body mass (r = 0.29; p = 0.027), flexed and tensed arm (r = 0.43; p < 0.001), chest girth (r = 0.44; p < 0.001), fat-free mass (r = 0.30; p = 0.020), AMA (r = 0.39; p = 0.002) and Brugsch's index (r = 0.29; p = 0.024). Finally, positive correlations between squat and thigh girth (r = 0.44; p < 0.001), fat-free mass (r = 0.38; p < 0.001), CSA (r = 0.59; p < 0.001) and Brugsch's index (r = 0.45; p < 0.001) were found. On the contrary, squat performance was negatively correlated with height (r = 0.28; p = 0.012), femur length (r = −0.23; p = 0.036), tibial length (r = −0.32; p = 0.005) and ectomorphy (r = −0.47; p < 0.001). All the correlations between anthropometric data and performance are reported in Table 3.

Table 1. The individual characteristics, anthropometric, body composition and performance variables of the participants according to the different weight classes and sex. All the data are reported as mean ± standard deviation.

Variables	**Female**			**Male**				
Categories	**−57**	**−63**	**−69**	**−66**	**−74**	**−83**	**−93**	**+93**
Participants	(n = 8)	(n = 8)	(n = 3)	(n = 12)	(n = 13)	(n = 14)	(n = 16)	(n = 5)
Individual characteristics								
Age (years)	28.7 ± 9.6	27.2 ± 9.5	35.3 ± 10.9	23.6 ± 4.9	24.4 ± 3.4	27.3 ± 4.9	25.0 ± 5.7	25.4 ±1.6
Experience (years)	2.6 ± 1.9	2.2 ± 1.6	7.0 ± 4.3	5.9 ± 3.3	6.8 ± 2.9	8.2 ± 4.9	5.8 ± 3.6	7.4 ± 2.4
Training volume (min)	502.5 ± 109.6	596.2 ± 129.7	520.1 ± 138.5	577.5 ± 145.9	633.8 ± 195.6	790.8 ± 246.1	723.7 ± 173.5	906.0 ± 116.9
Height (cm)	155.4 ± 3.5	164.7 ± 3.7	161.6 ± 3.7	167.0 ± 2.5	173.2 ± 3.5	175.8 ± 4.9	179.6 ± 3.4	184.8 ± 6.1
Body mass (kg)	51.62 ± 1.8	60.0 ± 1.5	65.4 ± 3.1	64.1 ± 2.7	69.9 ± 2.2	78.4 ± 2.6	86.2 ± 3.0	99.4 ± 8.1
Girths (cm)								
Flexed and tensed arm	28.7 ± 1.3	30.7 ± 1.1	34.0 ± 2.0	35.6 ± 1.5	37.8 ± 1.2	39.0 ± 1.2	40.3 ± 1.9	43.1 ± 1.5
Forearm	23.4 ± 0.5	24.8 ± 0.7	26.1 ± 0.8	27.9 ± 0.8	29.2 ± 0.9	29.7 ± 1.0	31.0 ± 1.0	32.0 ± 1.1
Chest	89.2 ± 4.8	92.7 ± 3.9	96.7 ± 6.3	100.2 ± 3.7	104.9 ± 3.0	108.7 ± 2.2	111.6 ± 3.7	119.6 ± 1.8
Hip	72.0 ± 4.5	75.7 ± 2.3	79.5 ± 3.4	78.4 ± 2.8	80.6 ± 2.7	83.2 ± 2.7	86.2 ± 4.8	95.0 ± 6.4
Thigh	53.9 ± 2.0	56.1 ± 1.6	58.3 ± 1.3	53.6 ± 2.3	54.75 ± 2.4	58.5 ± 2.5	61.9 ± 2.6	65.8 ± 2.1
Calf	34.5 ± 2.0	35.5 ± 0.5	37.1 ± 0.5	35.0 ± 1.0	36.2 ± 1.5	37.7 ± 1.5	38.5 ± 1.5	40.5 ± 1.0
Lengths (cm)								
