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Relationship of regional and whole body morphology to vertical jump in elite soccer players: a data-driven approach

Running title: Morphology and performance in soccer

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ABSTRACT

Background – This study aimed to analyse the relationship of regional and whole body morphology to vertical jump performance and to compare the morphological features outlining high and low performers in professional soccer players.

Methods – Twenty-one male soccer players were recruited. Whole and regional (upper and lower limbs) features were obtained in the form of body dimensional measurements. Then, all players were tested for vertical jump performance. A data-driven approach was used to group players according to their jump performance parameters (high vs low).

Results – The regional morphological features presented higher correlations with vertical jump than whole body features. High and low performers were significantly different among upper- and lower-limb morphology. No differences were observed among whole body features.

Conclusions – These findings indicate that, rather than the whole body, the use of morphological features linked to specific body regions may ensure a better interpretation of the soccer players' physical potential in jump performance.

Keywords: anthropometry; power; strength; body composition; football.

1. Introduction

It is worth bearing in mind that "there are myriad factors involved in the achievement of soccer performance, including technical, tactical, mental and physical qualities" [1]. Among physical qualities underpinning players' athleticism, anthropometry is an important determinant as capable of influencing players' potential on the field [2,3]. When dealing with anthropometry, aside from body mass, stature, and body mass index, acquiring direct morphological dimensions such as breadths, girths and skinfolds (SKFs) is a question of paramount importance to obtain the whole body (e.g. fat mass, fat free mass, bone) and upper- (e.g., arm fat area, arm muscle circumference, arm muscle area) and lower-body (e.g. thigh fat area, thigh muscle circumference, thigh muscle area) morphological features. These can also provide the practitioners with specific physiological information with high applicability to the field [4,5]. Of note, fitter soccer players presenting low percentage of fat mass versus high percentage of fat free mass are advantaged in developing marked levels of force and power [6,7]. Moreover, upper body morphological features (e.g., arm muscle circumference and arm muscle area) have been also considered important predictors of sprint performance in young soccer players [2].

During a match, a soccer player constantly plays within an unpredictable scenario that features powerful movement tasks (sprint, change of directions, jumps) to be rapidly accomplished [8]. Hence, the ability to briefly apply force and develop power is crucial in soccer. For instance, it is worth noticing that sprint and jump performance represent the first two most frequent tasks during goal and assist scenarios in professional soccer matches [9,10]. Notably, vertical jump performance is widely used as an indirect measure of lower-limb power and strength. It has been previously demonstrated its usefulness to discriminate the level of the players in youth soccer [11]. In adults, although it would not seem getting the same discriminatory capability [12], vertical jump assessment may be of interest to detect professional-standard players' ability [12], perhaps reflecting their remarkable level of muscle power.

Several studies successfully investigated the possible association between vertical jump performance and morphological features in soccer [6,7,13–16] indicating that body fat mass is negatively associated with jump height [14,15]. However, most of these studies are based on young players and share common whole body morphological features such as body fat and fat-free mass. Of note, maturity-related exercise changes due to growth spurt may induce confused interpretations if no (or inappropriate) scaling method is adopted in youth (i.e, scaling for body size difference) [17]. Moreover, the whole body morphology alone delivers general information on an individual's body composition. Yet, they are hardly to offer specific insights on how regional morphology (e.g., upper- and lower-limbs, arm muscle circumference) may be associated with vertical jump performance. Brocherie et al. 2014, investigated the relationship between several morphological features and athletic performance, including vertical jump in adult national soccer players. Besides conventional measures (e.g., body mass index), the authors found a large association between regional body dimensions linked to lower-body limbs (i.e., muscular cross-sectional area for mid-thigh and calf, and muscle-to-bone ratio) and vertical jump. Although the relationship does not provide for cause and effect, this result places emphasis on the relevance of power and strength in professional soccer players, guiding practitioners to target their training program over their own players' needs. In light of that, such data might move the physical assessment on a more individual level helping practitioners to get a better data interpretation on the morphological profile, perhaps focusing on a limited number of variables (regional) and saving time to assess adult players.

Therefore, the first aim of the present study was twofold: i) to analyze the potential relationship of regional and whole body morphology to vertical jump performance in professional soccer players; ii) to compare morphological features outlining high and low performers in vertical jump.

