The Journal of Sports Medicine and Physical Fitness
EDIZIONI MINERVA MEDICA

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The Journal of Sports Medicine and Physical Fitness 2021 Sep 21
DOI: 10.23736/S0022-4707.21.12911-1

Article type: Original Article

Article first published online: September 21, 2021
Manuscript accepted: September 13, 2021
Manuscript revised: September 3, 2021
Manuscript received: May 28, 2021

Association of phase angle and appendicular upper and lower body lean soft tissue with physical performance in young elite soccer players: a pilot study

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Abstract

Background. In soccer, a better understanding of the bioimpedance parameters with physical performance may be useful to efficiently monitor and interpret players' performance variation throughout a certain period of the season. Therefore, this study aimed to examine the association between phase angle (PhA) and arms and legs lean soft tissue (ALST and LLST) with physical performance in young elite soccer players.

Methods. Fifteen young male elite soccer players (age = 14.2±1.2 years, BMI = 20.51±1.38 kg/m^2) participated in this investigation. Raw bioimpedance parameters (reactance, resistance, and phase angle) were obtained by a bioelectrical impedance analysis (BIA) device. Then, ALST and LLST were estimated. All players underwent a physical testing battery including countermovement jump (CMJ), 10-m and 20-m sprint, and Yo-Yo Intermittent Recovery Test level 1 (YoYo IRTL1) in the domains of anaerobic and aerobic performance, respectively.

Results. The results showed that LST (total, arms and legs) positively correlated with CMJ ($0.64 < r < 0.69$; $p < 0.001$) and negatively correlated with 10-m ($-0.59 < r < -0.63$; $p < 0.05$) and 20-m sprint ($-0.67 < r < -0.73$; $p < 0.001$), while PhA positively correlated with CMJ ($r = 0.57$; $p < 0.05$) and negatively correlated ($r = -0.54$; $p < 0.05$) only with 20-m sprint. No significant association was found between the BIA-related parameters (PhA and LST) and Yo-Yo IRT level 1.

Conclusion. The present findings highlight the existing association of PhA and LST with jumping and sprinting performance in young elite soccer players. This result supports the use of BIA-related measures as a simple and practical approach to monitoring anaerobic performance changes, rather than aerobic, over time throughout the season.

Keywords: morphology; lean soft tissue; bioelectrical impedance analysis; anaerobic performance.

Introduction

In soccer, the assessment of body composition becomes relevant due to its inherent association with a wide range of strength- and power-related tasks underpinning players' physical performance [1–4]. A number of methods such as dual-energy x-ray absorptiometry (DXA), anthropometry, and bioelectrical impedance analyses (BIA) have been involved in the attempt to assess body composition features either regionally or at the whole body level [5], with a special emphasis on lean soft issue (LST) distribution. Even though DXA can be considered valid and reliable for the estimated total and regional (upper- and lower-limbs) LST in various populations [6–8]; however, it is the high-cost, low portability, and operational issues (e.g. subject positioning during DXA scans) concur to reduce its availability in the field setting [9] for assessing soccer players' body composition.

Anthropometric measures (e.g. girths and skinfolds) were previously used to predict appendicular LST compartment [10] and to obtain regional muscular mass data [3] in young boys. Although anthropometric data can be provided by simple and feasible measurements outside laboratory conditions, the derived estimates of body composition are susceptible to errors and may require a certified and trained anthropometrism to limit potential operator-dependent issues. Moreover, to explore an individual's body composition profile (LST and fat mass distribution), several measures (e.g., girths, skinfold thickness, and breadths) are often needed, which could impair the already scarce time availability for athletes' monitoring process within the "real-world" setting.

Conversely, BIA has been proposed as a more practical alternative method due to its non-invasiveness, high portability, reproducibility [11], and ablity to assess cellular health and body fluids distribution, through the measurement of the bioelectrical phase angle (PhA) [12]. Interestingly, the ratio between intracellular and extracellular water, as well as cellular integrity and density reported as bioelectrical phase angle (PhA), have been shown recently to be associated with soccer-related performance in elite players [13,14]. PhA represents a highly informative BIA-related parameter, which is derived from reactance and resistance measurements. It has gained relevance as a predictive indicator of hydration status and cellular function [15].

