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Original Research

Maximal Running Speed and Critical Speed Are Positively Related to Phase Angle in Healthy Young Adults

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ABSTRACT

International Journal of Exercise Science 17(4): 405-417, 2024. Phase Angle (PhA), derived from bioelectrical impedance analysis, is a measurement of cellular resistance to electrical current and a non-invasive tool to monitor neuromuscular performance. The relationship between PhA and components of athletic performance is not fully understood. The purpose of this study was to determine if maximal running speed, critical speed (CS), and/or D prime (D') derived from a 3-minute all-out-test (3MAOT) correlates to PhA, reactance (Xc), or resistance (R). Sixty-one (male n=35, female n=26) healthy young adults (23.4±3.9 years) completed bioelectrical impedance analysis (Inbody770) and a 3MAOT. The correlations between PhA, Xc, and R and 3MAOT results were evaluated using correlations. Simple and multiple linear-regressions were used to test if results from the 3MAOT (maximum running speed, CS, D') could predict PhA. Linear regression analysis indicated that maximum running speed and CS alone explained 32% and 9% of the variance in PhA, respectively (R^2=0.32, $p<0.05$; R^2=0.09, $p<0.05$). Multiple linear regression indicated that maximum running speed, CS, and D' explained 35% of the variance in PhA (R^2=0.35; $p<0.05$). Only maximum running speed remained a significant predictor of PhA after controlling for age (β=0.45; $p<0.05$), but not after controlling for both age and sex (β=0.14; $p>0.05$). Since maximum running speed was a stronger predictor of PhA compared to CS (proxy for endurance performance), practitioners should use discernment when using PhA as a readiness tool to monitor endurance performance.

KEY WORDS: Bioelectrical impedance analysis, athlete monitoring, maximum metabolic steady state, neuromuscular performance, resistance, reactance

INTRODUCTION

Critical Speed (CS) is considered a fatigue threshold that demarcates the heavy from severe exercise intensity domains, where the physiological responses to exercise can (when below CS) or cannot (when above CS) be stabilized (31). Above CS and within the severe exercise intensity domain, a continuous rise in oxygen consumption and blood lactate concentrations is observed until maximum oxygen consumption (VO_2 max) is reached, and subsequent fatigue occurs (9). Thus, CS is considered to be the gold standard for measuring the maximum metabolic steady-state (11), where a higher CS relates to faster steady-state running speeds. Graphically, CS is

represented as the asymptote of the inverse hyperbolic relationship between running speed and the duration of exercise (31). D prime (D′) represents a fatigability constant that is a measure of work (i.e., distance) at intensities above CS and is mathematically calculated as the hyperbolic curvature constant (31,36). CS and D′ can be measured with a 3-minute all-out test (3MAOT), in which CS is the average running speed in the last 30 seconds of the test, and D′ is estimated as the running distance covered at speeds above CS (29). Due to the all-out nature of the 3MAOT, maximum running speed can also be derived from this test. Together, CS and D′ predict the tolerable duration of exercise above CS, can inform endurance racing strategy, and can also be used to prescribe high-intensity interval training (29,30). Thus, the 3MAOT produces key performance indicators and provides insights into both aerobic and anaerobic capacities.

Likewise, bioelectrical impedance (BIA) variables such as reactance (Xc), resistance (R), and phase angle (PhA) have been used to predict athletic performance, including muscular strength (7,10,24), cardiorespiratory fitness (7,15), jumping and sprinting performance (2,19), and anaerobic sprint tests (26). PhA represents the geometric angle formed between Xc and R and can be calculated as PhA=arc-tangent (Xc/R) x 180°/π (33). Both Xc and R represent resistances to electrical current (33). R represents the opposition presented to the flow of an electric current and is primarily related to the amount and composition of water in the body's tissues (17,33). Xc represents capacitance or the resistive effect produced by cellular membranes acting as capacitors (14,33,34). Cell membranes acting as capacitors store and release energy in the form of an electrical charge, or action potential, that influences neuromuscular contractile capabilities and athletic performance. Low PhA values are considered an indirect representation of reduced cellular integrity and function (14), and as a result, would suggest poor athletic performance. High PhA values are associated with cellular health and intact cell membranes (34), and have shown positive relationships with superior athletic performance (10,23). In theory, an athlete with a well-functioning skeletal muscle cell membrane (high cellular integrity and ability to store electric charge) may have a superior ability to call upon the neuromuscular system, and transport substrates and metabolites to and from working muscles, which would improve an individual's ability to sustain high output, or a maximum metabolic steady state (CS).

