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Lower Limbs Power and Bioelectrical Impedance Phase Angle in Young Non-Athletes

Erna Davidović Cvetko, Dražen Pejić, Ivana Lovrić

Department for Health Studies, University of Applied sciences Lavoslav Ružička in Vukovar, Vukovar, Croatia

ABSTRACT

Relationship of bioelectrical properties of human body and vertical jump performance is still unexplored, especially in non-athletic population. The aim of this study is to evaluate association of bioelectrical impedance results with mean force and power of the lower limbs in non-athletic young adults, and to evaluate differences between sexes in both bioelectrical impedance results and vertical jump performance. The cross-sectional study included 75 healthy non-athletic college students (40 women and 35 men aged 19-24 years). Whole-body bioelectrical impedance analysis was performed for phase angle and body composition. Force and power of lower limbs were assessed by vertical jump test. There is difference between sexes in both body composition and vertical jump performance. Along to higher content of muscles (47.5% vs 40.5%) and lower content of fat in the body (19.25% vs 28.19%), men also had higher mean force (3691.75 N vs 2351.44 N) and explosive power of the lower limbs (5627.19 W vs 2752.21 W) compared to women. Leg force and power are in correlation with body composition and with phase angle obtained by bioelectrical impedance analysis. Difference between sexes in force and power of the legs persists even after adjustment for body composition.

Keywords: college students, leg power, force, vertical jump, phase angle

INTRODUCTION

One of the key components of health-related fitness tests is musculoskeletal fitness (Grgic, 2022) because it is associated with health and well-being in different life stages (Smith et al., 2014; García-Hermoso et al., 2019; Rijk et al., 2016). Musculoskeletal fitness is determinant of nutritional status (Norman et al., 2011) and mortality (Patel et al., 2020) in adults, as well as predictor of cardiovascular, bone and metabolic health and neuromotor development and future health benefits in children (Smith et al., 2014). Vertical jump is a common way of determination of lower limbs explosive power within musculoskeletal fitness tests (Grgic, 2022). Vertical jump performance is very important for athletes and trained young adults because of prognostic values it holds for performance in different sports. It could be used for talent identification, as well as for monitoring training effects (Pupo et al., 2021). However, although it is a measure directly connected to health-related fitness in non-athletes as well, it has been measured less often in general population than in athletes (Kljajević et al., 2021). Similarly, association between explosive power of lower limbs and body composition is not fully explained for general population, since majority of studies are performed on athletes. There is evidence in the literature that a percentage of body fat is inversely correlated to vertical jump performance (Ben Mansour et al., 2021). Mocanu (2023) showed that underweight and normal weights students had much better results compared to overweight in all lower body explosive strength tests. Cattem et al. (2021) found that fat-free mass is a predictor of muscle strength and physical abilities in young athletes. These data from literature indicate that the association between body composition and physical abilities is still inconclusive, and there is need for more evidence and data to explore this relationship in general population.

One of the simplest and easiest ways to determine body composition is by bioelectrical impedance analysis (BIA). This method is easy to perform, inexpensive and fast. Body composition is calculated from measured bioelectrical properties of the human body by using different models and equations. In order to produce accurate and useful results for body composition used models must be sex-specific, age-specific, ethnicity-specific and health condition-specific (Yamada et al., 2022). However, raw BIA data such as reactance, resistance and phase angle are directly measured and not influenced by the choice of model or equation. Phase angle is considered to be a measure of cell quality and quantity (Bellido et al., 2023). It is increasing in childhood and is highest at age 18–29 years, after which phase angle is declining with age (Mattiello et al., 2020). Since it is calculated from reactance and resistance, it is dependent on bioelectrical properties of the body, cell mass and hydration status. It has been shown that athletes have higher values of phase angle than general population (Mattiello et al., 2020), and that low value of phase angle is connected to malnutrition (Basile et al., 2014), low muscle strength (Slee et al., 2015), frailty (Kilic et al., 2017) and mortality (Basile et al., 2014; Kilic et al., 2017). Since the value of phase angle is indicative for muscle mass and ratio of intracellular and extracellular water (Francisco et al., 2020), it was proposed that phase angle has predictive value for muscle strength as well (Slee et al., 2015). Indeed, it was shown in studies on athletes that phase angle is in positive correlation with muscle strength and power and sport performance (Cirillo et al., 2023). On the other hand, there is limited evidence on phase angle associations with health-related fitness determinants in general population and non-athletes, especially on association between phase angle and force and power of the muscles. There is a substantial amount of college students who are not actively involved in any kind of sport, so the results of phase angle measured on athletes are not applicable to them. Therefore, the aim of this study is to evaluate association between body composition and especially phase angle obtained by BIA and mean force and power of the lower limbs measured by vertical jump performance in non-athletic young adults. Additional goal is to determine difference between sexes in both: vertical jump and bioelectrical properties of body.