Current research seems to indicate a link between PhA and muscle function [14,16–18]. Accordingly, it has been suggested that higher values of PhA would reflect a better muscle quality and functionality in older women [17] and young team sport athletes of different levels of play [16].

In the sporting arena, Nabuco et al. [14] examined the relationship between PhA and short-term maximal sprint in male soccer players. The authors found a positive association of PhA with maximum power emphasizing its potentiality as a useful marker of power-related performance (i.e., sprint). This claim appears in line with that observed by Pollastri et al. [19] who found the baseline PhA data associated with a maximal mean power of short efforts in elite cyclists during the Giro d'Italia. The importance of assessing bioelectrical PhA was further documented recently by Martins et al. [13]; The authors showed that young soccer players with higher PhA values had a better performance in anaerobic activities such as repeated sprint ability (RSA) and sprinting speed. However, while the evidence apparently points to PhA as an informative marker for monitoring athletes [14,16–18], its relationship with physical performance (e.g. aerobic and anaerobic) is still poorly understood, especially in team sports athletes (i.e, soccer).

Soccer players continuously undergo repeated sprinting and jumping activities (anaerobic physical tasks) during matches and training [20,21] throughout the season. In light of this, retrieving several informative data on muscular performance would be desirable in the attempt to account for training effects and injury prevention strategies [2,18,22,23] in anaerobic-based performance rather than aerobic. Of note, from a practical perspective, improving the understanding of the relationship of PhA and appendicular (total, upper and lower body) LST with physical performance may be useful to monitor and interpret players' performance variation throughout a certain period of the season.

Therefore, the aim of the present study was to verify the association of PhA and appendicular arms and legs LST (ALST and LLST, respectively) with physical performance (aerobic and anaerobic) in young elite soccer players. Our hypothesis was that PhA and ALST and LLST would be related to anaerobic performance (i.e., sprinting and jumping).

Materials & Methods

Participants

Fifteen young male elite soccer players (age = 14.2±1.2 years, body mass index = 20.51±1.38 kg/m^2, fat mass=10.6±1.49%) from the same Italian professional club competing in the first division (Serie A), voluntarily participated in the study. After a complete description of the study and an illustration of the procedures, all participants verbally agreed to the testing conditions. Moreover, a written consent was obtained from the participants and their parents after being fully informed about the experimental procedures, aims, and potential risks of the study. The study procedures were approved by the Ethics Committee of the University of Milan (Ethical Application Ref: 32/16).

Protocol

The experimental procedure occurred immediately after the competitive season 2017-18. At the time of the study, all players were accustomed to soccer training performing 4 regular training sessions per week (about 90-120 min per session) and playing one official soccer game per week. The players taking part in the study were tested on an outdoor artificial turf in the morning (10.00 am), 2 hours after a standardized breakfast (65%, 20%, 15% of total energy intake composed of carbohydrates, fat and protein, respectively) [2]. The second part of the testing session occurred in the afternoon (3.00 pm), 2 hours after a standardized lunch. All players were familiar with the physical testing battery as routinely underwent throughout the season. Specifically, all players consumed a mixed meal containing easy-to-digest carbohydrates (2 g/Kg of body weight), proteins (0.25 g/Kg of body weight) low in fats, dietary fibers, and gas-forming foods [2]. Participants were also advised to drink slowly 5-7 mL of body weight of water (about three hours) prior to the start of testing sessions to present in a euhydrated state [24].

All anthropometric and BIA measures were made in a resting and fasting state at least 24-hr after the last exercise session. Subsequently, players underwent a field-based testing battery based on an anaerobic domain (countermovement jump, 10-m and 20-m sprint). A 5-min standardized warm-up was employed before jumping and sprinting to get the players accustomed to the upcoming maximal efforts [20]. Then, in the afternoon, all participants were tested on the aerobic domain by the Yo-Yo intermittent recovery test level 1.