Upper arm	32.2 ± 0.9	34.0 ± 0.9	33.8 ± 0.4	34.7 ± 1.2	36.3 ± 1.6	37.0 ± 1.7	38.4 ± 0.9	39.4 ± 1.8
Forearm	23.5 ± 0.9	25.0 ± 0.7	24.8 ± 0.7	25.6 ± 1.0	26.7 ± 0.7	27.6 ± 1.2	28.0 ± 0.8	28.8 ± 2.2
Femur	36.8 ± 2.5	40.6 ± 1.6	38.7 ± 0.4	37.7 ± 0.9	39.9 ± 2.1	41.6 ± 2.0	42.5 ± 2.2	44.2 ± 1.3
Tibia	33.2 ± 1.3	36.2 ± 0.8	35.5 ± 1.5	35.6 ± 1.3	37.3 ± 2.1	38.9 ± 1.9	39.9 ± 1.3	39.5 ± 1.6
Breadths (cm)								
Biepicondylar humerus	5.6 ± 0.3	5.7 ± 0.2	5.6 ± 0.0	6.4 ± 0.2	6.5 ± 0.2	6.6 ± 0.3	6.8 ± 0.3	6.8 ± 0.4
Biepicondylar femur	8.3 ± 0.6	8.7 ± 0.3	9.2 ± 0.4	9.0 ± 0.6	9.4 ± 0.3	9.3 ± 0.8	9.6 ± 0.5	10.1 ± 0.2
Bi-acromial	31.1 ± 1.9	31.5 ± 1.9	31.6 ± 2.4	35.5 ± 1.9	35.3 ± 1.2	37.6 ± 2.8	36.8 ± 1.8	38.5 ± 1.4
Bi-iliocristal	23.9 ± 1.4	24.8 ± 1.0	25.9 ± 0.9	25.6 ± 1.2	26.6 ± 1.5	27.7 ± 2.9	26.8 ± 1.6	29.1 ± 2.5
Skinfolds (mm)								
Triceps	14.4 ± 4.0	12.8 ± 3.8	19.1 ± 5.1	5.9 ± 2.0	6.0 ± 1.7	6.7 ± 2.1	7.7 ± 2.2	11.8 ± 4.5
Abdominal	11.0 ± 3.9	10.3 ± 3.6	17.8 ± 2.8	7.3 ± 2.0	6.6 ± 1.6	9.2 ± 3.1	10.1 ± 4.7	18.7 ± 3.7
Subscapular	9.6 ± 1.3	11.3 ± 2.6	13.3 ± 3.2	8.2 ± 1.2	8.5 ± 1.2	9.9 ± 2.0	10.7 ± 2.3	18.5 ± 8.8
Supraspinal	9.1 ± 2.9	9.5 ± 3.4	12.9 ± 3.8	6.4 ± 1.3	7.3 ± 2.1	9.4 ± 3.2	11.1 ± 3.9	15.8 ± 5.0
Calf	12.9 ± 3.1	15.7 ± 4.9	17.0 ± 0.4	4.8 ± 2.1	5.5 ± 2.2	6.9 ± 2.2	7.3 ± 2.2	12.0 ± 5.4
Thigh	20.9 ± 3.6	20.9 ± 5.4	27.4 ± 3.9	7.4 ± 2.2	7.8 ± 2.6	10.1 ± 2.3	12.01 ± 5.2	16.4 ± 5.7
Performance (kg)								
Chin-ups	24.7 ± 7.5	25.8 ± 9.3	28.7 ± 14.4	67.4 ± 11.6	71.9 ± 9.1	69.1 ± 10.7	69.8 ± 11.2	80.0 ± 18.3
Dips	37.1 ± 8.9	42.1 ± 8.6	42.5 ± 10.8	94.0 ± 14.1	105 ± 13.4	102.6 ± 18.4	102.7 ± 16.7	125.0 ± 20.0
Muscle-ups	/	/	/	21.04 ± 7.4	26.8 ± 8.2	21.3 ± 8.3	21.0 ± 8.4	23.0 ± 9.0
Squat	101.8 ± 17.1	106.5 ± 25.7	113.3 ± 20.8	153.0 ± 31.0	158.4 ± 31.1	165.4 ± 29.1	191.0 ± 26.8	221.0 ± 28.8
Total	163.7 ± 29.3	174.5 ± 37.9	184.5 ± 45.1	335.5 ± 53.4	362.2 ± 43.0	358.6 ± 53.1	384.6 ± 49.3	449.0 ± 62.7

Table 2. The individual characteristics, body composition and performance variables of the participants according to the different weight classes and sex. All the data are reported as mean ± standard deviation. AMA = mid-arm muscle area; tCSA = thigh cross-sectional area; AL/H = arm length/height index; brachial index = forearm/upper arm lengths; crural index = tibia/femur lengths; Brugsch's index = chest girth/height; acromio-iliac index = bi-iliocristal/bi-acromial breadth.