METHOD

General study design

Seventy-five college students, non-athletes (40 women and 35 men), aged 19–24 years, voluntarily participated in this cross-sectional study. The need for volunteers was advertised at the classes of physical education attended by first year students. The exclusion criteria were any injury or illness which could influence jumping performance or be influenced by performing vertical jump. Additional criterion was that participants were not athletes (not involved in sports on competitive level) or had ever been involved in sport on competitive level. Every participant gave its written informed consent for participation in this study, guarantying that he/she has met all the criteria for participation in the study, particularly regarding involvement in sports. All of the participants were Caucasians.

General data on participants were gathered by questionnaire (age, sex, body height) at the same time when BIA measurements and vertical jump measurement were made. The study protocol and procedures conformed to standards set by the latest revision of the Declaration of Helsinki and national legislation and was approved by institutional Ethical committee (approval number 602-01/24-02/01).

Bioelectrical impedance analysis

All participants were measured for weight and analyzed for body composition by a bioelectrical impedance analysis (BIA) method using body composition analyzer Tanita MC780MA (Tanita corp., Tokyo, Japan). Participants were informed of the requirements they had to fulfil before the body composition measurement: no food or drinks 4 hours prior to the measurement, no exercise 12 hours before the measurements, no alcohol consumption within 48 hours before the measurement, and emptying the bladder 30 minutes prior to the measurement. Measurement results included: body mass index (BMI), lean body mass (LBM), mass of body fat (MBF), percent of body fat (%BF) and percent of skeletal muscle (%SM) in the whole body, and in separate segments (legs, arms and trunk), and phase angle (PhA). Measurement was performed in the morning (at 7–9 h AM), by the trained technician. Subjects were positioned to stand barefoot on two electrodes built in pedestal of the instrument and holding other two electrodes in hands, while small electrical current is running through the body. Body composition was calculated based on size of impedance by the manufacturer's software. Validity and reproducibility of Tanita MC780MA has been reported by Verney et al. (2015). Precision and repeatability of BIA analyzer was additionally determined by measuring 10 subjects on 3 consecutive days. %CV (coefficient of variability) and ICC (intraclass correlation coefficient) were calculated from these 4 sets of results. We obtained overall results as follows: for MBF: ICC=0.966, CV=1.9%. For PBF: CV=1.90%, ICC=0.941, for LBM: ICC=0.742, CV=1.7%, for PhA: ICC=0.895, CV=1.1%.