Testing Procedures

All anthropometric measurements were profiled by an accredited and trained anthropometrist following the International Society Advancement Kinanthropometry guidelines [25]. Height was recorded to the nearest 0.1 cm with a standing stadiometer (Seca 217, Basel, Switzerland), and body mass was measured to the nearest 0.1 Kg with a high-precision mechanical scale (Seca 877, Basel, Switzerland). Body mass index was calculated as the ratio of body mass to height squared (kg/m^2). The new youth soccer-specific equation recently developed by Munguía-Izquierdo et al. [26] was used to predict fat mass from two skinfold sites: triceps and supraspinal.

Fat-free mass data were therefore obtained by subtracting fat mass from body mass to obtain to the nearest of 0.1 Kg.

Whole-body impedance was obtained using a bioimpedance analyzer (BIA 101 Anniversary Edition, Akern, Florence, Italy). The device emits an alternating sinusoidal electric current of 400 mA at an operating single frequency of 50 kHz (±0.1%). Players were positioned with a leg opening of 45° with respect to the midline of the body, and arms were positioned with a 15° angle with respect to the trunk. After cleaning the skin with alcohol, electrodes (Biatrodes Akern Srl, Florence, Italy) were positioned on the right side of the body at the right wrist and hand (5 cm apart from each other), as well as on the right foot and ankle, each on the dorsal side and 5 cm apart from each other for all athletes, regardless of their side-dominance [27]. Prior to each test, the analyser was checked with the calibration deemed successful if R value was 383 Ohm and Xc equal to 46 Ohm. The test-retest CV for all participants was 0.3% for R and 0.8% for Xc.

ALST and LLST were also obtained using the new predictive equations developed and validated by Sardinha et al. [28]. The developed prediction equations were as follows: ALST = 0.940 x sex (0 = male; 1 = female) + 0.042 x total body weight (kg) + 0.080 x RI + 0.024 x Xc − 3.927; LLST = 1.983 x sex (0 =male; 1 =female) + 0.154 x total body weight (kg) + 0.127 x RI −1.147. RI ($height^2/R$) is the resistance index calculated as height (cm) squared divided by resistance (R). R (resistance) and Xc (reactance) are raw parameters directly measured with a bioimpedance analyzer. Total lean soft tissue was determined by summing ALST and LLST.

Anaerobic performance

Countermovement jump (CMJ). The players were requested to perform three jump trials. During all trials, each individual held a dowel across his shoulders to limit any contribution of the upper body to the jump height. Likewise, the players were also instructed to keep their lower limbs extended from the beginning to the end of the flight phase. Jump flight time was recorded by a photoelectric system (Optojump Next System, Microgate, Bolzano, Italy). The best jump height was considered in the analysis. After each trial, a 2-min recovery period was given. In case of incorrect or poor executions, the trial was repeated for an extra recovery of 2 min.

10-m and 20-m sprint. The players were asked to perform three maximal sprint bouts over 10-m and 20-m distance. Each sprint starts occurred from a standing position at the players' own decision. The foremost foot was placed 0.3 m behind the starting line. A 3-min recovery period was given between each bout. An electronic timing gates system (Witty, Microgate, Bolzano, Italia) was used to record the performance time for each sprint test (10-m and 20-m sprint). The best sprint time was included in the analysis.

Aerobic performance

Yo-Yo intermittent recovery test level 1 (Yo-Yo IRT level 1). The Yo-Yo IRT level 1 was performed at the end of the testing battery to reduce potential fatigue-related carryover effects likely to impact sprinting and jumping activities. The players were required to perform 2 x 20-m shuttle runs at increasing speeds, interspersed by 10 s of active recovery by means of audio signals. Due to the exhaustive protocol, each player stopped his run when he was no longer capable of maintaining the required speed. The corresponding distance covered was then considered for analysis.

