TOPICS IN EXERCISE SCIENCE AND KINESIOLOGY

Original Research

The Effect of Different Training Types on Phase Angle in Men - An Exploratory Study

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ABSTRACT

Topics in Exercise Science and Kinesiology Volume 4: Issue 1, Article 12, 2023. Phase Angle (PhA) has emerged as a valuable measure in clinical and sports settings due to its predictive relationship with health and sports performance. Fitness is related to PhA, but the type of exercise training that is most influential over PhA has yet to be determined. The purpose was to explore the effects of endurance training (ET), strength-based resistance training (RT), and sprint-interval training (SIT) on PhA, resistance (R), and reactance (Xc) in men. Thirty-five recreationally-trained healthy young adult males (24±4 years) were randomly assigned to one of three training groups or a control group. All interventions were performed 3 times/week, for 4 weeks, with 48 hours between sessions. Training sessions for ET, RT, and SIT included 30 minutes of moderate-intensity (85% critical speed) treadmill running, 4 sets of 5 repetitions of the barbell back squat at 85% 1 repetition-maximum (1RM), or 4 sets of repeated inclined treadmill sprints designed to induce fatigue in 30-60 seconds, respectively. Baseline and post-intervention tests were performed using bioelectrical impedance analysis, the 3-minute all-out exercise test, and the back squat 1RM. ET significantly increased critical speed (Δ=5.16%; $p<0.005$), but subjects in this group exhibited lower PhA and Xc values. These changes were not significant (PhA: Cohen's d=-0.44; Δ=-3.01%, $p>0.005$; Xc: Cohen's d=-0.48; Δ=-4.82%, $p>0.005$). RT significantly increased muscular strength (Δ=12.92%; $p<0.005$) and this coincided with a trend for increased PhA and Xc values, but this was not significant (PhA: Cohen's d=0.44, Δ=2.55%, $p>0.005$; Xc: Cohen's d=0.20, Δ=3.52%, $p>0.005$). Exploratory data from this study showed that ET tended to decrease PhA and Xc, whereas RT tended to positively affect PhA and Xc in healthy young adult males. Future research should examine to see if these trends remain true because it has the potential to impact the way we optimize exercise prescriptions.

KEY WORDS: Bioelectrical impedance analysis, reactance, resistance, sprint interval training, strength training, endurance training, critical speed

INTRODUCTION

Phase angle (PhA) has gained considerable attention in clinical and sports settings due to its predictive relationship with health and sports performance [1–3]. PhA is obtained with bioelectrical impedance analysis (BIA) and is calculated from raw BIA measurements such as resistance (R) and reactance (Xc). Within clinical populations, PhA values provide a non-

invasive and convenient snapshot of mortality risk [4], biomarkers [5], malnutrition [6], and muscular strength [7], where PhA is positively associated with health. Similarly, within athletic settings, BIA has been utilized to monitor neuromuscular performance [8], detect injuries [9], and has been shown to have a positive relationship with running performance [10], muscular strength [11, 12], power [11], sprint performance [13], and anaerobic capacity [13].

PhA represents the relative permittivity and electrical conductivity of the body's cells and tissues, which describes two forms of resistance to electrical current, Xc and R [14]. PhA represents the geometric angle formed between R and Xc. Xc represents a reactive characteristic that changes with altered electrical frequencies and is produced by cell membranes acting as capacitors that delay electrical current [1]. R represents a passive characteristic that does not change with frequency, it is related to the volume and composition of total body water [15]. High Xc values are associated with cellular health, function, and cellular membrane integrity [1, 16]. In contrast, low R values are associated with greater intracellular water volume and higher osmolality of the physiological milieu [17]. Therefore, exercise-based training programs designed to increase PhA should focus on increasing Xc while decreasing R.

Cardiorespiratory endurance and running performance have been shown to positively influence PhA [10, 12], as does concurrent training (a combination of resistance and endurance exercises) [18]. However, endurance athletes present significantly lower PhA values than dynamic intermittent field sport athletes and strength/power athletes [3, 19]. Current evidence suggests that resistance training results in increased Xc and decreased R, while inactivity produces the opposite effect [20]. A systematic review on the PhA of athletes observed that strength and power athletes display larger PhA values compared to endurance athletes, which might suggest that muscle strengthening may cause a greater increase in PhA compared to endurance training [3]. Based on these observations, one may deduce that endurance training and strength/power training will have divergent effects on PhA. The physiological adaptations of each respective training program could potentially influence R and Xc in different ways, resulting in disparate PhA values. For example, endurance training results in adaptations that may decrease R (e.g., plasma albumin, glycogen stores, water content) [18, 21, 22], while strength/power training leads to neuromuscular adaptations that may positively impact Xc (e.g., improve cellular membrane's integrity and conductivity) [20, 23, 24]. To our knowledge, there have not been any studies that examined the effect of different training programs on PhA.

The critical speed (CS) concept has shown to accurately predict cardiorespiratory endurance performance [25, 26]. CS can be derived from a 3 minute all out running test (3MAOT), in which subjects begin with an all out sprint with the objective of maintaining maximal running speed without pacing [25]. When presented graphically, a hyperbolic relationship between running speed and time appears, with the asymptote of the hyperbola representing CS [25]. Due to the maximal nature of the 3MAOT, the curvature constant (D prime or D') or distance covered while running at a speed above CS can also be predicted, which represents a fatigability constant. Together, CS and D' can be utilized to model cardiorespiratory endurance capacity. Furthermore, CS is considered the gold standard for measuring the maximum metabolic steady

state, a key performance indicator of endurance performance [27]. Thus, changes in endurance performance can be assessed by changes in maximum metabolic steady state, or CS [28].

We embarked on this pilot study to examine the effects of training (e.g. sprint interval training, endurance training, strength training) on PhA, Xc, and R. We hypothesized that all training programs will be effective in improving the targeted area of focus (e.g., anaerobic, endurance or strength performance) and all programs will result in an increased PhA. We hypothesized that sprint interval training and strength training will improve PhA by increasing Xc, and endurance training will improve PhA by decreasing R. Along the same lines of optimizing exercise prescription, a secondary aim of this study was to determine the effect of these different training methods on maximal running speed, CS, and D′. To date, research has not explored how divergent training regimens impact these measures of performance.