Sports practitioners often assess athlete readiness during the athletic season with vertical jump height and sprinting speed, which require players to produce maximum neuromuscular efforts. This is risky when performed midseason as it presents an unnecessary training load and increased risk of injury (3). PhA has emerged as a non-invasive, and easy-to-measure variable that can be used as a substitute for monitoring neuromuscular performance (3,14). As such, sports scientists are looking to develop PhA as a marker of fatigue that can be used on a weekly basis during the sports season to assess athlete readiness without taxing the athletes' bodies (3). Having PhA in the sports-scientist toolbox could provide a quick and easy way to maintain peak performance, and support the decision-making process of practitioners (e.g. altering training load or intensity) while minimizing the injury risk associated with the weekly check-ins.

However, the underlying physiological mechanisms that explain the relationship between PhA and performance metrics remain unclear, and the usability of PhA to assess athlete readiness in

endurance performance is unknown. Therefore, exploring the correlations between PhA and other indices of athletic performance, such as CS, are critical in furthering our understanding of the applications of PhA. Previous research has indicated that whole-body PhA, lower-body PhA, and urine osmolarity explain 81% of the variance in a 20-m sprint performance (3). In contrast, PhA explains 3.7% and 3.9% of the variance in endurance running performance for men and women respectively (15). Thus, research suggests that the PhA usability in monitoring endurance performance is trivial, while PhA may have greater predictability over anaerobic events. However, the relationship between PhA and CS, a key performance indicator that represents the maximum metabolic steady state (21,22), is unknown. To further understand the relationships between PhA and athletic performance, we sought to explore the relationship between PhA and 3MAOT metrics. Specifically, this study aimed to determine if maximal running speed, CS, and/or D′ were related to PhA, Xc, or R. We hypothesized that 3MAOT performance (maximum running speed, CS, D′) would predict PhA, but PhA would have a stronger relationship with maximum running speed and D′ (which represents anaerobic capacity) than CS (a measure of endurance performance).

METHODS

A cross-sectional study design was utilized to explore the relationships between BIA metrics (PhA, Xc, R) and the 3MAOT measures (maximum running speed, CS, and D′). The timeline of the current study is presented in Figure 1. All measurements were performed in February of 2023. A familiarization 3MAOT was completed by all subjects. Immediately prior to completing BIA urine-specific gravity (USG) was measured to ensure hydration. BIA was performed 24-72 hours before the 3MAOT. The same evaluator administered all the tests which also ensured consistency. Subjects completed the 3MAOT on an outdoor track wearing a Stryd foot pod (Stryd Summit Power Meter, Boulder, CO, USA) and an Apple Watch SE (Version 9.3, Cupertino, CA, USA) which measured running speed and distance in real-time. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (28).