Statistical analysis

Pearson correlation coefficients were assessed to detect the relationship between morphology features and players' performance. In accordance with the sample size (n = 15, correlation degree of freedom = 13) the statistical Pearson's correlation coefficient threshold was set at r = 0.514. Shapiro-Wilks' normality test showed that all the features were normally distributed. The coefficient of determination (r^2) was computed to assess the percentage of variance that one variable explained on the second variable. Moreover, the effect size (ES) of the correlation was assessed by using Cohen's d transformation of r into a d-value (see Equation 1). ES were interpreted as null (<0.2), small (0.2–0.5), medium (0.5–0.8), and large (>0.8). The level of significance was set at $p \leq 0.05$ (Ellis, 2010 [29]). All the analysis were conducted using Python 3.8 programming language.

$$ES = \frac{2*r}{\sqrt{1-r^2}} \quad \text{(Eq. 1)}$$

Results

Table 1 provides the descriptive statistics of all the features assessed in this study. Moreover, correlation analysis was reported in Figure 1. In particular, except for the relationship between PhA and ALST ($r = 0.52$; $p < 0.05$; ES = 1.22), no statistical significance correlation was detected among PhA and body morphology parameters. Additionally, in Figure 1, PhA showed a positive correlation trend with Free fat mass ($r = 0.43$; $p > 0.05$; ES = 0.95) and a negative correlation with fat mass ($r = -0.24$; $p > 0.05$; ES = -0.50). Differently, FFM was strongly positively correlated with total, ALST and LLST values ($r > 0.98$; $p < 0.001$; ES > 9.85). Moreover, Table 2 provides the association of PhA and ALST and LLST with physical performance. Overall, all BIA-related parameters were positively correlated with CMJ, while being negatively correlated with 10-m and 20-m sprint (large ES) except for PhA and 10-m sprint. Although no statistical significance was detected between PhA and 10-m sprint, a large ES was observed.

Table 1 here

Table 2 here

Figure 1 here

Discussion

The main findings of this study revealed that PhA significantly correlated with 20-m sprint and CMJ, while ALST and LLST significantly correlated with 10-m sprint, 20-m sprint, and CMJ. Moreover, neither ALST and LLST nor PhA exhibited a significant correlation with Yo-Yo IRT level 1. In accordance, our previous hypothesis based on a significant association of PhA and LST (total, arms, and legs) with sprinting and jumping was verified. Taken altogether, these findings support the combination of anthropometry- and BIA-derived measures to obtain practical information on anaerobic performance rather than aerobic performance in soccer players.

PhA is an indirect measure of the ratio between Extracellular Fluid and Intracellular Fluid and it is related to measures of muscular strength [18,30,31] mirroring not only the hydration status [32], but also cellular function, muscle quality (i.e., total muscular strength per kilogram of appendicular LST), and muscle functional capacity [17]. Given the link between PhA and muscle function, it would be plausible to recommend the use of PhA as sensitive enough to assess and monitor performance [14]. Indeed, muscle mass and function go “hand-in-glove” with increasing performance so that soccer players of different levels of competition may be classified according to PhA values [16].

In the present study, the observed link between PhA and anaerobic running performance appears in line with that found by Nabuco et al [14]. The authors detected a significant correlation between PhA and running maximum power output during six 35-m repeated sprints in adult soccer players. Taken altogether, our findings concur to support the claim that PhA can be considered a useful marker associated with anaerobic performance (power-related tasks) rather than aerobic performance in soccer [14,16]. It is worth noticing that even though PhA did not significantly correlate with Yo-Yo IRT level 1 and 10-m, the ES for each relationship was large. This might be explained by the sample size, which may be too small for detecting a significant relationship between PhA and aerobic performance measured by the Yo-Yo IRT level 1. Thereby, future studies will also have to explore the relationship between PhA and physical performance (both aerobic and anaerobic) including larger sample sizes in the attempt to clarify their potential link and to improve the monitoring process.

