Research article

Hydration in young water polo players: A bioelectrical impedance vector analysis (BIVA) approach

Sofia Serafini [a], Andrea Di Blasio [a], Iris Prestanti [a], Andrea Di Credico [a], Andrea Fusco [a], Jacopo Cilli [a], Gabriele Mascherini [b], Ruggero D'Anastasio [a,*], Pascal Izzicupo [a]

[a] *Department of Medicine and Aging Sciences, Gabriele d'Annunzio University of Chieti and Pescara, Chieti, Italy*
[b] *Exercise Science Laboratory Applied to Medicine "Mario Marella", Department of Experimental and Clinical Medicine, University of Florence, 50134, Florence, Italy*

ARTICLE INFO

ABSTRACT

Purpose: This study aimed to assess hydration status before and after training using the bioelectrical impedance vector analysis (BIVA) method.
Design: Pre-post quasi-experimental designs.
Method: Twenty-four young water polo players (mean age: 13.30 ± 0.55) underwent assessment for bioelectrical and anthropometric measurements before and after a water polo training session.
Results: Most players fell within the 50 % percentile of the bioelectrical tolerance ellipses of the reference population. The BIA vector differed statistically between players who achieved growth peaks (PGA: $T^2 = 9.1$, $p = 0.013$) and those who did not (GPNA, $T^2 = 28.9$, $p < 0.001$) compared to the reference and also differed between them ($T^2 = 37.7$, $p < 0.001$). After training, a decrease in body mass (BM) and BM adjusted for water intake ($p = 0.0001$) and changes in BIA variables ($p < 0.05$) were observed. BIVA also showed a significant pre-post vector migration in both GPA ($T^2 = 24.7$; $p < 0.001$) and GNPA ($T^2 = 43.1$; $p < 0.001$), characterized by a decrease in resistance and opposite reactance directions ($T^2 = 33.6$, $p < 0.001$).
Conclusion: Young water polo players exhibit a significant BM loss after training (~2.5 %). *Ad libitum* water intake seems to partially compensate dehydration. The resistance reduction indicates that BIVA captured the compensation for dehydration resulting from fluid intake.

1. Introduction

Adequate hydration is essential for maximizing athletic performance and preventing heat-related illnesses. In adults, maintaining euhydration typically occurs through the balance of normal daily fluid intake and losses. However, during physical activity, the body generates excess metabolic heat that must be dissipated to maintain core temperature and ensure proper metabolic functioning. Significant sweat losses during exercise can disrupt normal body-water balance, leading to detrimental effects on both performance and health [1,2]. Thus, it is crucial to replenish fluid losses from sweat to sustain euhydration.

* Corresponding author.
  E-mail addresses: sofia.serafini@phd.unich.it (S. Serafini), andrea.diblasio@unich.it (A. Di Blasio), iris.prestanti@unich.it (I. Prestanti), andrea.dicredico@unich.it (A. Di Credico), andrea.fusco@unich.it (A. Fusco), jacopo.cilli@gmail.com (J. Cilli), gabriele.mascherini@unifi.it (G. Mascherini), ruggero.danastasio@unich.it (R. D'Anastasio), pascal.izzicupo@unich.it (P. Izzicupo).

While in aquatic environments, heat dissipation occurs mainly through convection and conduction due to immersion in water, reducing the reliance on sweating as a cooling mechanism. Apart from perspiration and water loss through respiration, an increase in dilute urine output is another mechanism of water loss typical of water-based exercise [3–5]. Research indicates that up to 2.5 % of body weight can be lost during high-intensity aquatic training, primarily due to inadequate fluid intake, which can result in dehydration and impaired thermoregulation [6]. Accurately assessing hydration status in such environments is particularly challenging [7], and current literature is limited, mostly focusing on adult populations [3–6]. Children and adolescents seem less effective than adults at managing fluid intake during exercise, as they tend to recognize thirst less promptly [8]. Hormonal changes during puberty further affect fluid distribution and retention, contributing to significant interindividual variability in hydration needs [9,10]. During adolescence, the age of fastest growth in stature is named age at Peak Height Velocity (PHV). The age at PHV serves as an important marker for distinguishing between chronological age and biological maturity, as it reflects the individual's stage of pubertal development rather than just their age in years [11]. Pre-PHV individuals typically have a higher water content relative to their body mass, while post-PHV individuals, with more developed muscle mass, exhibit different patterns of fluid distribution and retention [12]. The onset of puberty also introduces hormonal changes that affect both fluid distribution and thirst perception, leading to potential imbalances in fluid regulation [9]. Notwithstanding, the extent to which training status and maturation interact to influence body water content and loss in training and competition are partially unknown.