Vertical jump test

My Jump2 application running on iPhone 11 (Apple Inc, Cupertina, CA, USA) was used to record and process high-speed videos (240 frames per second, 1080 pixels) of counter movement jump (CMJ) performed by participants (Pueo et al., 2023). The smartphone was positioned 1.5 m from the place of jump performance on a tripode at 30 cm height following the guidelines of the app (Balsalobre-Fernández et al., 2015). Participants performed standardized 10 min warm-up (De Rezende et al., 2016) followed by 3–5 familiarization jumps performed after detailed instructions on requested jumping technique. The main purpose of the familiarization jumps was, besides the warm-up, to practice jump technique so that the jumping and the landing technique is the same for all participants. After the warm-up they performed 3 counter movement jumps which were assessed by the application. Flight time was assessed as time between take-off (last frame with both legs touching the ground before jump) and landing (first frame with at least one leg touching the ground after the jump). The application assessed the jump height and speed, mean force and power of the lower limbs.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics (Version 29.0 for Windows; IBM, Armonk, NY, USA). Results are presented as arithmetic mean ± SD. Normality of distribution was confirmed by Shapiro-Wilk test. Since continuous variables met the assumption of normality (Shapiro-Wilk test $p>0.05$) and the sample size is >30, parametric statistics were applied (Simundic, 2012). Assumption of equal variances was met (Levene's test $p>0.05$). Differences between women and men were tested by unpaired t-test (results of BIA measurement) and ANCOVA (analysis of covariance) for differences between sexes in jump performance with controlling for body composition (%body fat, %muscles). Correlation was assessed by Pearson coefficient of correlation and interpreted as: negligible correlation (r= 0.0–0.1), weak correlation (r=0.1–0.39), moderate correlation (r=0.4–0.69), strong correlation (0.7–0.89), and very strong correlation (r=0.9–1) (Schober et al., 2021). Relations between phase angle obtained by BIA and leg power and leg mean force were additionally tested by two linear regression models with the dependent variables power in one linear regression model and mean force of the legs in other linear regression model and the independent variable phase angle in both models. The assumptions for calculating linear regressions according to Bazdaric et al. (2021) were met: there was a linear relationship between the dependent variable and independent variable; the variance of the residuals was constant (White test $p > 0.05$); and the residuals were normally distributed (Shapiro–Wilk test $p > 0.05$). Effect sizes are calculated with the help of online calculator (Lenhard & Lenhard, 2022). Cohen's d was calculated for the results of t-tests and interpreted according to Schober et al. (2021) as: trivial (Cohen's d< 0.1), small (Cohen's d 0.1–0.34), medium (Cohen's d 0.35–0.64), large (Cohen's d 0.65–1.19) and very large (Cohen's d ≥1.2). Effect sizes for ANCOVA results are presented as partial eta squared and interpreted as: small effect (0.01-0.039), intermediate effect (0.04–0.11) and large effect (>0.14) (Lenhard & Lenhard, 2022). Level of statistical significance was set at $p=0.05$.

RESULTS

Mean results of BIA measurements for the whole sample, as well as for separate sexes are presented in Table 1. together with statistical significance for differences between sexes.

Table 1. Results of bioelectrical impedance analysis for the whole sample and comparative statistics by sex

	whole sample (n=75)		men (n=35)		women (n=40)		Difference between women and men			
	mean	SD	mean	SD	mean	SD	95%CI of the difference lower	95% CI of difference upper	p	Cohen d
BMI (kg/m²)	23.98	4.26	25.16	2.74	23.54	4.66	-4.19	0.95	0.212	0.383
%BF	25.75	7.66	19.25	5.16	28.19	7.03	4.94	12.95	<0.001	-1.358
%BM	42.31	5.74	47.53	4.22	40.35	4.99	-10.09	-4.26	<0.001	1.499
LL %fat	29.04	9.46	16.60	6.06	33.69	5.40	13.61	20.35	<0.001	-2.989
LL %muscle	67.03	9.06	78.90	5.70	62.56	5.16	-18.73	-11.93	<0.001	3.016
PhA (°)	5.90	0.84	6.85	0.73	5.55	0.56	-1.67	-0.93	<0.001	2.157

BMI body mass index, %BF percentage body fat, %BM percentage body muscle, LL lower limbs, PhA phase angle

Most of the participants had BMI in the range 18.5–25 kg/m^2 indicating healthy body weight (67 participants or 89%), there was one underweighted participant, and 7 participants with BMI over 25 kg/m^2. There was no statistically significant difference in BMI between men and women, but they differed in body composition, with higher content of muscles and lower content of fat in men compared to women. Men also had statistically significant higher values of phase angle than women.

Vertical jump measurement yielded results summarized in Table 2.

Table 2. Results of vertical jump measurement for the whole sample and comparative statistics by sex

	whole sample (n=75)		men (n=35)		women (n=40)		Difference between women and men			
	mean	SD	mean	SD	mean	SD	95%CI of the difference lower	95% CI of difference upper	p	Cohen d
Jump height (cm)	30.99	15.75	45.22	18.21	25.37	10.42	-27.82	-11.87	<0.001	1.534
Flight time (ms)	488.06	118.24	593.8	119.59	446.32	88.97	-207.68	-87.28	<0.001	1.505
Velocity (m/s)	1.19	0.293	1.46	0.299	1.09	0.22	-0.515	-0.217	<0.001	1.539
Force (N)	2730.77	924.2	3691.75	876.48	2351.44	622.58	-1769.74	-910.88	<0.001	1.918
Power (W)	3565.89	2060.83	5627.19	2445.28	2752.21	1141.84	-3859.67	-1890.3	<0.001	1.804

Men had statistically significantly higher all measured variables (jump height, speed, time of flight, mean force and power) compared to women. Difference in force and leg power between sexes persisted even after controlling for body muscle content and muscle content in the legs ($F=23.3$, $p<0.001$, partial eta squared=0.374; $F=18.78$, $p<0.001$, partial eta squared=0.304 respectively).