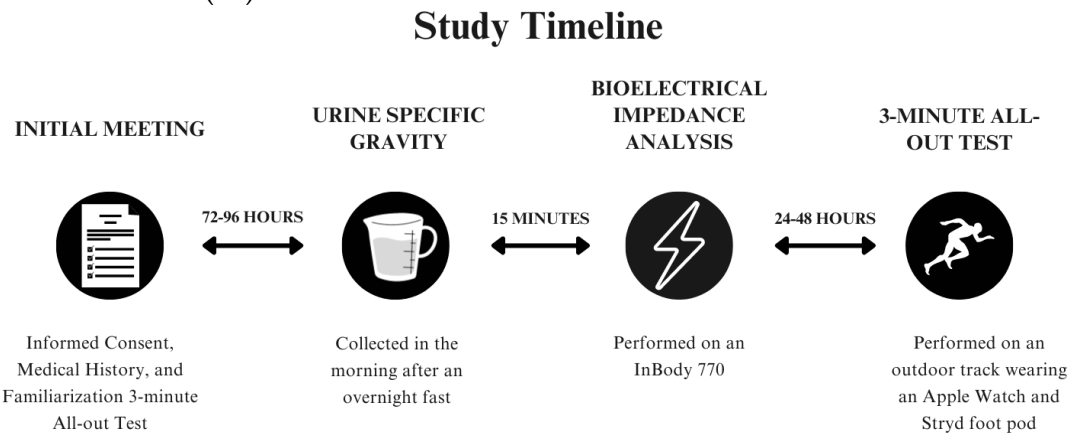

Figure 1. Study timeline.

Participants

Sixty-one healthy, recreationally active healthy young adults (male n=35, female n=26) voluntarily participated in the study. Recreationally active was defined as participating in less than or equal to twice-a-week aerobic activity and less than or equal to twice-a-week resistance training. Participants were deemed healthy if they had no neurological, orthopedic, or cardiovascular disorders and were not deemed high risk following the American Council of Sports Medicine risk stratification guidelines (16). Participant anthropometric characteristics can be found in Table 1. Inclusion criteria consisted of: (i) being 18-34 years of age with no neurological, orthopedic, or cardiovascular disorders, (ii) having medical clearance from their physician, (iii) and having literacy in English. After being informed of the study procedures, purpose, and risks, informed consent was obtained from all individual participants before the start of the study. The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the University of Hawai'i (#2022-00631) for studies involving humans.

Table 1. General Participant Characteristics.

	N	Age (years ± SD)	Weight (kg ± SD)	Height (cm ± SD)
Male	34	24.7 ± 4.3	85.7 ± 15.1	176.9 ± 9.1
Female	26	21.6 ± 2.5	62.2 ± 17.4	162.3 ± 8.3
Overall	61	23.4 ± 3.9	75.7 ± 19.9	170.6 ± 11.4

Protocol

Before BIA, height was measured to the nearest 0.1 inches with a digital stadiometer (InBody BSM 170B, Cerritos, CA, USA) and converted to centimeters. Immediately prior to completing the BIA measurements and after an overnight fast (10 hours), participants' urine-specific gravity (USG) was measured with a hand-held refractometer (URC-NE, Atago, Japan.) If USG was >1.020 g/cm^3 (37), subjects consumed 500 mL of water and USG was re-tested after 15 minutes. Participants were also instructed to not (i) eat or exercise 3 hours before testing, (ii) consume alcohol or excess caffeine or use 24 hours before testing, and (iv) or use lotion or ointment on hands or feet. Fluid shifts due to postural changes were controlled by asking patients to stand for 15 minutes before BIA measurement. In addition, participants were asked to remove any jewelry or metals. InBody Tissues (damp towelettes) were used to enhance the electrical conductivity between the hands and feet with the hand and foot electrodes. BIA was performed using a multifrequency device (InBody 770, Cerritos, CA, USA) and manufacturer guidelines were followed. R and Xc were directly measured in ohms at 50 kHz. Whole body Xc was calculated as the sum of right arm Xc, trunk Xc, and right leg Xc at 50 kHz. PhA was calculated as the arc-tangent (Xc/R) x 180°/π. R was calculated using: R = Xc/tan(PhA).