The novelty of this study is the observed link between PhA and vertical jump performance measured by CMJ. CMJ performance (e.g., height) is widely used as an indirect measure of lower-limb power and strength. Thus, the positive large association of PhA with CMJ height supports the notion of a link between PhA and muscle function. However, it should be noted that the current PhA significantly correlated only with 20-m sprint while no remarkable association was detected with 10-m sprint. This result is hard to be explained due to a dearth of information in the literature on the association between PhA and short anaerobic performance in soccer. However, it might be argued that the small size of the sample influenced the magnitude of the relationship. Again, future studies including a larger sample of soccer players are warranted to better explore the association between PhA and running anaerobic performance over short (<20 m) distances. Although muscle power and strength remain the most important component of sprint performance, it might be argued that other elements (e.g., intra- and inter-muscular coordination, step frequency, and step length) [33] may also impact acceleration, especially during the sprint start [34], which are apparently unlinked to PhA.

The appendicular LST primarily refers to a derived measure of skeletal muscle, which identifies the largest non-adipose tissue component as part of the body composition assessment [10]. Specifically, being a skeletal muscle-related parameter, LST can play a part within the monitoring process of athletes' physical performance. According to this, the present Total LST showed a remarkable association with 10-m and 20-m sprints and CMJ. This result is likely attributed to the primary role played by lower-limb muscle function (i.e., muscle power and strength production) in explosive tasks such as sprinting and jumping. Indeed, this can be inferred by the magnitude (large) of the relationship between LLST and anaerobic performance (10-m and 20-m sprint and CMJ). Of note, ALST showed comparable correlational outcomes with LLST, suggesting a consistent link between the appendicular LST of the upper and lower body with anaerobic performance. This might provide theoretical support for employing regional (i.e., upper and lower body) skeletal muscle measures within a field-based testing battery in the attempt to account for performance changes over time in young soccer players. Bongiovanni et al. [3] previously demonstrated the predictive role of upper body morphological features (e.g., arm muscle circumference and arm muscle area) on sprint performance in young soccer players. Overall, the general picture emerging from this finding places emphasis on the importance of assessing BIA-related parameters with regard to upper and lower body to improve the understanding of body composition changes and their link with performance in team sport athletes.

An interesting side finding was that Free fat mass consistently related to sprint and jump performance as PhA (except for 10-m sprint) and appendicular LST (Total, upper and lower body). If we consider that Free fat mass is commonly associated with physical tasks involving rapid muscle activation [35,36], such a finding would appear less surprising. This is also supported by the inter-correlations with LST parameters. However, within the body composition assessment, anthropometric-derived measures (Free fat mass) would require some passages (e.g., skinfold measurements) that might be potentially subjected to errors. Specifically, acquiring information on athletes' body composition from anthropometry has to be trained in order to achieve high precision and reduce the intra- and inter-observer variability. In light of this, the use of BIA-related parameters (i.e., PhA and appendicular LST), which may be also performed by non-certified practitioners, could represent an important precise area of inquiry with a special focus on performance monitoring.

The present preliminary study has two major limitations to be recognized. First, the relatively small sample size might have masked the potential association between BIA-related parameters and aerobic performance (measured by Yo-Yo IRT level 1). For instance, the large ES observed between PhA and Yo-Yo IRT level 1 seems to point in that direction. Nevertheless, while such data might be limited in scope within the aerobic domain, relevant results were found in the anaerobic domain supporting the existing sample size, which, after all, was in line with previous correlational studies [3,4,37]. Second, it did not include a measure of the players' stage of maturation. Since PhA appears to be affected by the pubertal stage [38], the inclusion of a measure of maturation would have provided a more informative outcome on its relationship with physical performance, perhaps clarifying the unexpected non-significant association between PhA and 10-m sprint. Either way, the current results provide preliminary convincing evidence about the association between BIA-related parameters (i.e., PhA and LST) and anaerobic performance (jumping and sprinting) from a number of selected athletes (elite soccer players), representing a homogenous sample less affected by within-group variability.

Conclusion

In conclusion, our pilot study provides preliminary evidence for a significant association of PhA and LST (total, arms, and legs) with physical performance based on jumping and sprinting (i.e., anaerobic) tasks. Our results shed new light on the potential use of BIA-related parameters to monitor anaerobic physical performance. The assessment of PhA and regional lean soft tissue and their link with performance could provide additional feedback on the training effects over time. This would offer a basis for evaluating not only the appropriateness of the training program employed by the practitioners, but also the inter-individual response of athletes.