Common field methods to assess dehydration are the percentage of body weight lost and urine color. While the latter can be impractical in aquatic environments, other methods include urine and plasma osmolality, as well as urine specific gravity, but these are invasive and require laboratory analysis, making them less practical for field use [1]. Another limitation is that none of these methods can distinguish between intracellular water (ICW) and extracellular water (ECW), a distinction crucial for understanding the severity of dehydration. The loss of ICW, in particular, can indicate more advanced dehydration, affecting cell function and overall performance [1].

Bioelectrical Impedance Vector Analysis (BIVA) provides a more detailed assessment by evaluating hydration status while accounting for compartmental fluid distribution [13,14]. Although not considered the gold standard, this method has shown promise in aquatic sports, offering a more accurate representation of body water status [15,16]. Water polo is characterized by high energy demands, with phases of intense activity interspersed with periods of lower intensity and recovery, all taking place in an aquatic environment [17,18]. As for other aquatic sports, effective hydration management is crucial [19], particularly for adolescents, who may face unique hydration challenges due to their varying stages of maturation. Even among athletes of the same age, differences in biological maturity can lead to significantly different hydration needs and fluid management capabilities [8–10,20]. Nonetheless, there aren't studies that evaluated the hydration status before and after water polo training in young athletes. Therefore, the present study aims to evaluate the hydration status of pre- and post-PHV water polo players before and after a typical training session for regional youth championship water polo participants, using BIVA to assess body water content and its compartmental distribution. We hypothesize that variations in the bioelectrical impedance vector after training will depend on both the training load and the *ad libitum* rehydration strategy employed during the session.

2. Materials and methods

2.1. Participants

Twenty-four young water polo players (mean age: 13.30 years ± 0.55), part of a team engaged in a regional championship, participated in the study. Inclusion criteria required continuous training participation over the preceding year and active involvement in the regional championship. Exclusion criteria included any injuries or clinical conditions at the time of the protocol, pharmacological treatment, or following a specific dietary regimen (e.g., hypo- or hyper-caloric diet). The study was conducted in accordance with the Declaration of Helsinki. All participants provided informed consent and submitted written parental consent for study participation. The technical staff approved the study's conduct. The data were collected during routine training practices and were initially gathered for monitoring purposes, rather than with a specific research intent. Since these data were collected retrospectively and did not interfere with the athletes' regular training routines, ethical clearance specific to this analysis was obtained post hoc. The study was approved by the Institutional Review Board of the Department of Human Sciences, Society, and Health of the University of Cassino and Lazio Meridionale (approval number 16259). Nonetheless, all performance data were anonymized before analyses to ensure player confidentiality.

2.2. Study design and procedures

The present study employs a pre-post quasi-experimental design to address the research question from an ecological perspective. This quasi-experimental pre-post design aims to evaluate the effect of a training session on hydration status in young water polo athletes, observing them in a realistic context without changing their regular training routines.

A few days before the procedure, demographic information (years of practice, training days and hours per week, and other sports practiced in the past or at the same time) was collected through a questionnaire. The day before, players were instructed to abstain from caffeine, alcohol and, physical exercise to achieve a state of euhydration for the bioelectrical impedance analysis (BIA). Additionally, for the BIA assessment, they were directed to drink 3.0 L of fluid over the course of 24 h, with 2.0 L to be consumed between 6:00 p.m. and 10:00 p.m., in addition to their habitual dietary practices. From 10:00 p.m. until the assessment the following day, no further food or fluid intake was permitted [1]. On the evaluation day, between 8:00 a.m. and 10:00 a.m., anthropometric and