The 3MAOT (29,36) took place on an outdoor track after a standardized warm-up. All participants were tested at the same time of day (± 1 hour) and ran in similar conditions (~27°C and ~63% humidity, wind < 10 km/hour, UV index 6-8). A verbal script was read to participants

to ensure they all received the same instructions. Strong verbal encouragement was provided during the test without feedback on the amount of time elapsed in an effort to prevent pacing. Subjects were instructed that the test would last 3 minutes, to ramp towards their maximal running speed without pacing, and maintain their fastest running speed throughout the test. Subjects were told the test had concluded when 3 minutes and 5 seconds elapsed to ensure adequate data were collected (29). Subjects wore a GPS watch Apple Watch SE (Version 9.3, Cupertino, CA, USA) on the right wrist while a Stryd foot pod (Stryd Summit Power Meter, Boulder, CO, USA) was firmly attached to the shoelaces of the right shoe as recommended by the manufacturer. The foot pod measured running speed and distance at a frequency of 1 Hz. Stryd is considered a reliable and valid running power meter for field-based analysis (5,12,13,20,27,35). The Stryd firmware version used was 2.1.16 and data was extracted in flexible and interoperable data transfer (FIT) format from the Stryd application (www.stryd.com/powercenter). The FIT file was converted to a comma-separated values (CSV) file using www.fitfileviewer.com and analyzed in Microsoft Excel®. The primary assumption of the 3MAOT is that a subject will expend D′ within the first 2.5 minutes of effort, indicating that the average running speed between 2.5 and 3 minutes represents CS. D′ was estimated by using the following equation: D′= t (S150s - CS), where time (t) equals 150 seconds (s), S150 s (m/s) equals the average speed for the first 150 s, and CS (m/s) is the average speed between 150 s and 180 s (29).

Statistical analysis

The sample size that would be required for a fully powered multiple regression was calculated using G*Power (Version 3.1.9.7) (8). While considering a medium (0.15) Cohen's *f*2 effect size, with a 5% type I error, 80% power, and 5 predictors (independent variables: maximum running speed, CS, D′, age, and sex), the estimated sample size was 55 participants.

The normality of the data was verified with the Shapiro-Wilk test. Since this was an exploratory study, Pearson's correlation coefficients and simple linear regression were first used to examine the relationship between PhA and maximum running velocity, CS, and D′. Correlations were considered trivial, small, moderate, and large when R squared was <0.1, 0.1-0.3, 0.3-0.5, and >0.5, respectively (6). To further explore these relationships, multiple linear regression was used to determine if maximum running speed, CS, and D′ could significantly predict PhA after adjusting for confounding variables (age and sex) (25). A variable inflation factor (VIF) of >5 was used as the cut-off value to identify multicollinearity (18). Significance was set at $P < 0.05$ for correlations and P was adjusted to < 0.0166 (0.05/3=0.0166) to account for multiple comparisons and type 2 errors in multiple regression analysis. Data were analyzed using GraphPad Prism (Version 9.2 for MacOS, GraphPad Software, San Diego, California USA). Below we present the results of both simple linear regressions and multiple regression models.

RESULTS

Mean USG for males, females, and the overall group were 1.013, 1.012, and 1.012, respectively. Table 2 provides the mean ± SD values from the 3MAOT and BIA tests.

Table 2. Results from the 3MAOT and BIA.

	Variable	Males (n=35) (mean ± SD)	Females (n=26) (mean ± SD)	Overall (n=61) (mean ± SD)
3MAOT	Maximum Speed (m/s)	7.20 ± 0.66	6.23 ± 0.58	6.79 ± 0.79
	Critical Speed (m/s)	3.51 ± 0.67	3.00 ± 0.54	3.29 ± 0.66
	D' (m)	152.5 ± 44.9	132.6 ± 40.6	144.0 ± 43.9
BIA	Phase Angle (degrees)	7.1 ± 0.5	5.8 ± 0.6	6.6 ± 0.9
	Resistance (ohms)	502.7 ± 62.9	655.4 ± 73.3	567.8 ± 101.4
	Reactance (ohms)	62.8 ± 8.3	66.0 ± 7.4	64.2 ± 8.0
	Intracellular Water (L)	71.2 ± 11.6	45.2 ± 8.3	60.1 ± 16.5
	Extracellular Water (L)	41.4 ± 7.0	27.1 ± 4.9	35.3 ± 9.4
	ECW/TBW	0.37 ± 0.01	0.38 ± 0.01	0.37 ± 0.01
	Lean Body Mass (kg)	70.0 ± 11.6	44.9 ± 8.2	59.3 ± 16.2
	Body Fat (%)	18.1 ± 6.1	25.6 ±7.1	21.3 ± 7.5

