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Original article

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SUMMARY

Background: A high phase angle derived from bioelectrical impedance analysis has been linked to a high level of physical activity. However, it is unknown whether a high phase angle is related to running performance.
Methods: We included all subjects who participated for the first time to the Course de l'Escalade between 1999 and 2016, a yearly city run occurring in Geneva. The subjects underwent a measurement by 50-kHz tetrapolar bioelectrical impedance analysis (Nutriguard®). Running time was converted to running speed in km/h. Results are shown as mean (SD) and as frequencies. We performed sex-specific univariate and multivariate regressions, adjusted for age, body mass index, categories of running distance and year of measurement, to evaluate whether the phase angle is associated with running speed.
Results: We analyzed 2264 subjects (1025 women and 1239 men). In univariate regressions, phase angle was significantly related to running speed in women (coeff 0.52, 95% CI 0.35–0.67, $p < 0.001$, adjusted R^2 0.037) and men (coeff 0.57, 95% CI 0.42–0.73, $p < 0.001$, adjusted R^2 0.039). Multivariate regressions showed that the phase angle was still significantly associated with running speed in women and men ($p < 0.001$ for both models), with an adjusted R^2 of 0.262 and 0.282, respectively.
Conclusions: The phase angle is positively associated with running performance in men and women. It remains to be demonstrated if this association reflects the benefit of regular training and whether the phase angle might be suitable to monitor improvements in running performance.
Clinical trial registry: clinicaltrials.gov, identifier: NCT03400761.

1. Introduction

Bioelectrical impedance analysis (BIA) measures electrical parameters, such as resistance, reactance, phase angle and impedance, which are introduced into population-specific equations to derive body composition. However, these equations are not accurate in certain circumstances, as for instance an abnormal hydration status or a body mass index in the extreme ranges (<16 kg/m^2 and >34 kg/m^2) [1]. An increasing amount of publications has thus focused on the health significance of raw electrical parameters, especially the phase angle.

BIA devices submit the human body to an alternating electrical current, and record the opposition to this current, namely the resistance and reactance [2]. The resistance reflects the pure resistive behavior of tissues and depends on the intra- and extracellular water content. The reactance is generated by the capacitance of cell membranes and tissue interfaces, which induces a time delay between the voltage and the current waveform corresponding to the phase angle. Mathematically, the phase angle can be obtained from the arctangent of the reactance to resistance ratio. Clinically, the phase angle supposedly reflects body cell mass and cell membrane function, and the higher the phase angle, the better is the cell function [3]. It is negatively correlated with the ratio of extra-to intracellular water, age, body mass index [3] but positively

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associated with physical activity [4]. Here, we hypothesize that a higher phase angle is related to a better running speed during a popular city run.

2. Methods

This observational study encompassed all runners aged >16 years who participated for the first time to the "Course de l'Escalade" between 1999 until 2016. In this yearly city run, men <18 yrs and non-elite women cover a distance of 4.8 km, and men >18 yrs and elite women a distance of 7.2 km "Datasport AG" (Gerlafingen AG) measured the running times, which allowed to calculate the running speed (km/h).

Under a heated tent at the "Course de l'Escalade", runners could benefit from free assessments of body composition by tetrapolar BIA [5]. These assessments were always performed in the 24-h preceding the run, by trained staff of the Geneva University Hospitals. Height and weight were determined with a height gauge and an electronic scale, respectively, both calibrated yearly by the Geneva University Hospitals. BIA measurements were performed while the subjects were lying in a supine position on a medical folding bed, with their legs and arms in 30° abduction [6]. Surface electrodes (3M Red Dot (3M, Rüschlikon, Switzerland)) were stuck on the dorsal side of the right hand, wrist, foot and ankle, according to published guidelines [6], and connected to the BIA device. The latter applied an alternative electrical current (800 mA, 50 kHz) and measured resistance and reactance, impedance and phase angle. We had used several BIA devices over the years but for this analysis, we kept only the measurements performed with the Nutriguard® device (Data Input GmbH, Darmstadt, Germany). This choice relies on the fact that we have used and are still using this device since 2001 and that the phase angle may vary slightly between devices [7]. All BIA devices have been calibrated against a calibration jig (CJ4000, Xitron Technologies) and the limit of tolerance was set at ±2° for 50 kHz PhA and ±5Ω for 50 kHz impedance. For Data Input devices, within-day repeatability for measurements performed by the same observer has been shown to be less than 2% for resistance and <1.5% for reactance [7].