2. Method

2.1. Participants

Twenty-one male professional soccer players (age = 27.17±5.07 years, body weight = 79.30±7.36 Kg, height = 184±5 cm, BMI = 23.31±1.15 Kg/m^2, fat mass = 8.80±1.10 %). The players taking part of the same team attending the Italian first division (Serie A) were selected to participate in this study. The players voluntarily decided to participate and provided a signed informed consent after a detailed description of the study procedures. The project was conducted according to the Declaration of Helsinki and was approved by the Bioethics Committee of the University of Milan (Approval number: 32/16).

2.2. Regional and whole body morphology

The morphological features included in the study were body mass, height, arm girth relaxed and arm girth flexed circumferences, waist girth circumference, gluteal girth circumference, right and left thigh circumferences, right and left calf circumferences, humerus and femur breadths, and 8 skinfolds (SKFs), i.e. triceps, subscapular, biceps, iliac crest, supraspinal, abdominal, anterior thigh and medial calf. Additionally, the sum of 4 SKFs (Σ4 = biceps + triceps + subscapular + iliac crest), 7 SKFs (Σ7 = triceps + subscapular + iliac crest + supraspinal + abdominal + anterior thigh + medial calf), 8 SKFs (Σ8 = triceps + subscapular + biceps + iliac crest + supraspinal + abdominal + anterior thigh + medial calf) were considered for the analysis.

Regional morphological features for muscle area of upper arm (AMA) and thigh (TMA), and for fat area of upper arm (AFA) and thigh (TFA) were calculated according to the literature [18]. Corrected arm muscle area (AMA_{corr}) was also obtained by the Heymsfield and colleagues' equation [19]. Additionally, arm muscle (AMC) and thigh muscle circumferences (TMC) were estimated using the formula (arm girth relaxed – π* triceps SKF and thigh girth – π* thigh SKF, respectively) [18]. Total arm (TAA) and total tight areas (TTA) were also obtained as previously reported in literature [2]. All measurements were recorded by an accredited (level 1) anthropometrist following the International Society Advancement Kinanthropometry guidelines [20]. Height was recorded to the nearest of 0.1 cm with a standing stadiometer (Seca 217, Basel, Switzerland), and body weight was measured to the nearest of 0.1 Kg with a high-precision mechanical scale (Seca 877, Basel, Switzerland). Body mass index (BMI) was calculated as the ratio of body mass to height squared (kg/m^2). Additionally, regarding whole body morphological features, fat mass was obtained from the Whiters and colleagues' equation [21], where body density was previously calculated from the equation of Siri adapted for age [22,23]. Then, the fat-free mass was obtained by subtracting it from the body mass. The Fat Mass Index (FMI) calculated as fat mass/$height^3$ [24]. All girths were taken to the nearest of 0.1 cm using a metric tape (Lufkin executive thinline, W606ME). Breadths were taken using a Campbell 10 sliding-branch caliper (Rosscraft, Canada), while SKFs were measured to the nearest of 0.1 mm using a caliper (Holtain Ltd, Crymych, UK). For each anthropometric site considered, three measurements were obtained and their mean was used for the analysis.

2.3 Food and fluid intake before jump test

On the testing day, all subjects consumed an easily digestible carbohydrates rich meal (1,5 g/Kg body mass) 2 h before the testing session to exclude differences in macronutrients and total energy intake [25]. In addition, 2 h prior to the physical assessment, all athletes ingested 6 mL/Kg body mass of isotonic fluid [26]. This allowed the excess fluid to be voided prior to exercise and ensure a euhydration status [27]. In addition, all participants were asked not to take any supplements.

2.4 Vertical jump assessment

In the 24 h period before executing the countermovement jump test (CMJ), participants did not engage in activity that was considered unduly fatiguing. Each participant executed three maximal jump trials on a portable force platform (Quattro Jump, Kistler, Winterthur, Switzerland). Each trial was performed from a standing position with hands placed on the hips. During an individual trial, the participants quickly bent downward and then performed a fast upward push to reach the highest height from the lower limbs action. CMJ height, power output, and strength were recorded within the upward phase by a dedicated software (Kistler software, Version 1.1.1.4). A recovery of 2 min was allowed between trials.