Variable	**Female**			**Male**				
Categories	**−57**	**−63**	**−69**	**−66**	**−74**	**−83**	**−93**	**+93**
Participants	(n = 8)	(n = 8)	(n = 3)	(n = 12)	(n = 13)	(n = 14)	(n = 16)	(n = 5)
Body composition								
Body fat (%)	20.4 ± 2.5	19.8 ± 2.6	24.8 ± 1.5	7.7 ± 0.9	7.5 ± 1.3	8.9 ± 1.6	9.9 ± 2.6	14.2 ± 2.9
Fat-free mass (kg)	41.09 ± 2.3	48.0 ± 1.8	49.1 ± 2.2	59.1 ± 2.5	64.6 ± 2.3	71.4 ± 2.3	77.6 ± 1.9	85.2 ± 6.5
AMA (cm^2)	40.5 ± 7.5	50.4 ± 8.6	56.3 ± 10.6	81.0 ± 8.7	93.0 ± 8.2	98.6 ± 9.5	105.1 ± 14.3	114.0 ± 9.3
tCSA (cm^2)	127.6 ± 12.3	138.1 ± 9.9	134.4 ± 3.1	154.4 ± 10.0	158.7 ± 11.9	171.8 ± 11.1	183.8 ± 10.7	192.9 ± 12.9
Somatotype								
Endomorphy	5.1 ± 0.8	4.9 ± 0.9	6.2 ± 0.8	3.4 ± 0.4	3.5 ± 0.5	3.9 ± 0.6	4.2 ± 0.7	5.6 ± 1.3
Mesomorphy	4.4 ± 0.7	4.1 ± 0.6	5.4 ± 0.4	5.8 ± 0.8	5.8 ± 0.5	5.8 ± 1.0	6.2 ± 0.7	6.5 ± 0.9
Ectomorphy	1.9 ± 0.5	2.2 ± 0.7	0.9 ± 0.3	1.9 ± 0.6	2.2 ± 0.5	1.5 ± 0.7	1.3 ± 0.5	0.8 ± 0.2
Indices								
AL/H (%)	35.8 ± 0.6	35.8 ± 0.7	36.3 ± 0.5	36.1 ± 1.2	36.4 ± 0.7	36.7 ± 0.9	36.9 ± 0.7	36.9 ± 1.0
Brachial (%)	72.9 ± 2.7	73.5 ± 2.4	73.3 ± 2.9	73.6 ± 3.0	73.6 ± 2.5	74.5 ± 1.7	73.0 ± 2.8	73.3 ± 5.3
Crural (%)	90.4 ± 5.0	89.0 ± 3.2	91.5 ± 3.0	94.3 ± 3.5	93.5 ± 5.7	93.6 ± 3.4	93.9 ± 4.2	89.4 ± 3.5
Brugsch's (%)	57.4 ± 3.0	56.3 ± 2.4	59.8 ± 3.3	60.0 ± 2.5	60.6 ± 2.6	61.8 ± 2.3	62.1 ± 2.6	64.7 ± 2.5
Acromio-iliac (%)	76.9 ± 4.5	79.1 ± 6.4	82.1 ± 3.7	72.1 ± 2.8	75.4 ± 4.8	73.8 ± 5.4	72.8 ± 4.7	75.8 ± 7.0
Relative strength								
Chin-up/body mass (%)	48.0 ± 14.4	43.4 ± 15.8	43.3 ± 20.6	104.8 ± 16.0	103.2 ± 15.1	88.4 ± 14.7	80.9 ± 13.6	80.0 ± 14.2
Dip/body mass (%)	72.1 ± 18.1	70.4 ± 14.4	64.3 ± 14.2	146.4 ± 19.5	150.3 ± 19.7	131.0 ± 24.6	119.6 ± 21.6	125.0 ± 9.9
Muscle-up/body mass (%)	/	/	/	32.6 ± 10.7	38.8 ± 12.	27.3 ± 10.9	24.5 ± 10.2	23.6 ± 9.6
Squat/body mass (%)	197.1 ± 3.14	177.6 ± 42.4	172.3 ± 25.7	237.9 ± 44.5	226.3 ± 42.1	211.3 ± 38.2	221.7 ± 31.5	222.2 ± 21.7
Corrected performance								
Chin-up corrected (kg)	76.3 ± 8.3	85.8 ± 9.3	94.2 ± 17.5	131.5 ± 13.3	141.8 ± 8.3	147.6 ± 10.2	156.0 ± 11.2	179.4 ± 25.1
Dips corrected (kg)	88.7 ± 9.0	102.1 ± 8.8	107.9 ± 13.9	158.2 ± 15.7	174.9 ± 13.6	181.1 ± 18.1	189.0 ± 15.7	224.4 ± 27.8
Muscle-ups corrected (kg)	/	/	/	85.2 ± 9.3	96.8 ± 7.1	99.7 ± 7.6	107.3 ± 8.4	122. 4 ± 11.2
Squat corrected (kg)	153.5 ± 17.8	166.5 ± 25.8	178.8 ± 23.6	217.2 ± 32.3	228.4 ± 32.1	244.0 ± 29.0	277.3 ± 26.5	320.4 ± 34.9
Total corrected (kg)	318.6 ± 31.2	354.5 ± 38.2	381.0 ± 54.1	592.2 ± 60.5	642.0 ± 44.5	672.5 ± 51.6	729.7 ± 48.6	846.9 ± 91.4