Note: 3MAOT = 3-minute all-out test; BIA = Bioelectrical impedance analysis; ECW/TBW = Extracellular water / Total body water.

Table 3 displays the results of the Pearson Correlation analysis between 3MAOT and raw BIA measures. Maximal running speed was significantly and positively related to PhA (R^2=0.32, $p<0.05$); the R^2 indicates a moderate correlation. Maximal running speed had a significant but negative relationship with both R and Xc (R^2=0.07, R^2=0.37, respectively; $p<0.05$), with Xc having a stronger relationship to PhA than R. CS showed a small but significant relationship with PhA (R^2=0.09, $p<0.05$) and Xc (R^2=0.07, $p<0.05$), but no relationship was found between CS and R ($p>0.05$). D′ was not associated with PhA, Xc, or R ($p>0.05$).

Table 4 displays the multiple regression analysis performed with and without adjusting the relationship between results from the 3MAOT (maximum running speed, CS, and D′) and confounding variables (age and sex) in predicting PhA. Maximum running speed, CS, and D′ alone explained 32% ($p<0.05$), 9% ($p<0.05$), and 4% ($p>0.05$) of PhA variance, respectively. The overall regression without adjusting for age or sex was statistically significant (R^2 = 0.35, $F(3, 57)$ = 10.29, $p<0.05$). Maximum running speed was found to be a significant predictor of PhA (β=0.471, $p<0.05$), while CS and D′ were not (β=0.368, $p>0.05$; β=0.004, $p>0.05$). Maximum running speed remained a significant predictor of PhA after controlling for age (β=0.45; $p<0.05$), but not after controlling for both age and sex (β=0.14; $p>0.05$).

Table 3. Pearson Correlation Analysis between BIA and 3MAOT Results (n=61).

BIA Variable	3MAOT Variable	r	95% confidence interval	R squared	P Value
Phase Angle (PhA) (degrees)	Maximum Running Speed (m/s)	0.56	0.37 to 0.72	0.32	<0.0001*
	Critical Speed (m/s)	0.30	0.07 to 0.52	0.09	0.0172*
	D' (m)	0.20	-0.06 to 0.43	0.04	0.130
Resistance (R) (ohms)	Maximum Running Speed (m/s)	-0.26	-0.48 to -0.01	0.07	0.0455*
	Critical Speed (m/s)	-0.02	-0.27 to 0.23	0.001	0.888
	D' (m)	0.09	-0.16 to 0.34	0.01	0.470
Reactance (Xc) (ohms)	Maximum Running Speed (m/s)	-0.61	-0.74 to -0.42	0.37	<0.0001*
	Critical Speed (m/s)	-0.26	-0.48 to -0.01	0.07	0.041*
	D' (m)	-0.07	-0.31 to 0.19	0.004	0.618

Note: 3MAOT = 3-minute all-out test; BIA = Bioelectrical impedance analysis, * $p<0.05$.

DISCUSSION

The central finding of this study is that maximum running speed and CS derived from a 3MAOT account for 32% and 9% of the variance in PhA, respectively, in recreationally active healthy young adults. When maximum running speed, CS, and D' are included in a multiple regression model, 35% of the variance in PhA is explained, and only maximum running speed remains a significant predictor of PhA. In other words, multiple regression analysis identified that maximum running speed is a stronger predictor of PhA than CS. These findings are consistent with previous studies, which indicate that PhA is positively related to the maximum power derived from a Running Anaerobic Sprint Test, after adjusting for fat-free mass and body fat (26). Furthermore, young soccer players with higher PhA values display better performance in linear sprinting speed after controlling for age and body composition (23).