METHODS

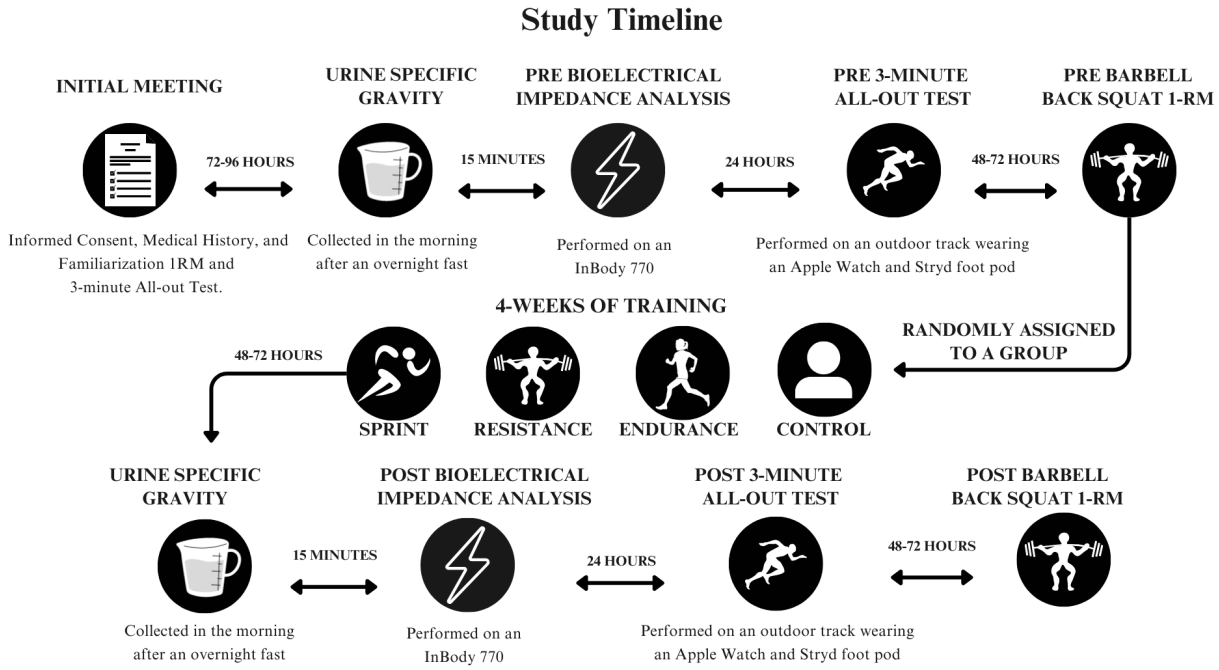
Participants

The following inclusion criteria were used: (i) 18-34-year-old males, (ii) no neurological, orthopedic, or cardiovascular disorders that could compromise study participation, (iii) medical clearance from their physician, (iv) literacy in English, (v) and subjects were required to participate in 83.3% of the training sessions, or only allowed to miss 2 training sessions. Female participants were excluded from the present study due to available resources. Thirty-six recreationally trained, young adult male (18-34 years old) subjects were randomly assigned to one of four groups: endurance training (ET), sprint interval training (SIT), strength-based resistance training (RT), or a control group (CON) that was instructed to maintain their usual exercise habits. To minimize the potential effect of nutritional intake or physical activity outside of the studies on BIA variables, we asked the participants in the training groups to refrain from any exercise training beyond their prescribed intervention and to maintain their normal dietary behavior. CON participants were asked to maintain their usual physical activity and diet during the study period. Subject characteristics are presented in Table 1. Informed consent was obtained from all subjects who participated in the study. The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the University of Hawaiʻi (#2022-00631) for studies involving human subjects.

Experimental Design

In this exploratory study, we used a randomized design which was completed within 6 weeks. Subjects were randomized to one of four groups (CON, SIT, ET, RT). All measurements were performed between January and March of 2023. An outline of the study timeline is presented in Figure 1.

Figure 1.



Performance-Based Measurements

Since hydration can affect BIA measurements, urine specific gravity (USG) was measured to assess euhydration with a cut-off value set at 1.020 g/cm^3. If a subject's USG was above 1.020 g/cm^3, they were instructed to drink 500 ml of water and were retested 15-30 minutes later. BIA measurements were performed in the morning after an overnight fast. Participants were instructed to not (i) wear jewelry or heavy metals, (ii) eat or exercise for at least 3 hours prior to testing, (iii) consume alcohol or excess caffeine or use a for at least 24 hours prior to testing, (iv) use a sauna, (v) or use lotion or ointment on hands or feet. Height and weight were recorded to the nearest 0.1 inches and 0.01 pounds (InBody BSM 170B, Cerritos, CA, USA; InBody 770, Cerritos, CA, USA), and then converted to cm and kg prior to data analyses. To account for fluid shifts due to postural changes, subjects were asked to stand for 15 minutes prior to BIA. Immediately before BIA, subjects used damp towelettes that clear the hands and feet of debris and enhance conductivity. A multi-segmental multi-frequency device (InBody 770, Cerritos, CA, USA) that is considered to be valid and reliable [29–31] was used to directly measure PhA, Xc, and R in ohms at 50kHz. PhA was calculated as the arctangent of Xc/R × 180°/π. Whole body Xc was calculated as the sum of the right leg Xc, trunk Xc, and right arm Xc. Whole body R was calculated as Xc/tan(PhA). The same technician performed all pre- and post-intervention measurements.

To ensure that the training programs improved performance, all participants completed a 3MAOT and barbell back squat 1-repetition maximum (1RM) before and after the intervention. The 3MAOT was selected to measure endurance and sprinting performance. The barbell back squat 1RM test was used to measure changes in muscular strength. These baseline measurements were also used to calculate the intensity of the exercise training protocol. Post-

training measurements were performed after 48-96 hours of rest following the final training session.