bioelectrical assessments were conducted in a thermoneutral room (25 °C) where both relative humidity and ambient temperature were monitored using thermohygrometer RS232-UR100+ (XS Instruments, Italy). The assessments were carried out after measuring skin temperature, with participants dressed in light clothing and without any conducting garments. Following this, participants consumed a standardized breakfast consisting of one cheese and ham sandwich, 1 banana, and 400 mL of fruit juice. At 11:00 a.m., all players underwent category-specific training in both 25-m and 21-m indoor pools. The training included a water warm-up, followed by a main set of repetitions in various swimming styles with differing durations and intensities, as well as drills for ball control, game phases, and shooting practice. Fluid intake (H_2O) was monitored throughout the session. After the conclusion of the training session, athletes abstained from fluid consumption for at least 1 h until post-testing was completed. One hour after the training session, and after verifying that body skin temperature aligned with pre-assessment, BIA and anthropometric evaluation were conducted again. The rating of perceived exertion (RPE) was also measured post-training using the Modified Borg RPE Scale [21].

2.3. Anthropometric assessment

A certified specialist (i.e., a level 1 certification of the International Society of the Advancement of Kinanthropometry, ISAK) performed all the anthropometric measurements according to the ISAK recommendation [22]. Body mass (BM), stature, and sitting height (SH) were measured using a stadiometer with a balance (Seca 200, Seca, Hamburg, Germany). Waist circumferences (WC), relaxed arm circumference, and calf circumference were measured using a Cescorf anthropometric tape (Cescof, Porto Alegre, Brazil). Skinfold measurements at the triceps, subscapular, supraspinale, and calf sites were obtained with a Holtain skinfold caliper (Holtain, Crosswell, UK). Body mass index (BMI) was calculated as BM in kilograms divided by the square of stature, expressed in meters. The waist-to-height ratio (W/Hr) was determined by dividing WC by stature. Additionally, mid-upper arm area (MUAA), mid-upper arm muscle circumference (MUAMC), mid-upper arm muscle area (MUAMA), mid-upper arm fat area (MUAFA), and arm fat index (AFI) were calculated according to the literature [23]. The percentage of fat mass (%FM) was calculated through the Slaughter equation for pubertal boys, and fat mass in kilograms (FM_{Sl}) was subsequently derived [24].

2.4. Maturity offset

The maturity offset was defined according to the Mirwald equation based on the distance from peak height velocity (PHV) in years (YPHV) and derived from BM, stature, SH, somatic dimension, chronological age, and their interaction. The predicted adult height (PAH) and the percentage of predicted adult height (%PAH) were estimated according to the Sherar method [25]. Players were classified as growth peak not-achieved (GPNA) or growth peak achieved (GPA) according to the YPHV.

2.5. Whole-body bioimpedance assessment

Bioimpedance analysis was performed using BIA (BIA 101 Anniversary AKERN srl, Florence, Italy) with an electric current at a frequency of 50 kHz (±1 %). The device was calibrated before assessment using the standard control circuit supplied by the manufacturer with a known impedance (resistance (R) = 380 Ω; reactance (Xc) = 45 Ω). The device's accuracy was 0.1 % for R and 0.1 % for Xc. For the bioelectrical impedance measurement, each participant was positioned supine for a minimum of 2 min to distribute the body fluid evenly. During this time, the legs were positioned at the 45° relative to the midline of the body, while the upper libs were positioned 30° away from the trunk. After cleaning the skin with alcohol, two electrodes (Biatrodes, Akern Srl, Florence, Italy) were placed on the back of the right hand and two electrodes on the neck of the corresponding foot [14].

To ensure accurate measurements, assessments were performed on an isolated cot away from any electrical conductors. The bioelectrical phase angle (PhA) was calculated as the arctangent of Xc/R × (180°/π) [26]. The hydration status was evaluated using the bioimpedance vector analysis method (BIVA), normalizing R and Xc parameters for stature in meters [14]. This analysis offers a comprehensive evaluation of hydration levels while considering the distribution of fluid across different compartments [13].

2.6. Temperature assessment

The temperature was taken in the subject's temple before performing the BIA using a digital infrared forehead thermometer without contact (Mini Flash, TFA Dostmann GmbH & Co, Wertheim, Germany). Skin temperature serves as a valuable proxy for assessing core temperature [27] and cutaneous blood flow, as it reflects the physiological responses of blood vessels and overall circulatory dynamics in the skin. Elevated skin temperature can indicate increased blood flow due to heightened metabolic activity or external environmental influences, while lower temperatures may suggest reduced perfusion. To ensure accuracy and reliability, the post-training examination was performed only after confirming that the skin temperature was comparable to the pre-training measurements [28]. This careful monitoring helps to minimize variability and allows for a more precise assessment of the physiological effects of training on the participants' hydration status and body composition [29].