The results revealed a negative and significant correlation for Xc and R with maximum running speed. However, it is important to note that the mathematical nature of PhA indicates that not all PhA values are created equal. For example, a PhA of 7.0° can have several combinations of Xc and R values. Thus, the magnitude of Xc and R is also an important consideration in BIA. Our data indicate that a low Xc (an indirect marker of cell membrane integrity (33) and high R (determined by total body water and the composition of the physiological milieu (33) have a moderate and significant inverse relationship with maximum running speed. Xc had a trivial but significant inverse relationship with CS, while no relationship between R and CS was

observed. Thus, Xc but not R seems to influence maximal running speed. The reactive characteristics of cell membranes that delay (or enhance) electrical current and act as capacitors (Xc) could be an integral component of sprinting performance, and this facet could help to explain the relationship between PhA, maximal running speed, and CS. This ties into research that has shown that PhA can be used to monitor and measure neuromuscular performance (2–4).

Table 4. Unadjusted and adjusted models using measures of maximal speed, critical speed, and D' for determining PhA.

						95% CI for coefficient		
Model	Variable	Coefficient	SE	t-value	p-value	Lower	Upper	VIF
Model 1 (R^2 = 0.35; SEE = 0.85°)	(constant)	1.87	0.85	2.20	0.0322	0.16	3.57	
	Maximum Running Speed (m/s)	0.47	0.15	3.22	0.0021*	0.18	0.76	1.60
	Critical Speed (m/s)	0.27	0.19	1.39	0.17	-0.12	0.65	1.96
	D' (m)	0.00	0.00	1.59	0.12	0.00	0.01	1.62
Model 2 (R^2 = 0.37; SEE = 0.94°)	(constant)	1.26	0.94	1.34	0.19	-0.63	3.15	
	Age	0.03	0.02	1.42	0.16	-0.01	0.08	1.04
	Maximum Running Speed (m/s)	0.45	0.15	3.07	0.0033*	0.16	0.74	1.62
	Critical Speed (m/s)	0.25	0.19	1.33	0.19	-0.13	0.64	1.97
	D' (m)	0.00	0.00	1.67	0.10	0.00	0.01	1.62
Model 3 (R^2 = 0.64; SEE = 1.13°)	(constant)	6.88	1.13	6.11	<0.0001*	4.62	9.14	
	Sex	-1.32	0.20	6.47	<0.0001*	-1.73	-0.91	2.20
	Age	-0.02	0.02	0.97	0.34	-0.06	0.02	1.25
	Maximum Running Speed (m/s)	0.14	0.12	1.20	0.23	-0.10	0.39	1.91
	Critical Speed (m/s)	-0.07	0.15	0.44	0.66	-0.37	0.24	2.20
	D' (m)	0.00	0.00	0.27	0.79	0.00	0.00	1.86

Note: PhA = Phase Angle, * = P < 0.01667, SE= standard error, VIF= variable inflation factor, CI = confidence intervals, Model 1 = Unadjusted model predicting PhA from maximal running speed, critical speed, and D'. Models 2 and 3 = Adjusted models predicting PhA from measures of maximal running speed, critical speed, and D' while controlling for age and sex.

The findings of the present study support that higher PhA values could be relevant to sprinting performance, regardless of age. In other words, regardless of age, higher PhA values were related to faster sprinting. However, the relationship between maximum running speed and PhA disappeared when sex was accounted for. This indicates that sex is a stronger predictor of PhA than maximum running speed. It is well-known that males have higher PhA values than females (25), so our findings align with the current literature.