All field-based 3MAOT measurements were conducted by the same evaluators, in similar environmental conditions (24-28°C and ~56-65% humidity, wind < 10 km/hour, UV index 6-9) and during the same time of day (± 1 hour). All training sessions and lab-based measurements (1RM) were conducted indoors in the Human Performance Laboratory. Results from the 3MAOT were used to prescribe the exercise intensity of ET and SIT. The 3MAOT [25, 32] was performed on a level outdoor track during similar environmental conditions and time of day after a standardized dynamic warm-up. Each subject wore a GPS-enabled Apple Watch SE (Version 9.3, Cupertino, CA, USA) and a Stryd foot pod (Stryd Summit Power Meter, Boulder, CO, USA) which instantaneously measures running speed and distance at 1 Hz. The Stryd foot pod was utilized according to manufacturer guidelines and is considered a reliable and valid running power meter for field-based analysis [33–37]. To improve validity, participants were required to complete a full familiarization 3MAOT prior to the official baseline test. A verbal script was read to participants to ensure the reliability of procedures. Participants were instructed to build up to maximum running speed and maintain their fastest running speed for 3 minutes without pacing [25]. Participants were told the test had concluded when 3 minutes and 5 seconds elapsed to ensure adequate data collection [25]. Strong verbal encouragement was provided during the test without feedback on the amount of time elapsed in an effort to prevent pacing but ensure maximal effort was given. Subjects were observed to ensure they did not look at the watch face and did not receive feedback on the test duration.

The Stryd firmware version utilized 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®. Maximum running speed was identified as the fastest instantaneous running speed value measured at a rate of 1 Hz, which occurred in the initial 5-15 seconds (s) of the test. The primary assumption of the 3MAOT is that a subject will expend D′ (the finite energetic reserve) within the first 2.5 minutes of maximal effort and that the average running speed between 2.5 and 3 minutes represents CS. D′ was derived by the following equation: D′= t (S150s - CS), where time (t) equals 150 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 [25].

Maximal dynamic muscular strength was assessed by the 1RM of the barbell back squat exercise. The evaluation of 1RM was performed according to the National Strength and Conditioning Association (NSCA) guidelines [38]. In short, participants completed 3 warm-up sets before attempting the initial 1RM load. A 3-5 minute rest period was provided between the last warm-up set and the 1RM load, and between three 1RM attempts. If the subject was successful or failed in moving the 1RM load, an adjustment of 5-10 kg was made. The form and technique of each exercise were standardized and monitored continuously by test administrators to ensure reliability. To ensure participant safety, 1RM assessments were administered by a minimum of 2 personnel who provided spotting.

Intervention

Each training group was prescribed 3 training sessions per week, separated by 48 hours of rest between each training session, for 4 weeks. The CON group was instructed to maintain normal exercise and nutrition habits throughout the duration of the intervention. Individualized exercise programs were designed based on the subjects' baseline measurements.

The SIT program was designed based on previous research that has been shown to significantly improve critical power [39] and W prime [40], which are analogs of CS and D′ respectively. The SIT group performed 4 sets of all-out repeated inclined treadmill sprints that were designed to induce volitional fatigue in 30-60 seconds. Due to the probability of injury during high-speed running, a grade of 15% was used to maintain an exercise intensity that would result in volitional fatigue within the target duration. Furthermore, commercial treadmills have maximal speeds of 12 mph and 15% grade. Therefore, to increase the practical application and adoption of the SIT methods in this study, a constant maximal grade of 15% was utilized.

In order to estimate a training intensity that would result in volitional fatigue between 30-60 seconds, a novel multi-step process was utilized. Initially, the flat ground running speed that would theoretically deplete D′ in 45 seconds was estimated with the following equation: Running speed = (D' x % D' depletion]/tLIM + CS, where D′ depletion equals 100%, and tLIM equals 45 seconds [25].

CS is the average running speed between 2.5 and 3 minutes, which was obtained from the 3MAOT. In order to convert the previously calculated flat ground running speed to an equivalent workload at a 15% incline, the work rate equivalent was calculated using the ACSM equation: (0.2*running speed (m/min) + (0.9* running speed (m/min) * % grade) + 3.5 [41].

For example, if a subject's CS is 4.04 meters/second (m/s), and D′ is 147.54 meters. Thus, $(147.56\ \text{m} \times 100\%) \div (45\ \text{s} + 4.04\ \text{m/s}) = 7.32\ \text{m/s}$, which represents the theoretical speed that would induce fatigue in 45 seconds on a flat surface. The workload equivalent of 7.32 m/s in terms of oxygen consumption while running on flat ground can be calculated as $(0.2 \times (7.32\ \text{m/s} \times 60\ \text{s/min}) + (0.9 \times (7.32\ \text{m/s} \times 60\ \text{s/min}) \times 0\%) + 3.5$ and is equal to 91.3 ml/kg/min. Then, the oxygen consumption equivalent while running at a 15% grade was calculated to determine the SIT speed

$$(0.2 \times (\text{unknown speed in m/s} \times 60\ \text{s/min}) + (0.9 \times (\text{unknown speed in m/s} \times 60\ \text{s/min}) \times 15\%) = 91.3\ \text{ml/kg/min}$$

Thus, solving for the unknown speeds in the equation, the workload equivalent with a 15% grade that would theoretically induce volitional fatigue in 45 seconds would be 4.37 m/s. Although the equation estimates running speed to volitional fatigue within 45 seconds, when used in practical settings, most subjects fatigue between 30 to 60 seconds.

After a 5-minute warm-up on a motorized treadmill at 50% of CS, subjects ran at their prescribed speed until volitional fatigue. After each sprint interval, subjects were given 4 minutes of active rest using a self-selected walking speed with no grade [38, 42]. Following each training session, a 5-minute cool-down was provided at a self-selected walking speed with no grade. Subjects trained on Mondays, Wednesdays, and Fridays which provided at least 48 hours of rest between sessions.

The ET group performed 30 minutes of treadmill running at 85% of their CS as determined from their baseline 3MAOT. The ET protocol was developed based on previous research that significantly increased critical power (an analog of CS) through continuous endurance training [39, 43]. Prior to the training session, participants completed a 5-minute warm-up on a motorized treadmill at 50% of CS, followed by a 5-minute rest period. Exercise intensity was prescribed based on previous research indicating that the ventilatory threshold and onset of blood lactate accumulation occur at ~85% of CS, which allows for a sustainable exercise duration of ~30-90 minutes [44]. Following the exercise, a cool-down was provided for 5 minutes at a self-selected walking speed.

The RT protocol was based on recommendations to improve muscular strength in healthy adults [45]. The sessions were conducted three times per week with 48 hours of rest between training sessions. The lower body RT program included the barbell back squat and subjects were asked to perform 4 sets of 5 repetitions at 85% 1-RM. Subjects were instructed to inhale during the eccentric muscle action with an approximate tempo of two seconds, followed by an exhalation during the concentric muscle action with an approximate tempo of 1 second. Rest intervals included 3-5 minutes of rest between sets. All training sessions were supervised by trained personnel to ensure safe and consistent performance.