2.5 Data analysis

The overall analysis was programmed using Python 3 programming language. Data are reported as mean ± standard deviation (SD). An alpha threshold of p-value < 0.05 was set to identify statistical significance.

2.5.1. A data-driven approach for players split

Since no profile has been defined to discriminate between high and low vertical jump performers, a data-driven approach was used to group players according to their jump performance parameters (i.e., height, power, and strength). This approach is helpful to obtain multidimensional information derived from the data without any external interference. To this aim, an unsupervised machine learning model was trained. This model permits to extract undetectable patterns in a data set with no pre-existing labels and without any supervision of humans. We hypothesized that higher vertical jump performance would be associated with a better morphological profile.

A silhouette analysis was used in order to detect the best number of clusters permitting grouping players based on their similarity in jump performance. The silhouette score is a measure of how similar a player is to its own cluster (cohesion) compared to other clusters (separation). This score ranges from -1 to 1. The silhouette was calculated as the Euclidean distance after normalizing the jump values from 0 to 1. Practically, the higher is the mean of silhouette scores of the players, the higher will be the cohesion of the players into the clusters. The players clustering was made by using the K-means algorithm (non-supervised model). K-means clustering partitioned *n* observations into *k* clusters in which each observation belongs to the cluster with the nearest mean (cluster centroid). This approach resulted in a split of the data space into Voronoi cells. The players were grouped by K-means algorithm from 2 to 10 groups and the best *k* clusters were assessed by the silhouette score.

2.5.2. Statistical analysis

The normal data distribution was verified by Shapiro-Wilks' normality test. Unpaired t-test or Mann-Whitney U test was performed in order to detect differences between groups of players with different jump performances. The magnitude of the difference was assessed by Cohen's d effect size (ES). ES was computed as the ratio between the two groups' mean difference and the pooled standard deviation. Absolute ES ≤ 0.2, $0.2 < ES \leq 0.5$, $0.5 < ES \leq 0.8$ and > 0.8 were considered a *trivial*, *small*, *medium* and *large* effect size. Moreover, the correlation of whole body and regional morphology to vertical jump performance was performed by using Pearson's correlation coefficient.

3. Results

Figure 1 shows the relationship of regional and whole body morphology between vertical jump performance. Overall, upper and lower body features exhibited higher correlations (*trivial* to *medium*) compared with whole body features (*trivial* to *small*) toward jump power and strength. Figure 2 shows the best number of clusters (i.e., 2) resulting in a silhouette score of about 0.48. Figure 3 shows the scatter plots of the three jump performance variables outlining high and low performer groups. The high performers presented significantly higher body mass (85.56 ± 6.30 kg vs. 75.09 ± 6.41 kg; $p < 0.001$, ES = -1.65), height (1.89 ± 0.04 m vs 1.81 ± 0.05 m; $p < 0.001$, ES = -1.78), and BMI (23.91 ± 1.25 kg/m^2 vs. 22.84 ± 1.10 kg/m^2; $p = 0.03$, ES = -0.91). Statistical differences between high and low performers were detected within jump height, power and strength variables (Table 1). Low performers showed lower jump height (p-value = 0.05), power (p-value < 0.001) and strength (p-value < 0.001).

In order to detect whether the difference in jump performance was also reflected within the morphological features, a number of unpaired t-tests were performed between groups. Table 2 shows that, overall, the high performers exhibited a better morphological profile (Table 2).

[Figure 1 near here]

[Figure 2 near here]

[Figure 3 near here]

[Table 1 near here]

[Table 2 near here]

4. Discussion

The main findings revealed that several upper and lower body morphological features exhibited higher relationship with power and strength yielded during jump compared with whole body ones. Furthermore, individual upper- and lower-limb data appear to better differentiate based on players' jump performance (low *versus* high performers). All together, these findings indicate that the use of morphological features linked to specific body regions, instead of the whole body, may ensure a better interpretation of the soccer players' physical potential in jump performance.