Thus, for each subject, we reported age, body weight and height, body mass index, phase angle at 50 kHz, running speed, and the date of measurement. The local Ethical Committee approved this protocol, which was registered under ClinicalTrials.gov, NCT03400761, and each subject gave his informed consent.

2.1. Statistics

Continuous data were described as mean (SD) and categorical data as frequency. The data were compared between women and men by unpaired t-tests and Mann–Whitney *U* tests, as appropriate.

Sex-specific univariate regressions evaluated whether the phase angle was associated with the running speed. The phase angle was plotted against the running speed. We calculated the regression coefficients (coeff), 95% confidence intervals (CI) and adjusted R^2, which corresponds to the variance of speed explained by the regression model. To evaluate whether the relationship was linear, we compared the adjusted value of R^2 of the univariate regression with the same regression containing the squared value of the phase angle. Forward stepwise multivariate regressions, performed separately by sex, were adjusted for age, body mass index, categories of running distance and year of measurement.

3. Results

The study population included 2264 subjects (1025 women and 1239 men). The baseline characteristics are shown on Table 1. All continuous data were significantly different between women and men, including the phase angle. The phase angle values were similar to previously published reference values of our group [8].

Univariate regressions showed that the phase angle was significantly associated with running speed in women (coeff 0.52, 95% CI 0.35–0.67, $p < 0.001$, adjusted R^2 0.037) and men (coeff 0.57, 95% CI 0.42–0.73, $p < 0.001$, adjusted R^2 0.039). The adjusted R^2 did not improve with the addition of the squared value of the phase angle to the regression, in women (R^2 0.038) and men (R^2 0.046), showing that the relationship between phase angle and speed is linear and not quadratic (Fig. 1). Multivariate regressions adjusted for age, body mass index, running distance and year of measurement showed that the phase angle was still associated with the running speed in women and men (Table 2) ($p < 0.001$ for both models), with an adjusted R^2 of 0.262 and 0.282, respectively. The forward stepwise introduction of variables showed that the regression models improved mostly with the addition of the body mass index. To determine which component of the phase angle is associated with the running speed, we repeated the same multivariate regressions using 50 kHz resistance or reactance instead of

Table 1
Characteristics of the study population at baseline (n = 2264).

Variables	Women					Men					p[a]
	n	%	Mean		SD	n	%	Mean		SD	
Continuous											
Age at measurement (yrs)	1025	45	37.1	±	12.1	1239	55	38.7	±	12.3	0.003
Body weight (kg)	1025	45	59.3	±	7.5	1239	55	75.6	±	9.1	<0.001
Height (cm)	1025	45	164.0	±	6.5	1239	55	177.1	±	6.9	<0.001
Body mass index (kg/m^2)	1025	45	22.0	±	2.5	1239	55	24.1	±	2.5	<0.001
Phase angle 50 kHz (degrees)	1025	45	6.3	±	0.6	1239	55	7.2	±	0.7	<0.001
Running speed (km/h)	1025	45	10.9	±	1.6	1239	55	12.9	±	2.0	<0.001
Categorical											
Running distances (km)											<0.001
4.8	1013	99				35	3				
7.2	12	1				1204	97				
Year of measurement											0.375
2002–2004	249	24				317	26				
2005–2007	235	23				281	23				
2008–2010	199	19				261	21				
2011–2013	156	15				160	12				
2014–2016	186	18				220	18				

[a] Unpaired t-test or Mann–Whitney *U*-test.