Statistical Analysis

The sample size for repeated measures mixed factorial analysis of variance (ANOVA) was calculated while considering a medium (0.25) Cohen's *f* effect size, with a 5% type I error, 80% power, 4 groups (ET, RT, SIT, CON) and 2 measurements (pre, post). Using previously reported data from studies that used similar training conditions, we calculated that the significant changes in PhA [45], 1-RM [46] and CP [43] had a moderate to large effect size. Thus, we expected at minimum, a medium effect on BIA variables, 1-RM, and 3MAOT variables in the current study. Based upon power analyses and previously reported data, the estimated sample size was calculated to be 36 participants. Although we expected a moderate effect on performance variables, the current study was designed with the aim of measuring large changes or effect sizes in performance. In addition, our pilot data showed that training had a large effect size on BIA and 3MAOT variables. Thus, the sample size for repeated measures mixed factorial multivariate analysis of variance (MANOVA) was calculated while considering a large (0.45) Cohen's *f* effect size, with a 5% type I error, 80% power, 4 groups (ET, RT, SIT, CON) and 2 measurements (pre, post). The estimated sample size was 32 participants. According to these power analyses, the enrollment of 36 subjects in the study should result in ample statistical power.

Data are presented as mean ± SD. The normality of data distribution was confirmed using the Shapiro-Wilk test. At baseline, a one-way analysis of variance (ANOVA) was performed to detect between-group differences before the intervention. This was done to satisfy the assumption of the repeated measures ANOVA, where there should be no between-group differences at baseline. Knowing the output variables of BIA are related to each other (PhA, Xc, R) and the metrics of the 3MAOT (maximum running speed, CS, D′) are related to each other, we decided to employ multivariate analysis of variance (MANOVA). Two separate 4 (group: ET, RT, SIT, CON) x 2 (time: pre, post) repeated measures MANOVAS with Bonferroni corrections were performed to detect the effects of training on BIA (PhA, Xc, and R) and the 3MAOT (maximum running speed, CS, D′). Post hoc tests with Bonferroni adjustment were conducted to identify statistically significant comparisons. Bonferroni-corrections were calculated by dividing the initial level of significance ($p = 0.05$) by the number of performed MANOVAS (n=2), resulting in an adjusted significance level of 0.025. MANOVAs were followed up with univariate 4 (group: ET, RT, SIT, CON) x 2 (time: pre, post) repeated measures ANOVAs for each dependent variable (PhA, Xc, R, maximal running speed, CS, D′, back squat 1RM). To decrease the likelihood of type 1 error, a Bonferroni correction was used by dividing the initial significance level by the number of performed MANOVAs and ANOVAs (n=9), resulting in an adjusted significance level of 0.005. Effect sizes for the main effects of "group" and "time" as well as group × time interactions were taken from the ANOVA output (partial eta squared). A partial eta squared (np2) ≥ 0.01 indicates a small effect, ≥ 0.059 is a medium effect, and ≥ 0.138 is a large effect [47]. To examine the effect of training interventions on each dependent variable, Cohen's d was calculated as a difference in the mean value between pre and post-divided by the pooled SD [47], with an effect size of 0.00–0.19, 0.20–0.49, 0.50–0.79, and ≥0.80 being trivial, small, moderate, and large, respectively [47]. Furthermore, the percent change for each variable from pre-post intervention was calculated (Δ%). The statistical analyses were performed using SPSS for Mac (version 29; SPSS, Inc., Chicago, IL, USA), and the initial significance level was set at $P < 0.05$.

RESULTS

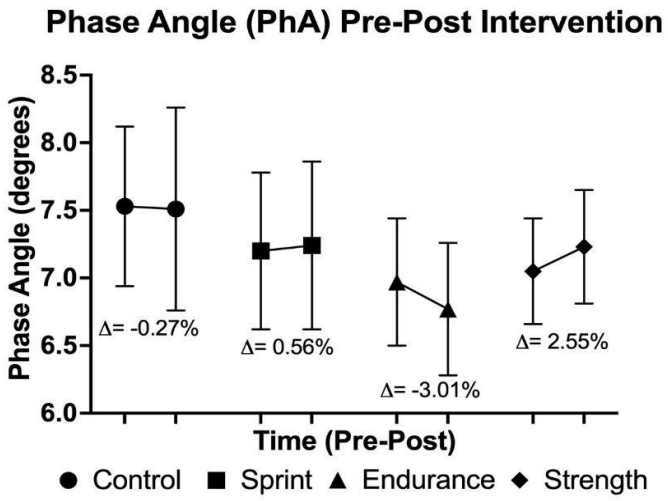
Of the 36 enrolled participants, 35 male subjects completed the intervention. Thirty-five complete datasets were included in the analysis. None of the participants reported any changes to their dietary or training habits during the 6-week intervention. Adherence rates were 91% overall, and 92%, 89%, and 93% for the SIT, ET, and RT groups respectively. Of the completed sessions, all subjects completed the protocol, indicating that the workload was tolerable in this sample. The average duration of the first inclined treadmill sprint during the initial SIT session was 43.4 ± 14.5 seconds, which improved by 21.7% to 52.8 ± 11.6 seconds during the last session of the intervention. Subject characteristics and anthropometrics derived from BIA before and after the intervention are presented in Table 1.

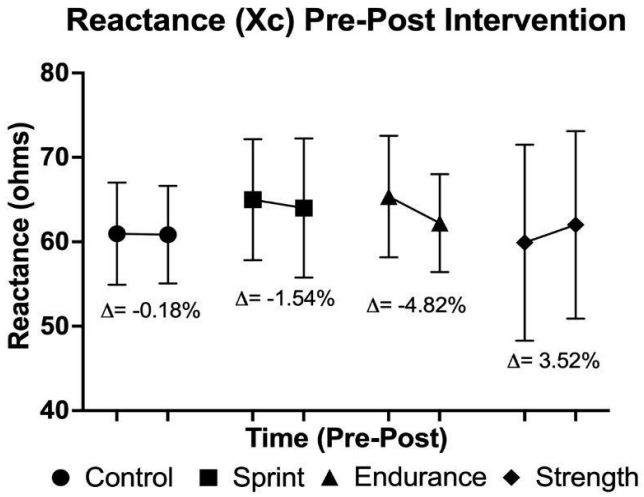
Significant between-group differences were observed at baseline for top running speed ($p < 0.05$), critical speed ($p < 0.05$), and barbell back squat 1-RM ($p < 0.05$). No significant between-group differences were observed at baseline for any BIA variables (PhA, Xc, R), D′ ($p > 0.05$), or USG ($p > 0.05$). Results from the 3MAOT, BIA, and muscular strength assessments are presented in Figures 2 and 3.