Correlation analysis revealed that BMI is not statistically significantly correlated to variables of vertical jump performance. However, body composition, as well as composition of legs is statistically significantly correlated to vertical jump performance, and to mean force and leg power. Correlations between results of BIA measurement and vertical jump diagnostic are presented in Table 3. Results for 95% CI obtained from Pearson correlation coefficient are uniformly distributed indicating weak to moderate correlations of BIA results and jump performance variables. Phase angle correlated significantly with mean leg force (95% CI r= 0.252 to 0.664), and leg power (95% CI r= 0.148 to 0.598). Muscle content in the lower limbs correlated to all of the vertical jump performance results: jump height (95% CI r= 0.201 to 0.616), flight time (95% CI r= 0.198 to 0.613), velocity (95% CI r= 0.199 to 0.614), force (95% CI r= 0.146 to 0.611) and power (95% CI r= 0.176 to 0.613). Similar results were obtained for muscle content of the whole body (%BM) which correlated statistically significant to: jump height (95% CI r= 0.170 to 0.557), flight time (95% CI r= 0.159 to 0.563), velocity (95% CI r= 0.161 to 0.562) and power (95% CI r= 0.083 to 0.519). Fat content in the lower limbs negatively correlated to all of the jump performance variables: jump height (95% CI r= -0.243 to -0.65), flight time (95% CI r= -0.25 to -0.645), velocity (95% CI r= -0.25 to -0.644), force (95% CI r= -0.175 to -0.645) and power (95% CI r= -0.217 to -0.645). Similarly, fat content of the whole body (%BF) negatively correlated to: jump height (95% CI r= -0.180 to -0.542), flight time (95% CI r= -0.139 to -0.544), velocity (95% CI r= -0.141 to -0.545) and power (95% CI r= -0.045 to -0.495).

Table 3. Pearson correlations between results of bioimpedance measurements and vertical jump measurement results

	PhA (°)	LL %muscle	LL %fat	BMI (kg/m^2)	%BF	% BM
Jump height (cm)	0.247	0.438**	-0.475***	0.013	-0.361**	0.382**
Flight time (ms)	0.271	0.432***	-0.470***	0.017	-0.354**	0.376**
Velocity (m/s)	0.261	0.434**	-0.471**	0.017	-0.355*	0.376***
Force (N)	0.393**	0.404**	-0.440***	0.264	-0.223	0.260
Power (W)	0.302*	0.428***	-0.464***	0.158	-0.291*	0.321*

*BMI body mass index, %BF percentage body fat, %BM percentage body muscle, LL lower limbs, PhA phase angle, *=p<0.05, **=p<0.01, ***=p<0.001*

Linear regression model applied to assess relations between dependent variable mean force and independent variable phase angle obtained by BIA was found statistically significant ($p<0.001$), with $R^2=0.154$ suggesting that PhA explains 15.4% of variance in mean leg force. Similar results were obtained for linear regression model with dependent variable power of the lower limbs and independent variable phase angle ($p<0.001$) with $R^2=0.091$ suggesting that PhA could explain 9.1% of variance in power of the lower limbs.