2.7. Internal training load assessment RPE

Perceived exertion during training was assessed using the individual session-RPE (s-RPE) method [21]. Following the training session conclusion, players were presented with the CR-10 RPE scale. The resulting scores were obtained by multiplying the training duration by the corresponding relative RPE values. To enhance measurement consistency and identify potential learning effects, a

minimum of three training sessions were conducted for all participants at least one week before the commencement of the study.

2.8. Statistical analysis

Descriptive statistics (mean, SD) were calculated for each variable, while the normality of the data was verified by applying the Shapiro–Wilk test. The student's unpaired *t*-test was used to analyze group differences in anthropometric variables according to the growth peak (GPNA and GPA) achievement for normally distributed variables and the Mann-Whitney *U* test for non-normally distributed variables, respectively. Whole-body impedance vectors were analyzed by the RXc graph method using the BIVA software by Piccoli et al. [30]. Each player was plotted in the tolerance ellipses (50 %, 75 %, and 95 %) of the 14- to 15-year-old healthy male Italian reference population [31]. Compared to our sample, this population represents the closest references in terms of age. The
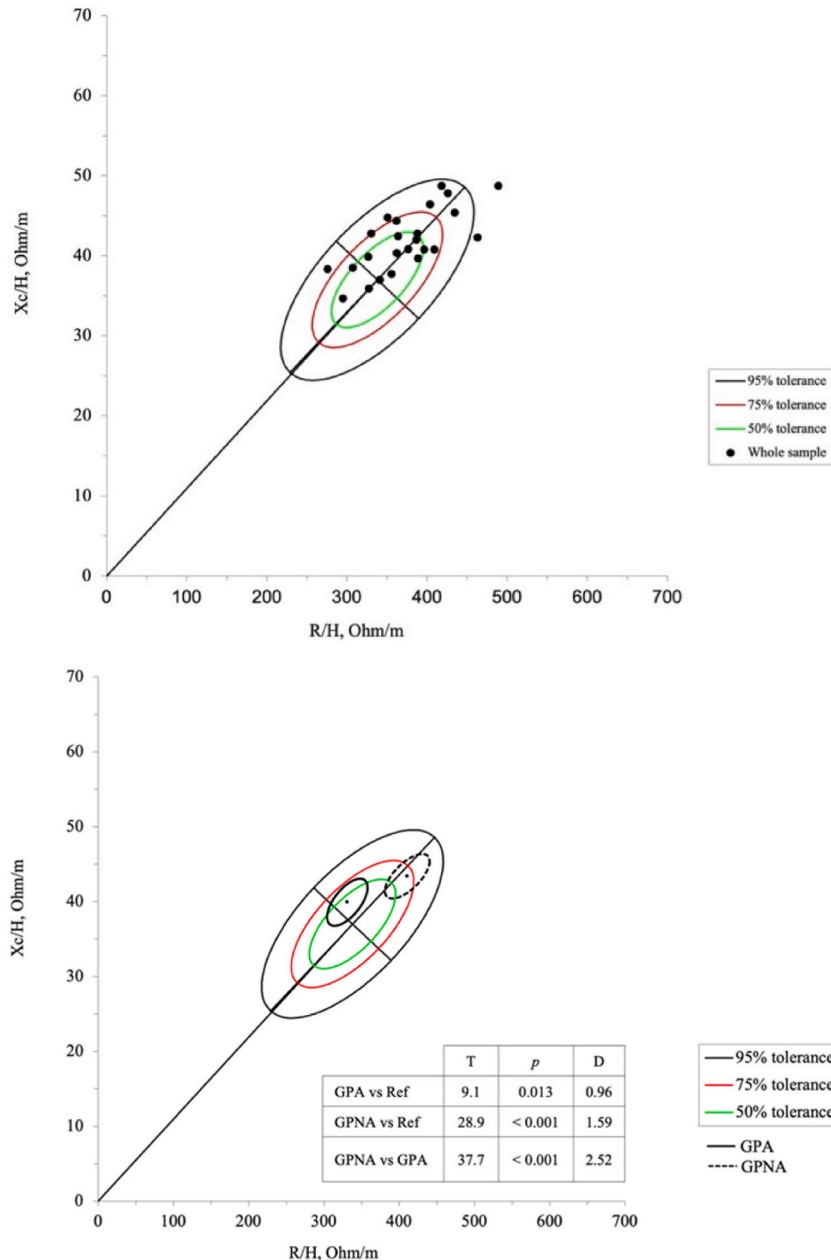