Table 1. Subject characteristics and anthropometrics before and after the intervention*

	Control (n=9)			Sprint Interval Training (n=8)			Endurance Training (n=9)			Strength Training (n=9)		
Variable	Pre	Post	Δ%	Pre	Post	Δ%	Pre	Post	Δ%	Pre	Post	Δ%
Age (years)	25.6 ± 3.3			25.1 ± 5.4			25.6 ± 4.8			22.1 ± 2.5		
Height (cm)	179.9 ± 8.5			175.3 ± 5.9			174.1 ± 11.9			178.8 ± 9.7		
Weight (kg)	92.86 ± 15.52	92.63 ± 15.11	-0.002%	78.26 ± 6.77	79.28 ± 6.42	1.30%	76.93 ± 12.30	76.21 ± 13.11	-0.01%	95.90 ± 15.50	95.97 ± 16.73	0.007%
% Body Fat (%) *	16.29 ± 5.84	15.91 ± 5.95	-2.39%	14.54 ± 4.65	14.71 ± 4.65	1.16%	18.51 ± 6.65	18.09 ± 6.47	-2.32%	21.63 ± 6.38	21.43 ± 6.46	-0.93%
Lean Body Mass (lb)*	170.54 ± 22.41	170.79 ± 20.73	0.15%	147.46 ± 15.36	149.00 ± 14.44	1.03%	137.67 ± 20.92	137.07 ± 22.26	-0.44%	165.99 ± 30.33	166.81 ± 31.03	0.49%
Skeletal Muscle Mass (lb)*	98.46 ± 12.99	98.79 ± 12.08	0.33%	84.48 ± 9.22	85.38 ± 8.82	1.05%	78.72 ± 12.54	78.12 ± 13.26	-0.77%	95.24 ± 17.74	96.05 ± 18.43	0.84%
Total Body Water (L)*	124.46 ± 16.13	124.68 ± 14.94	0.18%	107.59 ± 10.97	108.68 ± 10.31	1.00%	100.71± 15.06	100.24 ± 16.04	-0.47%	121.20 ± 22.23	121.69 ± 22.60	0.40%
Intracellular Water (L)*	78.90 ± 9.97	79.13 ± 9.25	0.29%	68.16 ± 7.01	68.89 ± 6.81	1.06%	63.73 ± 9.60	63.23 ± 10.13	-0.79%	76.43 ± 13.60	77.09 ± 14.14	0.86%
Extracellular Water (L)*	45.55 ± 6.19	45.53 ± 5.72	-0.04%	39.44 ± 4.03	39.83 ± 3.61	0.98%	36.98 ± 5.49	37.00 ± 5.93	0.05%	44.78 ± 8.66	44.64 ± 8.48	-0.31%
ECW/TBW *	0.366 ± 0.005	0.365 ± 0.006	-0.27%	0.367 ± 0.006	0.367 ± 0.007	0.00%	0.367 ± 0.005	0.369 ± 0.003	0.54%	0.369 ± 0.006	0.367 ± 0.005	-0.54%
RL PhA 50 kHz (degrees)	7.58 ± 0.53	7.66 ± 0.63	1.04%	7.38 ± 0.64	7.40 ± 0.63	0.27%	7.29 ± 0.65	7.07 ± 0.47	-3.11%	7.28 ± 0.49	7.48 ± 0.46	2.67%
LL PhA 50 kHz (degrees)	7.55 ± 0.48	7.61 ± 0.66	0.79%	7.40 ± 0.74	7.41 ± 0.75	0.13%	7.25 ± 0.61	7.07 ± 0.35	-2.55%	7.26 ± 0.61	7.49 ± 0.59	3.07%

Note. Data are expressed as mean ± standard deviation. Mean Δ% = (Post - Pre)/Pre. * = predicted from bioelectrical impedance analysis using an InBody 770. ECW/TBW = extracellular water divided by total body water.


Phase Angle (PhA) Pre-Post Intervention
Phase Angle (degrees)
8.5
8.0
7.5
7.0
6.5
6.0
Δ= -0.27%
Δ= 0.56%
Δ= -3.01%
Δ= 2.55%
Time (Pre-Post)
Control
Sprint
Endurance
Strength


Reactance (Xc) Pre-Post Intervention
Reactance (ohms)
80
70
60
50
40
Δ= -0.18%
Δ= -1.54%
Δ= -4.82%
Δ= 3.52%
Time (Pre-Post)
Control
Sprint
Endurance
Strength

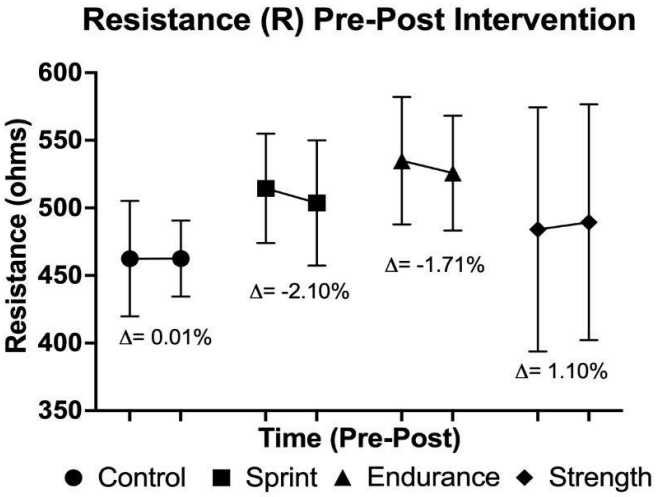

Resistance (R) Pre-Post Intervention
Resistance (ohms)
600
550
500
450
400
350
Δ= 0.01%
Δ= -2.10%
Δ= -1.71%
Δ= 1.10%
Time (Pre-Post)
Control
Sprint
Endurance
Strength