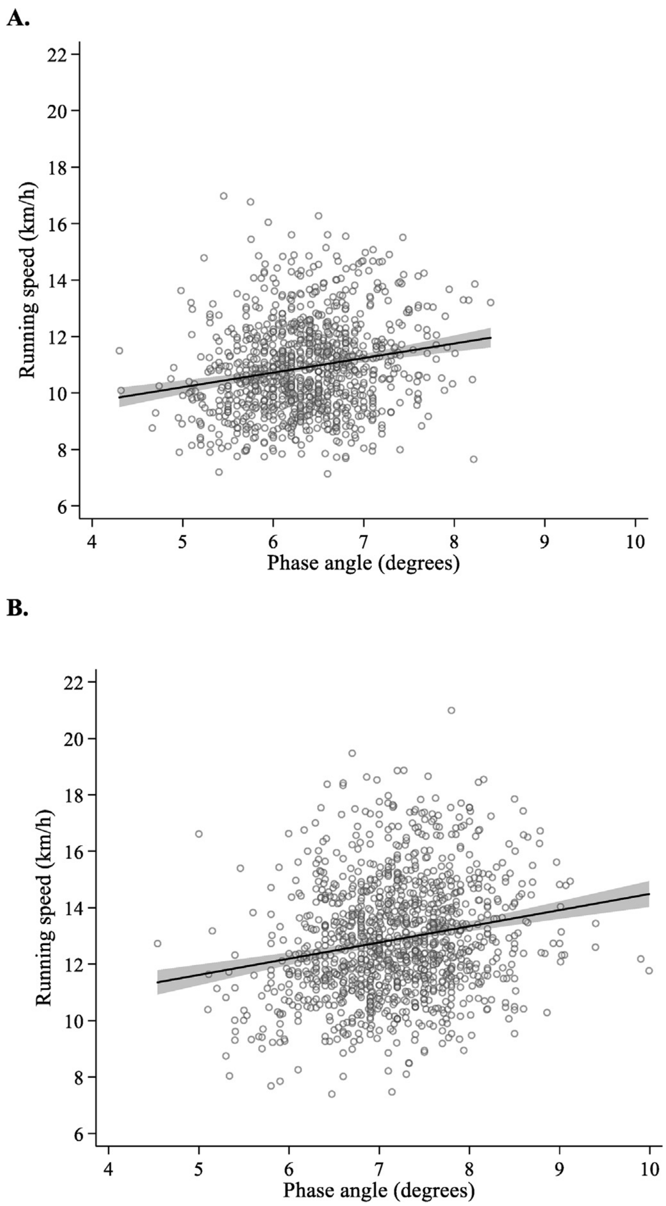

Fig. 1. Two-way scatterplot showing the actual running speed vs. phase angle in women (A, n = 1025) and men (B, n = 1239). The linear regression line is also shown for women (speed = 0.515*phase angle +7.630; SEE 0.081, p < 0.001) and men (speed = 0.574*phase angle+8.747; SEE 0.080, p < 0.001).

the phase angle. Only the resistance was significant (women: p < 0.001, men: p < 0.001).

4. Discussion

Our study shows that the phase angle derived from 50 kHz-bioelectrical impedance analysis is positively associated with the running speed during a timed city run, for men as well as for women, even when adjusted for age, body mass index, running distance and year of measurement. Resistance, but not reactance is the component of the phase angle related to the running speed.

The association between phase angle and running performance had not been tested so far. However, the phase angle was positively correlated with maximal mean power during a road bicycle race [9], which could be a marker of physical performance.

Since a good physical performance is generally the consequence of training, a high phase angle may just reflect regular physical exercise. Two recent systematic reviews report a positive association between phase angle and physical activity [4,10]. These associations were in line with the results of Ditmar et al. who studied 452 adults aged 60–90 years, categorized into 3 physical activity levels by way of a questionnaire. People with the highest physical activity had a higher mean phase angle than those with the lowest physical activity, but were also the youngest [11]. Similarly, longitudinal studies showed that the implementation of a physical activity program in non-athletes led to an increase in phase angle [12,13]. Interestingly, the phase angle values found in our runners are similar to the reference population data that we have published earlier [8]. This suggests that our runners may be as physically active as our reference population was.

Several cross-sectional studies focused on specific sports and showed that elite athletes have a higher phase angle than their less trained counterparts. For instance, the phase angle was higher in elite soccer players [14], professional cyclists [15] and ballet dancers [16] than in their less trained controls. No study on that topic was specifically performed in runners but, in view of these evidences, we may assume that elite runners, by definition performing better in timed runs than less trained persons, have also a higher phase. Whether the type of sport affects phase angle is however controversial [10].