Positive relationships between running performance and PhA have been identified, and indicate the potential for PhA to be used when monitoring endurance athletes (15). Correlation analysis indicates that CS explains 9% of the inter-individual variance in PhA. Xc (an indirect marker of cell membrane integrity (33)) displayed a weak but significant negative relationship with CS, explaining 7% of the interindividual variance. This finding highlights the importance of cellular membrane integrity and function in endurance performance. No relationship between R and CS was found in the present study, which was expected due to the moderate relationships between PhA and plasma albumin (32). However, the most interesting outcome of the present study was that CS did not remain a significant predictor of PhA when included in a multiple regression model with maximum running speed and D′. Our findings indicate that maximum running speed derived from a 3MAOT is a stronger predictor than CS. To put this in context, this suggests that PhA may be more strongly related to neurological capacity (e.g., powerlifting or events that require high neurological drive), whereas CS is a measure of metabolic capacity and ability to balance metabolic demands and metabolites (e.g., endurance capacity). PhA is considered a valuable tool to indirectly monitor lower body neuromuscular function since a large proportion of sprint and jump performance variance can be estimated solely from PhA (3). However, in the present study, only 9% of the interindividual variance in PhA was explained by CS. This evidence suggests practitioners should proceed with caution when utilizing PhA to monitor endurance performance.

Findings from the current study indicate that D′ is not a significant predictor of PhA and is not related to Xc or R in recreationally active young adults. D′ traditionally represents a finite distance capacity or fatigability (29), which provides insight into exercise limitations (31). Previous research has identified that PhA is inversely associated with the repeated-sprint ability (22) and the fatigue index derived from a Running Anaerobic Sprint Test after adjusting for fat-free mass (26). D′ has been considered to be related to the accumulation of metabolites (inorganic phosphate, H^+, lactate, and ammonia) and extracellular potassium during severe-intensity exercise (1). Furthermore, D′ is considered to utilize only stored energy sources within the localized active muscles (e.g. adenosine triphosphate, phosphocreatine, glycogen, and oxygen-bound hemoglobin) (1). Higher levels of cellular hydration indicated by higher levels of intracellular water may reflect glycogen storage (4). PhA is considered an index of the extracellular to total body water ratio (33), which led us to believe that D′ would be associated with PhA, as higher D′ values indicate large amounts of substrate storage and buffering capacity (1). However, it is important to note the mathematical nature of D′ and its connectedness with CS (1), as studies have shown CS and D′ usually change in opposite directions in response to exercise stimuli (31). Considering the associations between D′ and anaerobic characteristics in

combination with previous studies on PhA and anaerobic capacity, we hypothesized that D' would have a significant relationship with PhA, Xc, and R. However, this was not the case. Overall, this suggests that PhA is related to the neural system which heavily relies on action potential propagation, more so than just the health of the muscular system in a static state (i.e., hypertrophic state, metabolic state, energy storage). In other words, PhA seems to be related to the *functionality* of the neuromuscular system.

The present sample is limited to recreationally active healthy young adults with a wide range of athletic capabilities. The relationships presented in this study may differ from data collected from heterogenous athletic populations. Although we controlled for USG, urine osmolality was not assessed during the study, which may affect BIA. This study also utilized a cross-sectional design, which does not allow the establishment of a cause–effect relationship. Future longitudinal research should be considered in different populations with larger sample sizes to corroborate the findings of the present study.

Conclusion: This study indicates that PhA, Xc, and R have stronger relationships with maximum running speed (a measure of neuromuscular performance) than CS (a measure of maximum metabolic steady state). When maximum running speed, CS, and D' are included in a multiple regression model, only maximum running speed remains a significant predictor of PhA. However, maximal running speed was no longer a significant predictor when sex was included in the model. Practitioners should proceed with caution when using PhA to monitor endurance performance. Longitudinal studies with ample statistical power are needed to explore if PhA is a relevant and informative tool for monitoring endurance performance.

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