It has been previously established the importance of jump performance in soccer [9,10]. Players exhibiting better outcomes are likely to possess a good level of lower-limb muscle power and strength, which are determinant when training and playing. Yet, morphology is hardly to detach from the factors influencing soccer performance. Morphology assessment is a valid tool involved not only to monitor training process [28] but also sports performance [2]. According to the present results, the difference in jump performance outlines as many differences in the regional body morphology between high and low performers. Of note, the high performers presented significant greater dimensional characteristics in the upper (i.e., AMA, AMAcorr, TAA, arm girths flexed and relaxed, and humerus breadth) and lower limbs (i.e., TTA, TFA, TMA, TMC, gluteal girth, and femur breadth) compared with low performers. This suggests that large body segments, reflecting a certain muscularity, play a role in the force development during a vertical jump. This is supported by the present significant relationship among the regional features with jump strength in professional soccer players. Moreover, Brocherie et al. 2014, found a large association between morphological data linked to lower-body limbs (i.e., muscular cross-sectional area for mid-thigh and calf) with vertical jump height in elite soccer players.

To the authors' knowledge, no studies have been investigated in the role of regional morphology to discriminate high from low performers in a vertical jump within a professional group of soccer players. Although other determinants might predominantly concur to the highest performance, the regional morphology may provide a unique wealth of information. Indeed, also within a homogeneous group of players (without mingling players' level of competition), whole body features (e.g., fat-free mass) could exhibit low correlation with physical variables, such as strength [29] compared with regional features (e.g., AMA). Of note, the muscle group involved within an exercise (e.g., vertical jump) might not be regarded for the correlation analysis. Accordingly, the present data showed a low non-significant correlation between fat free mass and jump performance parameters, including strength.

The novel findings of this study indicated that the high performers exhibited significant greater upper-limb dimensional characteristics than low performers within a homogeneous group of players (i.e., professional level). Of note, the same result was observed on the lower-limb, which is conceivable because of the nature of the exercise used for grouping players' performance. Yet, the existing remarkable difference on the upper-limb features shade light on the relevance to gather such data for monitoring purposes in professional soccer.

Interestingly, in a previous study, the lower limb fat free mass (of both right and left legs) changed up to 5.6 and 5.9 % from the beginning to the end of the in-season period in young (< 17 years old) male professional soccer players [30]. At the same time, upper limb fat free mass (of the right and left arms) increased up to 11.1 and 15.6 % [30]. Moreover, another study found that legs fat free mass remained unchanged over the competitive period, while arm fat free mass underwent substantial increases (up to 6.6 and 8.6 % for the right and left arms, respectively) in older (> 17 years old) professional soccer players

[30]. Hereby, practitioners may be advised to move their attention to the upper limbs, which can provide them with additional and extended knowledge on the players' vertical jump performance. Even though other factors than morphology (regional and whole body) may represent a key determinant within elite professional competitions [31], it might be speculated that players with high performance profile have the propensity for upper-limb development. This would explain the observed tendency to muscularity over the upper-limb dimensional characteristics [29].

It is worth noticing that among whole-, upper- and lower-body SKFs, the triceps SKF was the only measure significantly differing (with an ES barely *large*) between high and low performers. Being an important estimator of the subcutaneous fat content [32], its measure appears worth to obtain an immediate and practical picture of the morphological profile of the fittest players. This is also true within a homogeneous sample of players (playing at professional level) in which a whole body composite measure of fat and muscle (derived from several regional features) might be comparable as observed in the present study.

This study presents a main limitation that should be clearly stated. All anthropometric data estimating muscle and fat fractional masses were derived by regional body measurements. Yet, methods suited for laboratory-based research such as Dual-Energy X-ray Absorptiometry (estimate bone mineral content), hydrostatic weighing or plethysmography (measurement of body volume) e dilution techniques (total body water) are capable to provide a more accurate data interpretation. However, body measurements have the merit to be costless guiding the practitioners to promptly get morphological data linked to performance over both cross-sectional and longitudinal measurement.

5. Conclusion

This study showed that several regional morphological features correlated with jump performance in terms of power and strength. Moreover, upper and lower limb morphology presented different values between high and low performers. Taken together, these findings indicate that, instead of whole body morphology, the focus on regional features linked to upper and lower limbs ensured a better interpretation of the players' physical potential. The results from this study take an initial step towards an investigation of regional morphology for identifying players with different performance levels. Indeed, professional players producing higher levels of jump force possessed a specific morphological profile, characterized by higher muscularity in upper and lower limb and low adiposity profile. Futures studies should also examine the specific impact of players' morphology linked to their playing position on sport-specific performance.