DISCUSSION

This study aimed to investigate the relationship of phase angle and body composition derived from BIA measurement and lower extremities force production and power in young non-athletes obtained by vertical jump performancemeasurement. Participants involved in this study were college students who are not involved in any sports at a competitive level. Their body height and mass, as well as BMI are in compliance with the results of similar studies (Martínez-Rodríguez et al., 2023; Pilipović Spasojević et al., 2020). Average BMI is indicating normal and healthy body weight for most of the participants. Although men and women involved in this study did not differ in BMI, their body composition was different, as expected. Men had significantly higher content of muscles and lower content of body fat compared to women, due to physiological differences between sexes recognized by earlier studies (Ben Mansour et al., 2021; Hunter et al., 2023). Phase angle obtained by BIA for women in our study was 5.5°, and for men 6.85°. According to Mattiello et al. (2020) average value of phase angle for women aged 19–28 is 6.1° with 95% CI: 5.8°–6.3°, and for men of same age 6.9° with 95%CI: 6.6°–7.2°. Results for phase angle in women included in this study was somewhat lower (lower than 95% CI) compared to the reference value for this age and sex reported by Mattiello et al. (2020). However, reduction in phase angle observed in this study is not clinically relevant. Mattiello et al. (2020) suggested that for the difference in phase angle to be considered clinically relevant in meaning of indicating difference in health status it should be at least 0.9°. The difference between phase angle of women in this study and the reference value for the same age group was 0.6°, which indicates that the women in this sample have somewhat lower phase angle compared to the reference value but reduced phase angle found in women in this study is not indicative for impairment in health status.Vertical jump measurement revealed additional differences between men and women. Men had higher jump height and speed, as well as force and power compared to women. This difference between sexes in ability to produce force and in power of lower limbs was statistically significant even after adjustment for body composition, which indicates that body composition differences between sexes are not the only determinants of sex difference in force production and power. According to Giuriato et al. (2024) major factor responsible for males' ability to generate higher and faster force is their greater muscle mass and the ability to produce force is linked to the control of gene expression, regardless of sex. They also showed (Giuriato et al., 2024) that men, along the greater force production, have higher levels of antioxidant proteins, essential for damage and inflammation control in the muscle tissue, while females tend to have higher levels of pro-inflammatory cytokines, related to muscle injury/regeneration ability. Our results indicate that the difference in jump performance between men and women persist even after adjustment for muscle content in the whole body and muscle content in lower extremities which is consistent with the findings of Giuriato et al. (2024) about physiological diversity among sexes which is beyond body composition differences..

There was no correlation between BMI and variables obtained by vertical jump measurement in this study. This is different from results of some studies (Geßner et al., 2024; Manzano-Carrasco et al., 2023). Possible explanation for this difference is that participants in our study were mostly with BMI indicating normal weight, while in other studies there was higher prevalence of overweight participants. Overweight (BMI>25) is usually connected to higher percent of fat and that can influence jump performance. We found in this study that body composition in the whole body and in the lower extremities is correlated to vertical jump performance, mean force and power. This result was as expected, since force and power necessary for high vertical jump are the results of muscle contraction and more muscles can produce greater power, while fat tissue is negatively correlated to height of jump, force and power because it increases the mass that should be lifted in the jump, while do not contribute in the force production. Our participants were mostly of normal weight and with body fat content in the normal range, which could be the reason for lack of correlation between BMI and vertical jump performance. Phase angle was positively correlated to force and power in this study. That means that higher value of phase angle was associated to higher explosive leg power. There is evidence in literature that phase angle is a valuable indicator of muscle mass and function in athletes (Cattem et al., 2021), older adults (Custódio Martins et al., 2022), with prognostic utility in health and disease (Bellido et al., 2023). Results of this study confirmed that it could be the same for young non-athletes as well. Results of linear regression additionally confirmed association between phase angle and leg mean force and power. Although the model explains only 15.4% of variance in mean leg force and 9.1% of variance in power, we believe that this confirmation of association between phase angle and mean force and power of the lower limbs is clinically very interesting and has potential to help in planning future studies on the topic. This study has some limitations. Firstly, since only college students were involved in this survey, there is limitation in generalizability of the study to population of all young people. Another limitation is the lack of data on habitual physical activity of participants, as well as on hydration status of participants or on contraceptive use among women involved in the sample. There is also a question of knowledge of the participants' sports history, which could potentially influence vertical jump performance. However, participants have been informed that involvement in sports in the present and past is exclusion criteria for involvement in this study. Finally, body height of participants was not measured, but self-reported.

CONCLUSION

This study results provide new data on relationship between explosive power of the lower limbs and bioelectrical properties and composition of the body in non-athletic young adults. Results indicate that there is linear association between phase angle and leg force and power confirmed by correlation and regression analysis. Body composition, and especially content of fat and muscles in the lower limbs are in correlation with vertical jump performance and mean force and leg power. Another important finding of this study is that the difference in jump performance between sexes in young non-athletes is not the exclusively connected to sex differences in body composition but is evident even after adjustments for muscle and fat content in the body.

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Contact Information:

Erna Davidović Cvetko,
University of Applied Sciences Lavoslav Ružička in Vukovar, Blage Zadre 2, Vukovar, Croatia
Phone: +38598502199
e-mail: erna.davidovic@gmail.com