Figure 2. Phase Angle, Resistance, and Reactance Pre-Post Intervention

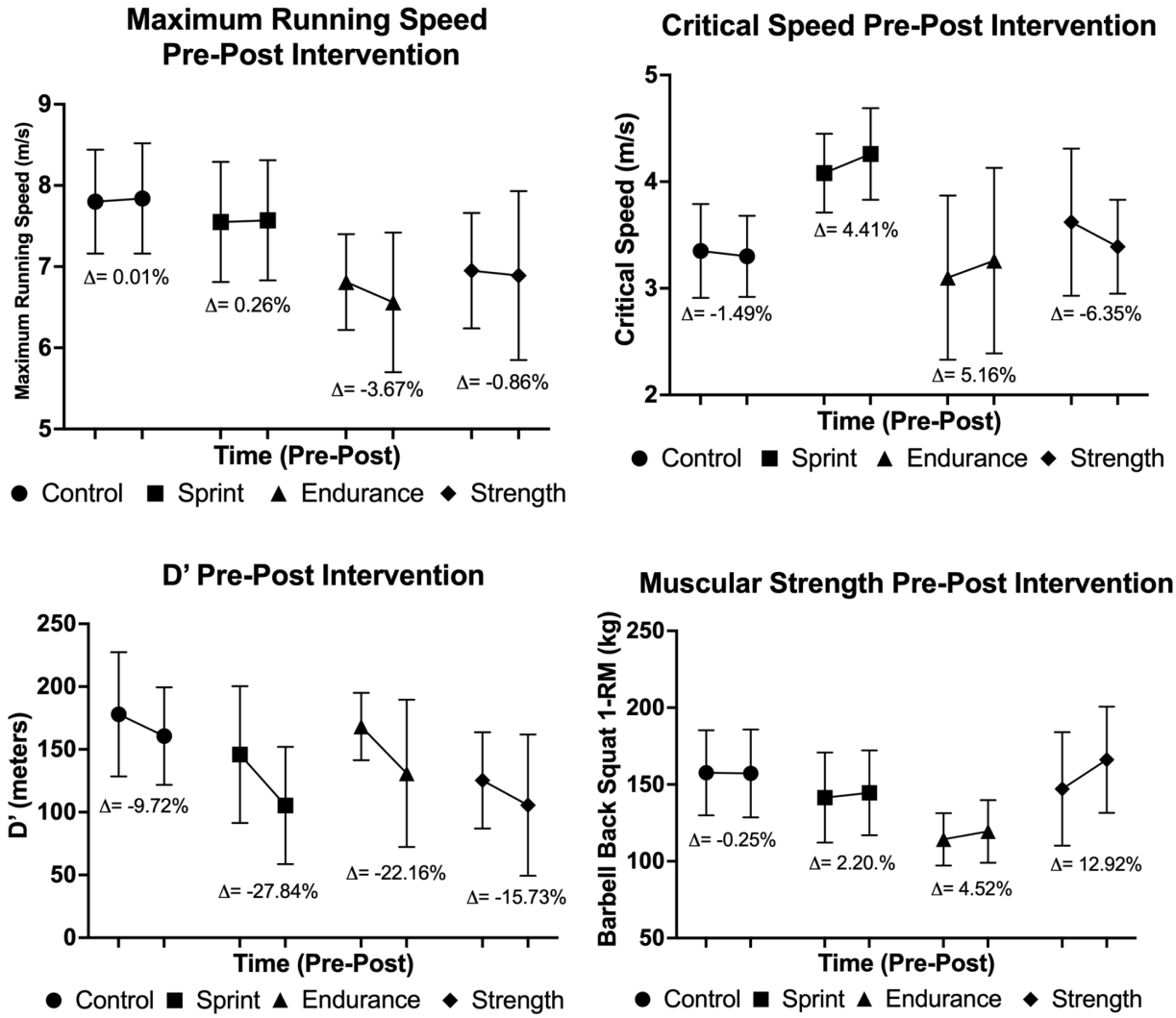


Figure 3. Performance Metrics Pre-Post Intervention

With regard to the ANOVA and MANOVA analyses, the main effects of group, time, and group x time interactions are displayed in Table 2 and Table 3. No significant multivariate group (ηp^2=.139), time (ηp^2=.120), or group x time (ηp^2=.141) interaction was found for BIA variables (PhA, Xc, R) before or after the intervention ($p > 0.025$). MANOVA results revealed significant multivariate main effects of time and group for the 3MAOT and a large effect size, respectively (ηp^2=.382, ηp^2=.250, $p > 0.025$). The multivariate group x time interaction effects for the 3MAOT were not significant (ηp^2= .078, $p > 0.025$). ANOVA results revealed a large main univariate group effect for maximum running speed (ηp^2= .340, $p < 0.005$). Multiple comparisons post hoc analysis identified that ET resulted in significantly lower maximum running speeds than CON ($p < 0.05$). For CS, a large main univariate group effect was found (ηp^2= .335, $p < 0.005$). Multiple comparisons post hoc analysis identified that sprint training resulted in significantly higher CS than CON ($p < 0.05$), and that sprint training resulted in significantly higher CS than ET ($p < 0.05$). For D', a large main effect of time was found across all groups (ηp^2= .248, $p < 0.005$). For

the barbell back squat 1-RM, a significant large main effect of time (ηp^2= .496, $p < 0.005$) and group x time (ηp^2= .557, $p < 0.005$) was detected.

Table 2. Bioelectrical Impedance Analysis variables before and after intervention (n= 35)