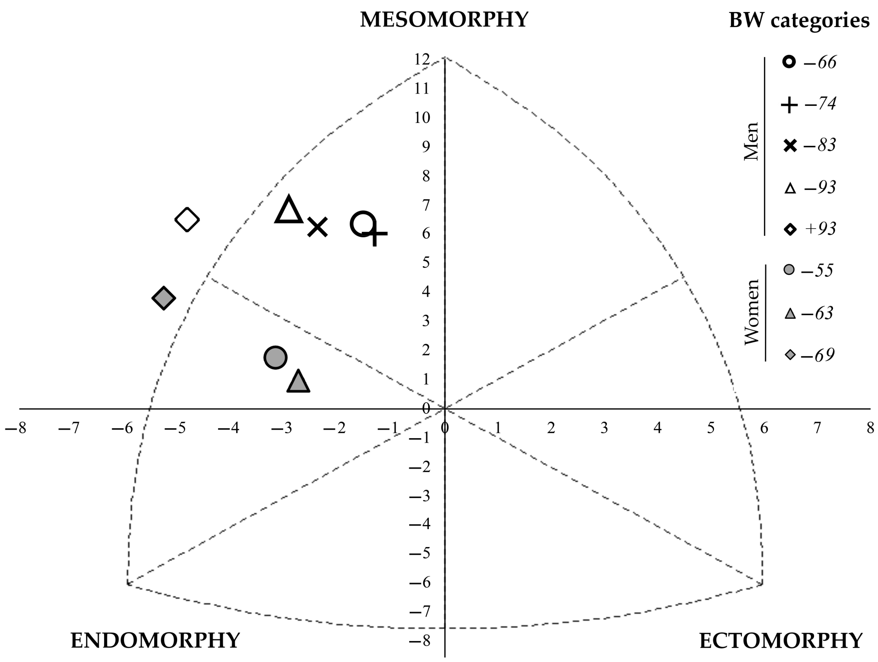

Figure 1. Somatochart of the streetlifting athletes' somatotypes for sex and body weight categories. BW = Body Weight.

Table 3. Partial Pearson correlation accounted for sexes and body weight categories between anthropometry, body composition and corrected strength performance; significance is equal to * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$. AMA = mid-arm muscle area; tCSA = thigh cross-sectional area; AL/H = arm length/height index; brachial index = forearm/upper arm lengths; crural index = tibia/femur lengths; Brugsch's index = chest girth/height; acromio-iliac index = bi-iliocristal/bi-acromial breadth.