Fig. 1. a. BIVA point graph of water polo players compared with the reference population [31]. R/h, height-adjusted resistance; Xc/h, height-adjusted reactance. b. Classic BIVA mean graph between subgroups and reference population [31]. GPNA: growth peak not-achieved, GPA: growth peak achieved; R/h, height-adjusted resistance; Xc/h, height-adjusted reactance; T^2, Hotelling's T^2 test; *p*-value (significance at *p* < 0.05); D, Mahalanobis distance.

BIVA mean graph was performed to compare whole-body vectors between GPNA and GPA players and with respect to the reference population. A two-sample Hotelling's T^2 test was used to determine the BIA vector differences between groups and with respect to the reference population. Distances between ellipses were calculated by the Mahalanobis test [30]. A repeated measure analysis of covariance (RM-ANCOVA), with water intake as covariate, time (pre-, post-training) as within-subject factor, and achievement of peak growth (GPNA and GPA) as between-subject factor was performed after checking for violation of the assumptions, to investigate the effect of an acute training session on anthropometric and bioelectrical hydration markers as dependent variables. The BIVA paired graph was used to analyze pre-to post-training changes in the vectors of GPNA and GPA players. To examine the magnitude of pre-post ratio changes in anthropometric and bioelectrical variables, delta values (Δ, % of pre) were calculated. Pearson's correlation coefficient was used to determine the extent of correlation between delta values of BM (ΔBM), BM adjusted for fluid intake (ΔBM_{adj}), total fluid intake during the training session, and delta values of bioelectrical hydration markers (ΔR/h, ΔXc/h, ΔZ/h, ΔPhA, ΔECW:TBW). The magnitude of correlations was considered as r = 0.00–0.09, negligible; r = 0.10–0.39, weak; r = 0.40–0.69, moderate; r = 0.70–0.89, strong; r = 0.90–1.00, very strong [32]. A paired one-sample Hotelling's T^2 test was used to analyze pre-to post-training changes in the vector through the 95 % confidence ellipses, while vector shifting was calculated by the Mahalanobis test [30]. The a priori sample size was determined using G*Power (version 3.1, Heinrich Heine University, Düsseldorf, Germany) based on the following parameters: significance level (α) of 0.05, statistical power (1 - β) of 0.80, and an effect size (f) of 0.3. The calculation, conducted for a RM-ANCOVA with a 2 × 2 mixed design, indicated that a total of 24 participants would be required.

3. Results

3.1. Baseline characteristics of the sample and maturity offset

The current water polo sample was composed of 13 players who did not achieve the peak growth (GPNA) and 11 who already passed the peak growth (GPA). GPA players showed higher age and training volume ($U = 24.0$, $p = 0.006$; $U = 24.0$, $p = 0.018$, respectively). Furthermore, stature, SH, BM and BM_{adj} were higher in GPA group players ($t = -5.1$, $p < 0.001$; $t = -5.4$, $p < 0.001$; $U = 17.0$, $p < 0.001$; $U = 18.0$, $p = 0.001$, respectively), while the triceps skinfold ($U = 109.0$, $p = 0.032$) was lower. Players in the GPNA group showed higher R/h, Xc/h, and Z/h ($t = 5.8$, $p < 0.001$; $t = 2.4$, $p < 0.025$, $t = 6.1$, $p < 0.001$, respectively), and lower PhA ($t = -4.6$, $p < 0.001$), than GPA players. The BIVA point graph (Fig. 1a), indicates that half of the sample fell inside the 50 % tolerance ellipse of the reference population [31]. The remaining participants were distributed outside of the 50 % and 75 % tolerance ellipses, with the majority in the left quadrant and fewer in the right quadrant. The BIA vector comparison showed that both subgroups differed statistically from the reference population [31]. GPNA players showed a longer vector and GPA players fell on the left of the reference population and slightly above. Furthermore, the subgroups were also statistically different (Fig. 1b).