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Conflicts of interest statement

The authors declare no competing interests.

Authors' contributions

- Study conception and design: Tindaro Bongiovanni, Alessio Rossi, and Athos Trecroci.
- Acquisition of data: Tindaro Bongiovanni, Giulio Pasta, and Paolo Manetti.

- Analysis and interpretation of data: Tindaro Bongiovanni, Alessio Rossi, and Athos Trecroci.

- Drafting of manuscript: Tindaro Bongiovanni, Alessio Rossi, and Athos Trecroci.

- Critical revision: F Marcello Iaia, Angela Di Baldassarre, and Giampietro Alberti

All authors read and approved the final version of the manuscript.

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Table 1. Descriptive statistic and statistical differences in jump performance variables between high and low performers.

Vertical jump performance	Low performance	High performance	p-value
Height (cm)	47.89 ± 4.63	52.13 ± 5.12	0.05*
Power (Watt)	4189.00 ± 396.95	5029.80 ± 407.97	<0.001*
Strength (N)	1915.45 ± 210.17	2178.00 ± 131.57	<0.001*

Table 2. Descriptive statistics and statistical differences based on the anthropometric features by group splitting.

Morphological features		Low performers	High performers	p-value	ES
Whole body	***Σ8 SKFs (mm)***	64.11 ± 7.66	61.42 ± 10.82	0.10	0.29
	Σ7 SKFs (mm)	52.04 ± 5.68	49.9 ± 7.89	0.14	0.32
	Fat mass (%)	9.19 ± 0.97	8.83 ± 1.35	0.14	0.31
	Fat free mass (%)	90.81 ± 0.97	91.17 ± 1.35	0.14	-0.31
	FMI (Kg/m^3)	1.16 ± 0.12	1.12 ± 0.22	0.09	0.24
Upper body	***Σ4 SKFs (mm)***	32.20 ± 4.42	30.26 ± 5.28	0.19	0.40
	Triceps SKF (mm)	6.11 ± 1.49	5.12 ± 1.00	0.04*	0.80
	Subscapular SKF (mm)	9.95 ± 1.31	9.76 ± 1.72	0.42	0.13
	Biceps SKF (mm)	4.07 ± 0.64	3.86 ± 0.47	0.23	0.38
	Iliac Crest SKF (mm)	12.07 ± 2.49	11.52 ± 3.30	0.25	0.19
	Supraspinale SKF (mm)	6.53 ± 1.21	6.40 ± 1.72	0.38	0.09
	Abdominal SKF (mm)	11.80 ± 3.27	11.00 ± 2.81	0.26	0.26
	Arm girth relaxed (cm)	29.50 ± 1.43	31.10 ± 1.29	0.01*	-1.18
	Arm girth flexed (cm)	32.14 ± 1.79	34.50 ± 1.39	0.01*	-1.48
	Humerus breadth	7.03 ± 0.40	7.52 ± 0.25	0.002*	-1.51
	Waist girth (cm)	82.68 ± 2.97	85.60 ± 4.23	0.05*	-0.81
	AFA (cm^2)	8.70 ± 2.02	7.73 ± 1.42	0.19	0.56
	AMAcorr (cm^a)	50.74 ± 6.82	59.39 ± 6.64	0.01*	-1.29
	AMC (cm)	27.58 ± 1.54	29.49 ± 1.41	0.01*	-1.29
	TAA (cm^2)	69.44 ± 6.92	77.13 ± 6.31	0.01*	-1.16
Lower body	***TTA (cm^2)***	271.79 ± 19.39	297.32 ± 17.77	0.003*	-1.37
	TFA (cm^2)	25.22 ± 10.52	29.36 ± 12.27	0.21	-0.36
	TMA (cm^2)	246.57 ± 15.68	267.95 ± 20.33	0.01*	-1.19
	TMC (cm)	55.94 ± 1.87	58.42 ± 1.59	0.01*	-1.43
	Gluteal girth (cm)	98.50 ± 3.17	101.95 ± 3.22	0.01*	-1.08
	Femur breadth	10.35 ± 0.42	10.71 ± 0.43	0.03*	-0.85
	Front Thigh SKF (mm)	7.85 ± 1.58	8.52 ± 1.51	0.16	-0.43
	Medial Calf SKF (mm)	5.73 ± 1.06	5.24 ± 1.21	0.14	0.43
	Right Thigh girth (cm)	59.4 ± 1.91	60.19 ± 2.75	0.25	-0.33
	Left Thigh girth (cm)	58.85 ± 2.26	60.00 ± 2.78	0.21	-0.46
	Right Calf girth (cm)	38.35 ± 1.56	38.94 ± 2.32	0.31	-0.30
	Left Calf girth (cm)	37.6 ± 1.29	38.44 ± 2.06	0.26	-0.50