Partial Correlation Accounted for Sex and Body Weight Categories				
Parameter	**Chin-Up**	**Dip**	**Muscle-Up**	**Squat**
Body mass	0.00	−0.04	0.29 *	0.32 **
Height	0.15	−0.07	0.06	−0.28 **
Girths (cm)				
Flex and tensed arm	0.47 ***	0.60 ***	0.43 ***	0.16
Forearm	0.35 **	0.54 ***	0.26 *	0.19
Chest	0.40 ***	0.41 ***	0.44 ***	0.37 **
Hip	−0.05	−0.05	0.13	0.14
Thigh	−0.19	−0.23 *	0.04	0.44 ***
Calf	−0.23 *	−0.33 **	−0.00	0.06
Length (cm)				
Upper arm	−0.01	−0.18	0.19	−0.29 *
Forearm	0.16	−0.038	−0.00	−0.18
Femur	−0.21	−0.31 **	−0.19	−0.24 *
Tibia	−0.05	−0.34 **	0.05	−0.32 **
Breadths(cm)				
Humerus	0.07	0.22	−0.03	−0.10
Femur	−0.20	−0.11	−0.10	−0.09
Bi-acromial	0.15	0.17	−0.09	0.05
Bi-iliac	−0.02	−0.00	0.03	0.03
Body composition				
Body fat (%)	−0.42 ***	−0.42 ***	0.02	0.04
Fat-free mass (kg)	0.42 ***	0.37 *	0.30 *	0.38 ***
AMA (cm^2)	0.52 ***	0.64 ***	0.39 **	0.10
tCSA (cm^2)	0.19	0.16	0.03	0.59 ***
Somatotype				
Endomoprhy	−0.32 **	−0.28 *	−0.00	0.13
Mesomoprhy	0.02	0.26 *	0.06	0.17
Ectomoprhy	0.13	−0.03	−0.11	−0.47 ***
Proportional indices				
AL/H (%)	−0.04	−0.11	0.11	−0.12
Brachial (%)	0.18	0.12	−0.17	0.06
Crural (%)	0.20	0.11	0.24	−0.01
Brugsch's (%)	0.25 *	0.38 ***	0.29 *	0.45 ***
Acro-iliac (%)	−0.17	−0.16	0.11	−0.02

3.3. Regression Analysis

The investigative analysis showed that the final score was influenced by 25% for chin-ups, 26% for dips and 49% for squats in women, while in men, the final score was influenced by 18% for chin-ups, 25% for dips, 44% for squats and 13% for muscle-ups. Four prediction equations were developed to calculate the streetlifting performance using girths and body composition. Table 4 reports the models of the linear regression analysis used to predict the corrected streetlifting performance. The values of the predicted maximum performance were not significantly different to the corrected streetlifting performance for chin-ups (132.47 ± 32.34 kg vs. 132.49 ± 30.44 kg, $p = 0.986$), dips (160.84 ± 41.82 kg vs. 160.85 ± 39.61 kg, $p = 0.997$), muscle-ups (100.12 ± 13.05 kg vs. 100.19 ± 10.63 kg,

p = 0.949) and squats (229.48 ± 53.91 kg vs. 229.45 ± 48.38 kg, p = 0.993). Furthermore, near-perfect correlations were detected between the predicted performance and chin-ups (overall: r = 0.94; male: r = 0.74; female: r = 0.84), dips (overall: r = 0.95; male: r = 0.79; female: r = 0.84) and muscle-ups (male: r = 0.81), while the predicted squat performance showed a very large correlation with the corrected squat performance in the overall sample (r = 0.89) and in men (r = 0.82) and a moderate correlation in women (r = 0.48). The RMSE of the prediction equations were 11.14 kg, 13.58 kg, 7.70 kg and 24.08 kg for chin-ups, dips, muscle-ups and squats, respectively.

Table 4. Linear regression model for corrected streetlifting performance. Tensed and flexed arm and chest girth are expressed in cm. tCSA = thigh cross-sectional area; sex: 0 = women and 1 = men. RMSE = root-mean-square error.

Performance	Prediction Equations	R^2	RMSE
Corrected Chin-up	−110.375 + (3.088 × tensed and flexed arm girth) + (1.383 × chest girth) − (1.226 × %bodyfat)	0.89	11.14
Corrected Dip	−113.455 + (7.880 × tensed and flexed arm girth) − (1.305 × %bodyfat)	0.90	13.58
Corrected Muscle-up	−79.593 + (1.059 × chest girth) + (1.688 × tensed and flexed arm girth)	0.66	7.707
Corrected Squat	−94.110 + (1.931 × tCSA) + (15.420 × sex)	0.81	24.081