These evidences strongly suggest that the link between a high phase angle and a better running performance found in our study is actually explained by regular physical activity. In athletes, the phase angle is positively associated with total body water and intracellular water, measured by dilution techniques [17,18]. Our study confirms these findings as resistance, which depends on ratio of intra-to extracellular water content, positively correlates to running

Table 2
Multivariate linear regression to running speed.

	Women (n = 1025)					Men (n = 1239)				
	Coefficient	SE	p	95% CI		Coefficient	SE	p	95% CI	
Phase angle 50 kHz	0.59	0.07	<0.001	0.44	0.74	0.42	0.07	<0.001	0.26	0.57
Age at measurement (yrs)	−0.01	0.01	<0.001	−0.02	−0.01	−0.03	0.01	<0.001	−0.04	−0.02
Body mass index (kg/m^2)	−0.28	0.02	<0.001	−0.32	−0.25	−0.32	0.02	<0.001	−0.36	−0.28
Running distances (km)										
4.8	0					0				
7.2	0.05	0.42	0.897	−0.76	0.87	0.64	0.31	0.039	0.03	1.24
Calendar time (years)										
2002–2004	0					0				
2005–2007	−0.09	0.13	0.464	−0.34	0.16	0.28	0.14	0.048	0.01	0.56
2008–2010	0.01	0.13	0.962	−0.26	0.27	0.11	0.14	0.418	−0.17	0.40
2011–2013	−0.56	0.15	<0.001	−0.84	−0.27	−0.45	0.17	0.007	−0.78	−0.12
2014–2016	−0.51	0.14	<0.001	−0.78	−0.23	−0.59	0.15	<0.001	−0.89	−0.29

CI: confidence interval.

performance. Thus, the higher phase angle in physically active people seems to reflect physiological cellular adaptations leading to a higher intracellular water content. A hypothesis could be that physically active people often practice carbohydrate loading to improve performance and consequently have a higher intracellular water content to store glycogen [19]. Physical activity has also been associated with modifications of cell membrane function. For instance, it enhances the activity of the transmembrane Na/K-ATPase pump [20,21]. However, our study shows that running performance is not related to reactance, which is the other component of the phase angle and reflects the capacitance of cell membranes.

The strength of this study is the large number of subjects participating in a popular run and the use of a single BIA brand, which limits the device-related phase angle variability. This study suffers a few limitations such as being retrospective and no record of possible co-morbidities or modalities of the participants' habitual physical activity (frequency, intensity, duration. Finally, we are aware that performance is also influenced by motivation, which cannot be captured by the phase angle.

5. Conclusion

The phase angle is positively associated with the running performance in men and women. Whether this association reflects the benefit of regular training remains to be demonstrated. Future longitudinal studies should determine the exercise modalities to improve the phase angle, evaluate if an improvement is associated with a better performance and whether the phase angle might be suitable to monitor the running performance.

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Author Contributions

Conceptualization: LG, CG, FRH. Methodology: LG, CG, FRH. Validation: LG, CG, FRH, JM, LK, CP. Formal analysis: LG, JM, LK, NA, MD, FRH. Investigation: LG, JM, LK, NA, MD, CP, CG, FRH. Ressources: CP. Writing-original Draft preparation: LG. Review: JM, LK, MD, CP, CG, FRH. Editing: LG. Vizualization: MD. Project administration: LG. Funding acquisition: CP.

Declaration of Competing Interest

None of the authors has a conflict of interest related to this work.