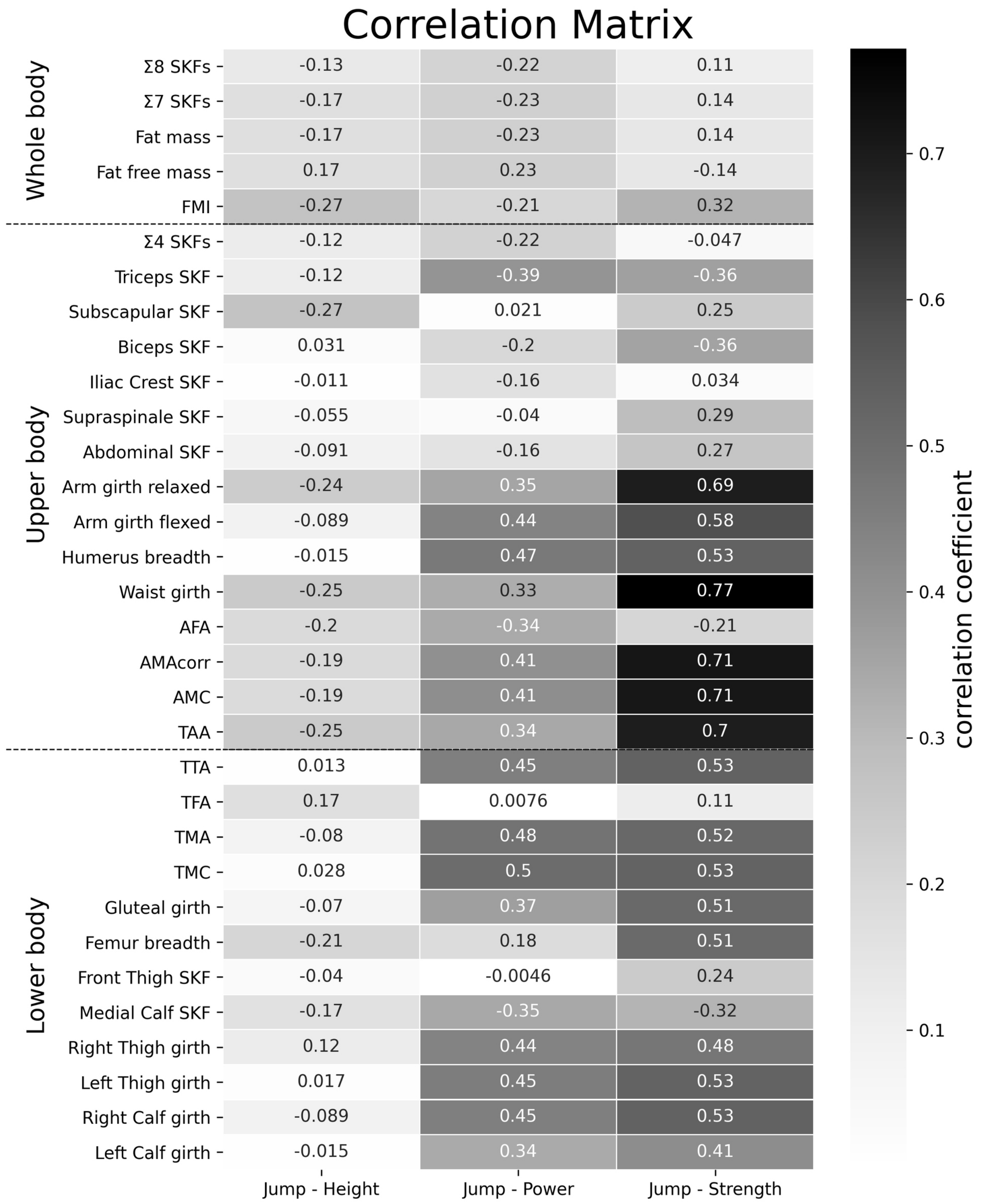
Note. ES = effect size, Σ8 SKF = sum of 8 skinfolds, Σ7 SKF = sum of 7 skinfolds , Σ4 SKF = sum of 4 skinfolds, FFM = fat-free mass, AFA = arm fat area, AMAcorr = corrected arm muscle area, AMC = arm muscle circumference, TAA = total arm area, TTA = total thigh area, TFA = thigh fat area, TMA = thigh muscle area, TMC = thigh muscle circumference.