4. Discussion

The aim of this study was to identify the anthropometric profile of streetlifting athletes and to study the relationships between anthropometry, body composition variables and sport-specific strength performance. The results of this study showed that as the weight category increases, the athletes are characterized by increased heights, larger circumferences and greater endomorphic components. This is consistent with previous investigations conducted on competitive powerlifters [3,4,21]. On the contrary, ectomorphy tended to be lower in the heavy-weight categories of both sexes, compared to the lighter categories. According to Sanchez-Martinez and colleagues [22,23], mesomorphy tends to remain stable in the different body weight categories of both sexes. Male athletes included in the −66 kg and −74 kg categories were characterized by the lowest body fat percentages (7.5–7.7%) and by the highest relative strength in chin-ups (104.8–103.3% of body mass), dips (146.4–150.3% of body mass) and muscle-ups (32.6–38.8% of body mass). On the contrary, the men in the +93 kg body weight category showed the highest body fat percentage (14.2%) and the lowest strength-to-weight ratios in chin-ups (80% of body mass), dips (125% of body mass) and muscle-ups (23.6% of body mass). Similar trends in body fat and relative strength were calculated in the women included in the −57 kg and −63 kg categories. This is consistent with other investigations conducted on Olympic weightlifters of both sexes [5,24]. Curiously, the relative strength was similar in the −69 kg category compared to the −63 kg body weight category in women. This is probably related to the limited number of women included in this body weight category (n = 3).

According to Vanderburgh and Edmonds [25] and Johnson and colleagues [26], an excess of body fat may have a negative impact on the pull up performance in both sexes. In addition, both chin-up and muscle-up performance (the latter performed by men only) present similar correlations with anthropometric and body composition parameters. The potential similarity between these exercises partially explains our finding. This is also confirmed by the fact that chin-up performance influenced the variance in the muscle-up performance by 87.6%. In addition, and similarly in both sexes, the tensed and flexed arm girth and AMA were more correlated to dip performance (r = 0.60 and r = 0.64 for tensed and flexed arm girth and AMA, respectively) compared to chest girth (r = 0.41). The regression analysis indeed showed that arm size explains over 50% of the variance in dip performance. Although the dip exercise includes an extension of the glenohumeral joint [27] and a strong activation of the pectoral muscle [28], arm extensor muscles may be more important than chest girth for the final performance. A relevant contribution of the triceps muscle was also reported by the same research group [29]. As previously mentioned for chin-ups, a high body fat percentage showed a negative influence on dip performance. Squats represent the exercise included in the streetlifting program that has more influence on the final total score in the competition (44% for men and 49% for women). In contrast to chin-ups and dips, body fat may not be considered as a limiting factor for squat performance. This is confirmed by Siahkouhian [30] who found no relationships between fat mass and the 1RM squat in elite male weightlifters. Thus, according to previous investigations [31], the results of the present study indicated that squat performance was mainly supported by fat-free mass and tCSA. The results of the present study showed that tCSA was more predictive than thigh girth for the maximum squat performance in women. Women, indeed, are characterized by a higher fat mass compared to men, and large girths of the thigh do not necessarily indicate big muscle cross-sectional areas [32]. In addition, ectomorphy, height, and leg length showed a negative correlation with squat performance ($r = -0.47$, -0.29 and -0.25 for ectomorphy, height and leg length, respectively). This is consistent with Vigotsky and colleagues [33] who suggest that tall athletes may be penalized by a longer bar displacement compared to shorter athletes.

The equations developed in the present study allowed for the prediction of athletes' performance in chin-up, dip, muscle-up and squat exercises, with a high level of accuracy (R^2 = 0.66–0.90). The RMSE of the prediction equations suggested that errors in the prediction of the 1RMs should not be totally ignored by coaches and athletes. These equations, however, represent useful tools for estimating performance without performing any physical tests. Furthermore, they can be employed to calculate the optimal load in the different exercises based on percentages of the predicted 1RM. However, the prediction equations do not consider the technical components of the performance that are different for each athlete and may deeply influence their final results. A limitation of the present study is represented by the low number of women included in the −69 kg body weight category (n = 3). The differences in the pre-competition warm-up performed by each athlete and the absence of doping tests are also possible limitations. Thus, the use of performance-enhancing substances cannot be completely excluded.

To the best of our knowledge, the present study was the first to analyze anthropometry, body composition and performance of streetlifting athletes of both sexes. The normative data presented in this investigation and the prediction equations developed may help coaches and practitioners in athlete evaluation and comprehending the key factors of streetlifting performance. The importance of fat-free mass and the negative influence of fat mass suggests the adoption of training and nutritional strategies that maximize the first and minimize the second, to increase the overall score of streetlifting athletes. Further investigations are needed to compare the performance and anthropometric characteristics of the different body weight categories of streetlifting athletes of both sexes.

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