Funding details

This work is supported by the European Community's H2020 Program under the funding scheme H2020-INFRAIA-2019-1 Research Infrastructures grant agreement 871042, www.sobigdata.eu, SoBigData++: European Integrated Infrastructure for Social Mining and Big Data Analytics.

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, and Giulio Pasta.
- 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, and Giampietro Alberti

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

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Table 1. Descriptive statistics.

Features	mean	standard deviation	25%	50%	75%
Age (years)	14.20	1.21	13.00	14.00	15.00
Body weight (kg)	63.55	6.90	59.35	64.50	67.80
Height (m)	1.76	0.06	1.73	1.76	1.79
Body mass index (Kg/m^2)	20.51	1.38	19.75	20.30	21.50
Yo-Yo IR liv 1 (m)	1508.00	342.91	1220.00	1600.00	1760.00
10-m sprint (s)	1.90	0.10	1.84	1.90	1.96
20-m sprint (s)	3.25	0.13	3.19	3.23	3.32
CMJ (cm)	34.08	5.46	29.75	32.80	37.25
PhA (°)	7.12	0.68	6.75	7.10	7.80
LLST (Kg)	16.39	1.78	15.51	16.56	17.60
ALST (Kg)	5.15	0.76	4.73	5.28	5.57
Total LST (Kg)	21.54	2.53	20.17	21.78	23.12
Fat mass (%)	10.59	1.49	9.50	11.00	11.31
Free fat mass (kg)	56.83	6.29	52.65	57.73	60.60

Note: PhA = phase angle, LST = lean soft tissue, Yo-Yo IR liv 1 = Yo-Yo intermittent recovery test level 1, CMJ = countermovement jump, 25% = 1st quartile, 50% = median, 75% = 3rd quartile.

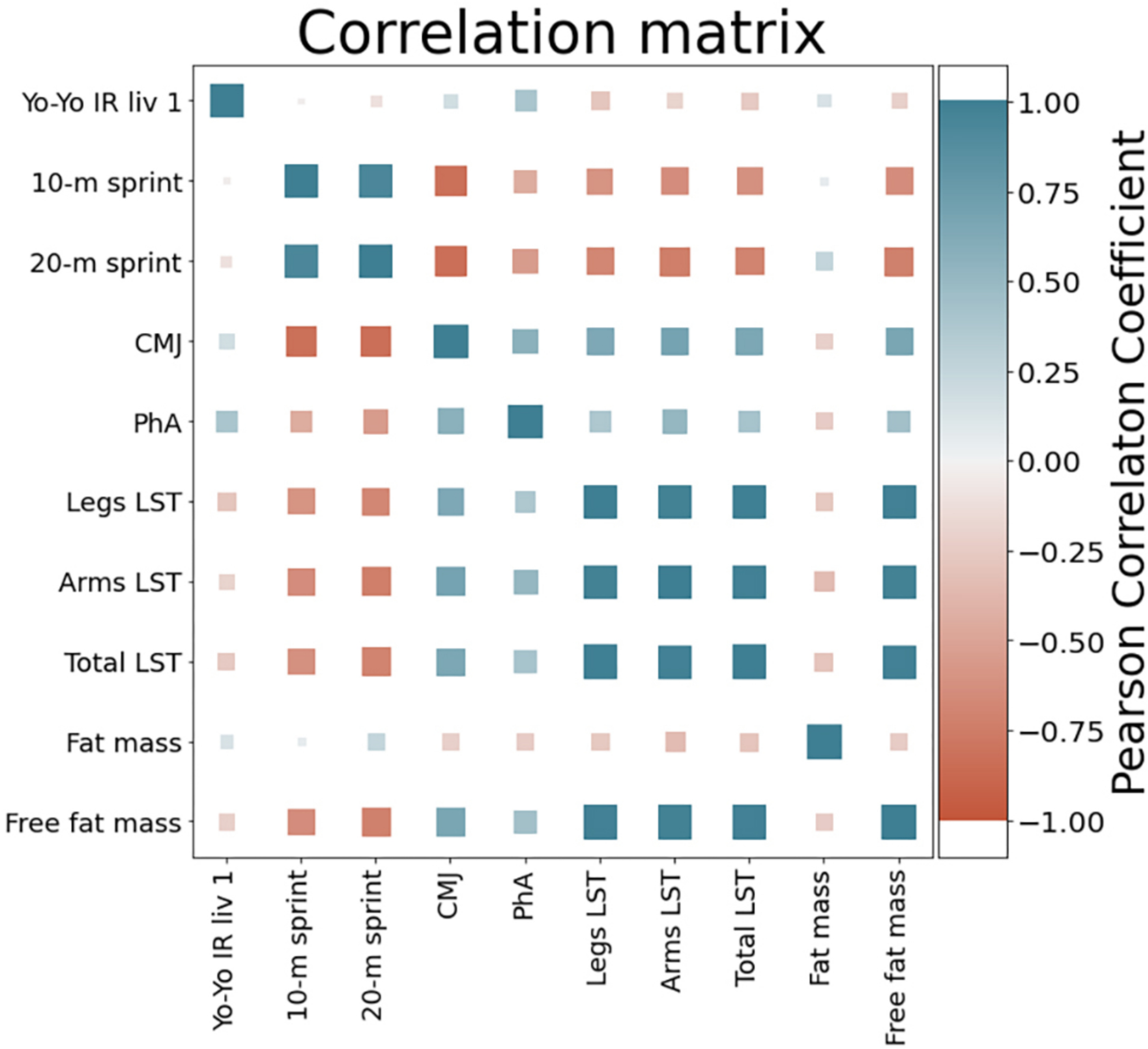
Table 2. The overall output of the correlation analysis.