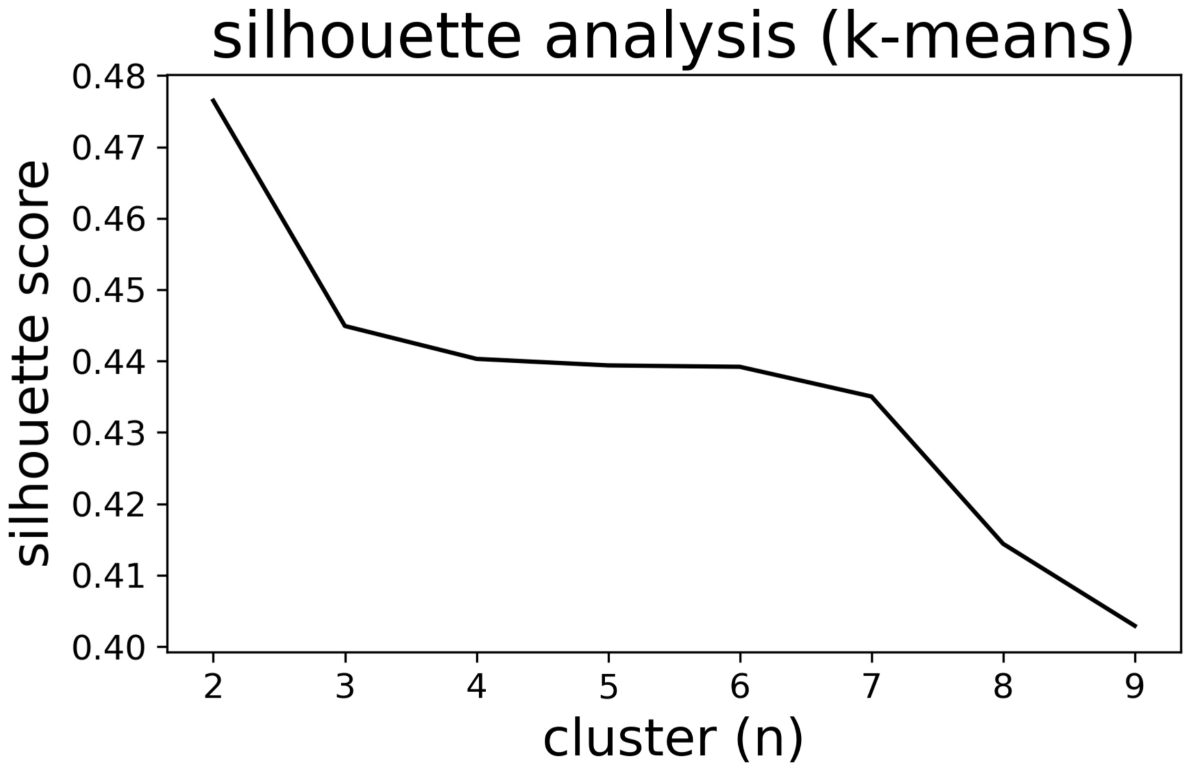
Figure captions

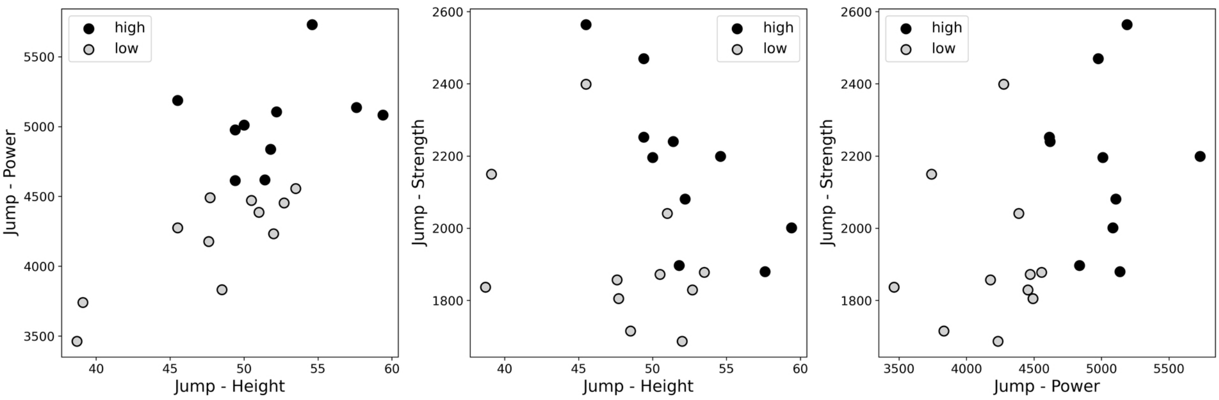
Figure 1. Correlation matrix of regional (upper and lower body) and whole body morphology to jump performance. Note. Σ8 SKF = sum of 8 skinfolds, Σ7 SKF = sum of 7 skinfolds, Σ4 SKF = sum of 4 skinfold (biceps, triceps, subscapular, iliac crest) FFM = fat-free mass, AFA = arm fat area, AMAcorr = corrected arm muscle area, AMC = arm muscle circumference, TAA = total arm area, TTA = total thigh area, TFA = thigh fat area, TMA = thigh muscle area, TMC = thigh muscle circumference.

Figure 2. Silhouette analysis cores for *k* cluster.

Figure 3. Scatter plot of the jump performance variables grouped in accordance with players split.


Correlation Matrix
Whole body
Upper body
Lower body
Σ8 SKFs
Σ7 SKFs
Fat mass
Fat free mass
FMI
Σ4 SKFs
Triceps SKF
Subscapular SKF
Biceps SKF
Iliac Crest SKF
Supraspinale SKF
Abdominal SKF
Arm girth relaxed
Arm girth flexed
Humerus breadth
Waist girth
AFA
AMAcorr