Variable					MANOVA p (ηp^2)		
					Time	Group	Group x Time
Bioelectrical Impedance Analysis (BIA)					.288 (.120)	.135 (.139)	.128 (.141)
					ANOVA p (ηp^2)		
Variable	Pre-training	Post-training	Mean Δ%	Effect Size (Cohen's d)	Time	Group	Group x Time
Phase Angle (PhA, degrees)					.773 (.003)	.228 (.128)	.049 (.221)
Control	7.53 ± 0.59	7.51 ± 0.75	-0.27%	-0.03			
Sprint Interval Training	7.2 ± 0.58	7.24 ± 0.62	0.56%	0.07			
Endurance Training	6.97 ± 0.47	6.76 ± 0.49	-3.01%	-0.44			
Strength Training	7.05 ± 0.39	7.23 ± 0.42	2.55%	0.44			
Reactance (Xc, ohms)					.254 (.042)	.602 (.057)	.239 (.125)
Control	60.96 ± 6.05	60.85 ± 5.77	-0.18%	-0.02			
Sprint Interval Training	64.99 ± 7.17	63.99 ± 8.24	-1.54%	-0.13			
Endurance Training	65.36 ± 7.20	62.21 ± 5.80	-4.82%	-0.48			
Strength Training	59.9 ± 11.61	62.01 ± 11.1	3.52%	0.20			
Resistance (R, ohms)					.116 (.078)	.080 (.193)	.546 (.065)
Control	462.47 ± 42.71	462.53 ± 28.07	0.01%	0.00			
Sprint Interval Training	514.47 ± 40.40	503.66 ± 46.28	-2.10%	-0.25			
Endurance Training	534.90 ± 47.22	525.75 ± 42.41	-1.71%	-0.20			
Strength Training	484.09 ± 90.23	489.42 ± 87.18	1.10%	0.06			

Note. Data are expressed as mean ± standard deviation. Mean Δ% = (Post - Pre)/Pre. A Cohen's d of 0.00–0.19, 0.20–0.49, 0.50–0.79, and ≥0.80 represent trivial, small, moderate, and large effects, respectively. A partial eta squared (ηp^2) ≥ 0.01 indicates a small effect, ≥ 0.059 is a medium effect, and ≥ 0.138 is a large effect. Repeated measures MANOVA results for the BIA (PhA, Xc, and R) are listed in the top upper right-hand corner. Repeated measures univariate ANOVAs results are in the 3 columns to the right, where an ANOVA was run for each dependent variable.

DISCUSSION

Since baseline measurements among groups were not statistically equivalent, this limits our ability to draw concrete conclusions. Still, the main finding of this exploratory study is that ET had a small negative (and non-significant) effect on the PhA of young males, which differs from

Table 3. Performance variables before and after intervention (n= 35)

Variable					MANOVA p (ηp²)		
					Time	Group	Group x Time
3 Minute All-Out Test (3MAOT)					**.003 (.382)**	**.002 (.250)**	.595 (.078)
					ANOVA p (ηp²)		
Variable	Pre-training	Post-training	Δ%	Effect Size (Cohen's d)	Time	Group	Group x Time
Maximum Running Speed (m/s) *					.549 (.012)	**.004 (.340)**	.870 (.022)
Control	7.8 ± 0.64	7.84 ± 0.68	0.01%	0.00			
Sprint Interval Training	7.55 ± 0.71	7.57 ± 0.74	0.26%	0.03			
Endurance Training	6.81 ± 0.59	6.56 ± 0.86	-3.67%	-0.34			
Strength Training	6.95 ± 0.71	6.89 ± 1.04	-0.86%	-0.07			
Critical Speed (m/s) *					.658 (.006)	**.005 (.335)**	.240 (.125)
Control	3.35 ± 0.44	3.3 ± 0.38	-1.49%	-0.12			
Sprint Interval Training	4.08 ± 0.37	4.26 ± 0.43	4.41%	0.45			
Endurance Training	3.1 ± 0.77	3.26 ± 0.87	5.16%	0.19			
Strength Training	3.62 ± 0.69	3.39 ± 0.44	-6.35%	-0.40			
D' (m)					**.003 (.248)**	.094 (.184)	.765 (.036)
Control	177.92 ± 49.48	160.62 ± 38.81	-9.72%	-0.39			
Sprint Interval Training	145.89 ± 54.49	105.28 ± 46.7	-27.84%	-0.80			
Endurance Training	168.19 ± 26.82	130.92 ± 58.64	-22.16%	-0.82			
Strength Training	125.33 ± 38.3	105.61 ± 56.26	-15.73%	-0.41			
Barbell Back Squat 1-RM (kg) *					**<.001 (.496)**	.074 (.203)	**< .001 (.557)**
Control	157.6 ± 27.66	157.2 ± 28.6	-0.25%	-0.01			
Sprint Interval Training	141.46 ± 29.3	144.58 ± 27.64	2.20%	0.10			
Endurance Training	114.28 ± 17.08	119.45 ± 20.38	4.52%	0.25			
Strength Training	147.1 ± 36.94	166.1 ± 34.6	12.92%	0.49			

Note. Data are expressed as mean ± standard deviation. Mean Δ% = (Post - Pre)/Pre. A Cohen's d of 0.00–0.19, 0.20–0.49, 0.50–0.79, and ≥0.80 represent trivial, small, moderate, and large effects, respectively. A partial eta squared (ηp²) ≥ 0.01 indicates a small effect, ≥ 0.059 is a medium effect, and ≥ 0.138 is a large effect. Repeated measures MANOVA results for the 3MAOT (maximum running speed, CS, D') are listed in the top upper right-hand corner. Repeated measures univariate ANOVAs results are in the 3 columns to the right, where an ANOVA was run for each dependent variable.

our hypothesis. This is surprising because CS, a marker of endurance performance, tended to increase after ET. We postulated that ET would increase PhA by decreasing R. Our results

indicate that both R and Xc tended to decrease in the ET group. This is suggestive that positive intracellular adaptations occurred which reduced the R to electrical current (a beneficial change), but cell membrane capacitance to hold an electrical charge also was reduced (a detrimental change). What is even more surprising is that while endurance performance tended to improve, the PhA of males in the present study tended to decline.

Reference values for PhA indicate endurance-based athletes have significantly lower PhA values when compared to field sport athletes and power-based athletes [3, 19]. The present study also suggests that ET results in regional decreases in the PhA of the right and left leg, -3.11% and -2.55% respectively. PhA is considered an index of the amount of extracellular water divided by total body water [1], which presented a positive trend as a result of ET, indicating that more water was outside of the cells relative to total body water. Increased plasma volume is a common adaptation to ET that supports cardiovascular performance [48], and may explain some of the fluid shifts that occurred in this study. However, plasma albumin, the primary protein responsible for exercise-induced hypervolemia [48], has a significant positive relationship with PhA [21]. Thus, we hypothesized that an increased CS would result in an increased PhA and Xc, and a decreased R. These exploratory findings may suggest moderate intensity endurance training produces trends towards a decreased PhA, and Xc in males.