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References

[1] Deutz NEP, Ashurst I, Ballesteros MD, Bear DE, Cruz-Jentoft AJ, Genton L, et al. The underappreciated role of low muscle mass in the management of malnutrition. J Am Med Dir Assoc 2019;20(1):22–7.
[2] Earthman CP. Body composition tools for assessment of adult malnutrition at the bedside: a tutorial on research considerations and clinical applications. JPEN - J Parenter Enter Nutr 2015;39(7):787–822.
[3] Gonzalez MC, Barbosa-Silva TG, Bielemann RM, Gallagher D, Heymsfield SB. Phase angle and its determinants in healthy subjects: influence of body composition. Am J Clin Nutr 2016;103(3):712–6.
[4] Mundstock E, Amaral MA, Baptista RR, Sarria EE, Dos Santos RRG, Filho AD, et al. Association between phase angle from bioelectrical impedance analysis and level of physical activity: systematic review and meta-analysis. Clin Nutr 2019;38(4):1504–10.
[5] Genton L, Mareschal J, Karsegard VL, Achamrah N, Delsoglio M, Pichard C, et al. An increase in fat mass index predicts a deterioration of running speed. Nutrients 2019;11(3).
[6] Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Manuel Gomez J, et al. Bioelectrical impedance analysis-part II: utilization in clinical practice. Clin Nutr 2004;23(6):1430–53.
[7] Bosy-Westphal A, Danielzik S, Dorhofer RP, Later W, Wiese S, Muller MJ. Phase angle from bioelectrical impedance analysis: population reference values by age, sex, and body mass index. JPEN - J Parenter Enter Nutr 2006;30(4):309–16.
[8] Kyle UG, Genton L, Slosman DO, Pichard C. Fat-free and fat mass percentiles in 5225 healthy subjects aged 15 to 98 years. Nutrition 2001;17(7–8):534–41.
[9] Pollastri L, Lanfranconi F, Tredici G, Burtscher M, Gatterer H. Body water status and short-term maximal power output during a multistage road bicycle race (giro d'Italia 2014). Int J Sports Med 2016;37(4):329–33.
[10] Di Vincenzo O, Marra M, Scalfi L. Bioelectrical impedance phase angle in sport: a systematic review. Sports Nutr Rev J 2019;16(49).
[11] Dittmar M. Reliability and variability of bioimpedance measures in normal adults: effects of age, gender, and body mass. Am J Phys Anthropol 2003;122(4):361–70.
[12] Langer RD, Silva AM, Borges JH, Cirolini VX, Pascoa MA, Gerra-Junior G, et al. Physical training over 6 months is associated with improved changes in phase angle, body composition, and blood glucose in healthy young males. Am J Hum Biol :Off J Hum Biol Counc 2019;31(5):e23275.
[13] Cunha PM, Tomeleri CM, Nascimento MA, Nunes JP, Antunes M, Nabuco HC, et al. Improvement of cellular health indicators and muscle quality in older women with different resistance training volumes. J Sports Sci 2018;36(24):2843–8.
[14] Micheli ML, Pagani L, Marella M, Gulisano M, Piccoli A, Angelini F, et al. Bioimpedance and impedance vector patterns as predictors of league level in male soccer players. Int J Sports Physiol Perform 2014;9(3):532–9.
[15] Giorgi A, Vicini M, Pollastri L, Lombardi E, Magni E, Andreazzoli A, et al. Bioimpedance patterns and bioelectrical impedance vector analysis (BIVA) of road cyclists. J Sports Sci 2018;36(22):2608–13.
[16] Marra M, Sammarco R, De Filippo E, De Caprio C, Speranza E, Contaldo F, et al. Resting energy expenditure, body composition and phase Angle in anorectic, ballet dancers and constitutionally lean males. Nutrients 2019;11(3).
[17] Silva AM, Nunes CL, Matias CN, Rocha PM, Minderico CS, Heysmfield SB, et al. Usefulness of raw bioelectrical impedance parameters in tracking fluid shifts in judo athletes. Eur J Sport Sci 2019;26:1–10.
[18] Marini E, Campa F, Buffa R, Stagi S, Matias CN, Toselli S, et al. Phas and and bioelectrical impedance vector analysis in the evaluation of body composition athletes. Clin Nutr 2019;2019. https://doi.org/10.1016/j.clnu.2019.02.016.
[19] Shiose K, Yamada Y, Motonaga K, Sagayama H, Higaki Y, Tanaka H, et al. Segmental extracellular and intracellular water distribution and muscle glycogen after 72-h carbohydrate loading using spectroscopic techniques. J Appl Physiol 2016;121(1):205–11.
[20] Pirkmajer S, Chibalin AV. Na,K-ATPase regulation in skeletal muscle. Am J Physiol Endocrinol Metab 2016;311(1):E1–31.
[21] Nielsen JJ, Mohr M, Klarskov C, Kristensen M, Krustrup P, Juel C, et al. Effects of high-intensity intermittent training on potassium kinetics and performance in human skeletal muscle. J Physiol 2004;554(Pt 3):857–70.