Detailed data of the whole sample characteristics and group comparisons based on maturity offset are provided in Table 1.

3.2. Changes evoked by training

After training, both BM and BM_{adj} significantly decreased (-0.72 % $\pm$ 1.04 and -2.60 % $\pm$ 1.14 respectively) (Table 2). These changes were paralleled by a decrease in R/h and Z/h, an increase in PhA and ECW:TBW as well as a BIA vector migration on the top-left side of the graph (Fig. 2a). GPA players showed higher BM, BM_{adj}, PhA, and ECW:TBW values and lower R/h, Xc/h and Z/h values than GPNA, before and after training. An interaction effect was found for Xc/h with the post-hoc analysis indicating a significant difference after training. However, using water intake as a covariate, all the significant changes evoked by training were not significant.

Regarding BIVA, The BIA vector migration was significantly shifted on the top-left side (Fig. 2a). Considering the effect of maturation, Bia vector shifted on the top-left side for GPNA players and the bottom-left side for GPA (Fig. 2b).

3.3. Correlation

A negative correlation was found between ΔBM_{adj} and ΔXc/h (r = -0.489, $p < 0.05$). A tendency for a negative correlation was also found between ΔBM_{adj} and ΔR/h (r = -0.384, $p = 0.063$), ΔZ/h (r = -0.388, $p = 0.061$), and ΔPhA (r = -0.489, $p = 0.054$) and for positive correlation between ΔBM_{adj} and ΔECW:TBW (r = -0.382, p < 0.65).

4. Discussion

The main finding of the present study is that a typical training session in young water polo players resulted in a significant reduction in BM ($\sim$2.5 %), primarily due to fluid loss. The BIA analysis further revealed a vector migration towards the upper left quadrant of the graph, indicating shifts in fluid distribution, with a significant decrease in R/h accompanied by an increase in PhA and the ECW:TBW ratio, suggesting partial compensation achieved through *Ad libitum* fluid intake. This interpretation is further supported by the fact that when water intake was added as a covariate in the analysis of bioelectrical values, the observed significances disappeared, suggesting that these effects were closely linked to fluid intake. Additionally, a notable difference in Xc/h values was observed between groups: the GPNA group experienced an increase in reactance values, whereas the GPA group showed a decrease (Fig. 2a).

Age and maturation are known to affect vector length: typically, younger and late-maturing adolescents show longer vectors [33]. The findings of this study align with existing literature, as the average vector length in our sample exceeded that of the nearest

Table 1
Descriptive data of water polo players based on maturity status.