In contrast, RT tended to increase muscular strength and displayed a small, positive (but non-significant) effect on PhA and Xc. This observation is in agreement with our hypothesis as we postulated that RT would prime the neuromuscular system and improve Xc or the ability of the cell membrane to store electrical charge. Xc is considered an index of cell membrane integrity and function, which can be affected by ruptures caused by damaging eccentric contractions during RT [1, 24]. As calcium enters the breach and acts as an ionotropic alarm, membrane repair is initiated, which improves the membrane's ability to handle subsequent stress and thereby altering the dielectric properties of tissue [24]. This prospective pathway may be an important consideration in our understanding of the effects of different training types on PhA, as in the current study RT was the only intervention that tended to improve PhA with a moderate effect. Furthermore, increased intracellular water volume is considered a stimulus for anabolism [49] and may stimulate pathways that increase protein synthesis [50]. On average, the strength training group in this study increased skeletal muscle mass by 0.84%, with increased total body water (0.40%), and intracellular water (0.86%), which may partially account for the significantly improved strength of the RT group. Meanwhile, extracellular water decreased (-0.31%), resulting in a decreased extracellular water to total body water ratio (-0.54%), which may also contribute to the trend of increased PhA [50].

The effects of RT on PhA have primarily been explored in older adults, suggesting that ≥ 8 weeks of RT increases PhA on average by 0.52 degrees with increased Xc and decreased R [45]. In the current study, young male RT subjects had a 12.9% improvement in the barbell back squat 1-RM, concomitant with a 3.5% increase in Xc and 1.1% increase in R. Previous research has identified RT 3 times per week provides superior adaptations in PhA compared to 1 time per week, indicating that training frequency is a critical variable to consider when prescribing exercise [51]. In the present study, subjects performed 4 sets of 5 repetitions of the barbell back

squat at 85% 1RM, 3 times per week, for 4 weeks. Therefore, in terms of modifying the protocol, future research could implement a longer intervention of at least 8 weeks [45].

We hypothesized that SIT would have a similar effect based on previous research on the relationships between PhA and sprinting performance [13]. Interestingly, SIT had a larger effect on CS than ET but did not affect PhA. To the best of our knowledge, this is the first study to present the effects of SIT on raw BIA variables. SIT had trivial effects on PhA and Xc, with small negative effects on R. A slight increase in total body water (1.00%), intracellular water (1.06%), and extracellular water (0.98%) was observed with no change in the extracellular to total body water ratio (0.0%). The lack of improvement in PhA as a result of SIT may be due to the nature of the exercise prescription utilized in the present study. Subjects performed 4 sets of repeated inclined treadmill sprints designed to induce volitional fatigue in 30-60 seconds, which are dissimilar to the 10 and 30-meter sprints that were shown to have positive relationships with PhA [13]. The intervals we used may have been too long and lacked intensity compared to 10 and 30-meter sprints.

Still, PhA has a direct inverse relationship with the fatigue index derived from the running anaerobic sprint test, revealing that PhA appears as a valid predictor of fatigue [52]. A 21.68% increase in time to volitional fatigue during SIT was observed in the present study with no change in maximal running speed. When considering the relationships between anaerobic capacity and PhA, and the improvements in anaerobic capacity observed in this study, one could assume that PhA would increase. Future research should examine the effects of maximal sprint training on PhA since previous research has shown that PhA exhibits a positive relationship with maximum running power [52].

Lower body regional BIA is considered more informative during indirect monitoring of lower body neuromuscular status than whole body PhA [8]. In the present study, the right and left leg PhA for the RT group increased by 2.67% and 3.07% respectively, concomitant with a significant increase in muscular strength. Thus, the trend towards increased lower body regional PhA may partially explain enhanced performance for the back squat 1RM [8]. In contrast, the right and left leg PhA for the ET group decreased by -3.11% and -2.55% respectively, concomitant with a significant increase in CS. The present observation challenges the notion that lower body PhA could be used as a tool in the sport-scientist toolbox to monitor changes in endurance performance.

With regard to the secondary aim of investigating the effects of different training types on the 3MAOT, we found that none of the interventions produced significant increases in maximum running speed. In fact, ET had a small negative effect (-3.67%). These findings make sense as SIT did not train near maximal sprinting speeds [53]. To our surprise, SIT presented a small positive effect on CS (4.41%), whereas ET increased CS by 5.16%. Considering that the improvements in CS were similar between the SIT and continuous moderate-intensity endurance exercise interventions, it would be interesting to compare the efficacy of these training programs on endurance performance (e.g. 5 km or 10 km time trial). D′ tended to decrease following training interventions that increase CS [54], which was observed in the present study as SIT and ET had

a large negative effect on D′ (-27.84%; -22.16%). However, RT resulted in a -6.35% change in CS and a -15.73% change in D′. Interestingly, all training groups improved in the barbell back squat 1RM, including a 4.52% increase observed in ET.

The findings presented in this study are limited to recreationally active young adults with varying capacities for athletic performance. Unfortunately, our randomization of subjects resulted in diverse groups at baseline which limited our ability to detect statistical differences in PhA. Therefore future research should consider allocating subjects based on fitness to ensure equally fit groups at baseline. A strength of our pilot study is that we identified the type of exercise intervention that should be utilized to maximize PhA and Xc, e.g., weight lifting or intense exercise lasting <15 seconds such as short-distance sprinting. The current study is also limited by not controlling participants' food intake the night before measuring BIA, whereby increased carbohydrate loading may increase intracellular water and glycogen, affecting BIA measurements. Subsequent exploration of the effects of different exercise types on PhA should include a variety of exercise intensities (e.g., low, moderate, and high-intensity endurance exercise) and longer interventions (>8 weeks). Future research should focus on repeating the moderate-intensity endurance exercise intervention trial with a larger sample size to determine if PhA indeed does decrease. Also, since we utilized a healthy population, which means the potential of the intervention to impact PhA may have been small due to diminishing returns, testing subjects of different degrees of fitness should be considered. If PhA indeed decreases with endurance training, this will undoubtedly affect the way PhA should be used in exercise prescription and testing when working with endurance athletes as current literature suggests that PhA increases with all training types.

The findings described in this study provide a valuable first step in determining the effectiveness of different training types on PhA, Xc, and R in young adult males. The primary finding of this study is that ET produced a small negative effect on PhA and Xc, regardless of a significant increase in CS. In contrast, RT had a small positive effect on PhA and Xc, concomitant with a significant increase in muscular strength. The observations from this study could be used to design future research focused on deciphering the training effect on PhA.

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