Feature 1	Feature 2	Pearson correlation coefficient (r)	Coefficient of determination (r^2)	Effect size (cohens'd)
PhA	Yo-Yo IR liv 1	0.402	0.162	0.878
	10-m sprint	-0.437	0.191	-0.972
	20-m sprint	-0.543*	0.295	-1.293
	CMJ	0.574*	0.329	1.401
LLST	Yo-Yo IR liv 1	-0.271	0.073	-0.563
	10-m sprint	-0.595*	0.354	-1.481
	20-m sprint	-0.677**	0.458	-1.839
	CMJ	0.640**	0.410	1.666
ALST	Yo-Yo IR liv 1 (m)	-0.191	0.036	-0.389
	10-m sprint	-0.632**	0.399	-1.630
	20-m sprint	-0.731**	0.534	-2.142
	CMJ	0.691**	0.477	1.911
Total LST	Yo-Yo IR liv 1	-0.248	0.062	-0.512
	10-m sprint	-0.608**	0.370	-1.532
	20-m sprint	-0.696**	0.484	-1.938
	CMJ	0.657**	0.432	1.743
Fat mass	Yo-Yo IR liv 1	0.141	0.020	0.285
	10-m sprint	0.051	0.003	0.102
	20-m sprint	0.252	0.064	0.521
	CMJ	-0.21	0.044	-0.430
Free fat mass	Yo-Yo IR liv 1	-0.208	0.043	-0.425
	10-m sprint	-0.632**	0.399	-1.630
	20-m sprint	-0.717**	0.514	-2.057
	CMJ	0.665**	0.442	1.780

Note: PhA = phase angle, LST = lean soft tissue, Yo-Yo IR liv 1 = Yo-Yo intermittent recovery test level 1, CMJ = countermovement jump. Symbols * and ** refer to $p < 0.05$ and $p < 0.001$, respectively.

FIGURE CAPTIONS

Figure 1. Correlation matrix heatmap. The size of the squares refers to the strength of the relationship between two variables. Blue and red colors provide the direction of the correlation (i.e., positive and negative, respectively). According to the squares size, the darker is the color the stronger is the correlation.



Correlation matrix
Yo-Yo IR liv 1
10-m sprint
20-m sprint
CMJ
PhA
Legs LST
Arms LST
Total LST
Fat mass
Free fat mass
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
Pearson Correlaton Coefficient