AMC
TAA
TTA
TFA
TMA
TMC
Gluteal girth
Femur breadth
Front Thigh SKF
Medial Calf SKF
Right Thigh girth
Left Thigh girth
Right Calf girth
Left Calf girth
Jump - Height
Jump - Power
Jump - Strength
correlation coefficient
-0.13 -0.22 0.11
-0.17 -0.23 0.14
-0.17 -0.23 0.14
0.17 0.23 -0.14
-0.27 -0.21 0.32
-0.12 -0.22 -0.047
-0.12 -0.39 -0.36
-0.27 0.021 0.25
0.031 -0.2 -0.36
-0.011 -0.16 0.034
-0.055 -0.04 0.29
-0.091 -0.16 0.27
-0.24 0.35 0.69
-0.089 0.44 0.58
-0.015 0.47 0.53
-0.25 0.33 0.77
-0.2 -0.34 -0.21
-0.19 0.41 0.71
-0.19 0.41 0.71
-0.25 0.34 0.7
0.013 0.45 0.53
0.17 0.0076 0.11
-0.08 0.48 0.52
0.028 0.5 0.53
-0.07 0.37 0.51
-0.21 0.18 0.51
-0.04 -0.0046 0.24
-0.17 -0.35 -0.32
0.12 0.44 0.48
0.017 0.45 0.53
-0.089 0.45 0.53
-0.015 0.34 0.41
0.7
0.6
0.5
0.4
0.3
0.2
0.1


silhouette analysis (k-means)
silhouette score
cluster (n)
0.48
0.47
0.46
0.45
0.44
0.43
0.42
0.41
0.40
2
3
4
5
6
7
8
9


high
low
Jump - Power
Jump - Height
Jump - Strength
Jump - Height
Jump - Strength
Jump - Power