	Whole sample	GPNA	GPA			
	(n = 24)	(n = 13)	(n = 11)	t	U	p
General						
Age (years)*	13.30 ± 0.55	13.00 ± 0.44	13.66 ± 0.45	–	24.00	0.006
Training (h/week) *	10.73 ± 2.09	9.75 ± 1.74	11.90 ± 1.93	–	24.00	0.018
RPE	3.98 ± 1.57	3.64 ± 0.75	4.39 ± 2.19	–	46.50	0.845
Fluid intake (l)	1.03 ± 0.37	1.06 ± 0.42	0.98 ± 0.30	0.53	–	0.602
Anthropometric						
BM (Kg) *	58.07 ± 10.41	52.37 ± 6.27	64.81 ± 10.48	–	17.00	<0.001
BM$_{adj}$ (Kg) *	56.64 ± 10.39	51.02 ± 6.27	63.28 ± 10.55	–	18.00	0.001
Stature (cm)*	165.59 ± 8.93	159.66 ± 7.14	172.60 ± 4.77	−5.11	–	<0.001
SH (cm) *	85.96 ± 4.85	82.67 ± 3.48	89.85 ± 2.99	−5.37	–	<0.001
SH/Hr (cm)	0.52 ± 0.01	0.52 ± 0.01	0.52 ± 0.01	−0.66	–	0.673
W/Hr (cm)	0.44 ± 0.04	0.44 ± 0.05	0.43 ± 0.04	–	82.50	0.540
BMI (cm)	21.08 ± 2.44	20.57 ± 2.14	21.68 ± 2.74	−1.12	–	0.274
WC (cm)	72.14 ± 7.02	70.52 ± 6.64	74.06 ± 7.28	−1.25	–	0.225
Arm relaxed circumference (cm)	27.42 ± 2.95	26.46 ± 2.13	28.56 ± 3.45	−1.83	–	0.081
Calf circumference(cm)	33.70 ± 2.17	32.96 ± 1.81	34.59 ± 2.31	−1.94	–	0.065
Subscapular skinfold (mm)	11.80 ± 5.45	12.45 ± 6.35	11.02 ± 4.32	–	76.50	0.794
Triceps skinfold (mm)*	15.55 ± 6.56	18.09 ± 6.33	12.56 ± 5.71		109.00	0.032
Supraspinale skinfold (mm)	14.44 ± 7.95	15.53 ± 8.11	13.15 ± 7.95	–	83.00	0.524
Calf skinfold (mm)	13.13 ± 5.21	14.39 ± 4.46	11.76 ± 5.83	1.23	–	0.140
ΔBM (%)	−0.72 ± 1.04	−0.58 ± 1.29	−0.88 ± 0.69	0.70	–	0.494
ΔBM$_{adj}$ (%)	−2.60 ± 1.14	−2.68 ± 1.37	−2.06 ± 0.83	−0.37	–	0.715
Bioelectrical						
R (Ω) *	615.41 ± 61.60	653.66 ± 47.82	570.20 ± 42.81	4.47	–	<0.001
Xc (Ω)	69.02 ± 4.71	69.12 ± 3.77	68.91 ± 5.83	0.11	–	0.916
Z (Ω) *	376.17 ± 51.82	412.53 ± 36.35	333.21 ± 29.01	5.83	–	<0.001
PhA (°)*	6.45 ± 0.63	6.05 ± 0.40	6.91 ± 0.52	−4.60	–	<0.001
R/h (Ω/m) *	373.82 ± 51.83	410.23 ± 36.29	330.80 ± 28.96	5.85	–	<0.001
Xc/h (Ω/m) *	41.82 ± 3.88	43.41 ± 3.64	39.94 ± 3.39	2.40	–	0.025
Z/h (Ω/m)*	229.15 ± 42.41	259.37 ± 30.77	193.44 ± 20.26	6.07	–	<0.001
ΔR/h (%)	−2.22 ± 2.75	−1.36 ± 2.32	−3.23 ± 2.97	1.74	–	0.096
ΔXc/h (%)	0.59 ± 3.85	1.89 ± 3.72	−0.95 ± 3.58	1.90	–	0.071
ΔZ/h (%)	−2.18 ± 2.75	−1.32 ± 2.32	−3.20 ± 2.97	1.74	–	0.096
Body composition						
MUAMA*	41.02 ± 10.74	34.48 ± 4.43	48.75 ± 10.96	–	8.00	<0.001
MUAA	60.51 ± 13.39	56.04 ± 8.90	65.79 ± 16.15	−1.87	–	0.075
MUAFA	19.49 ± 8.64	21.56 ± 8.09	17.04 ± 9.00	–	93.00	0.228
AFI*	31.76 ± 11.08	37.45 ± 9.95	25.04 ± 8.47	3.25	–	0.004
FM$_{Sl}$ (kg)	13.41 ± 6.12	13.31 ± 5.36	13.52 ± 7.18	−0.08	–	0.937
%FM$_{Sl}$	22.70 ± 8.44	25.00 ± 8.62	19.98 ± 7.72	–	101.00	0.093
FFM$_{BIA}$ (kg) *	43.60 ± 7.23	38.42 ± 3.57	49.74 ± 5.33	−6.20	–	<0.001
FM$_{BIA}$ (kg)	14.58 ± 5.86	13.99 ± 4.68	15.28 ± 7.18	−0.53	–	0.600
%FM$_{BIA}$	24.63 ± 6.93	26.28 ± 6.50	22.69 ± 7.22	1.28	–	0.214
%FFM$_{BIA}$	75.37 ± 6.93	73.72 ± 6.50	77.31 ± 7.22	−1.28	–	0.214
FMI $_{BIA}$	5.34 ± 2.00	5.52 ± 1.81	5.12 ± 2.27	0.49	–	0.632
FFMI$_{BIA}$*	15.79 ± 1.23	15.05 ± 0.79	16.66 ± 1.10	−4.15	–	<0.001
MB*	1459.10 ± 147.34	1351.22 ± 59.26	1586.60 ± 112.70	−6.55	–	<0.001
BCM*	24.45 ± 5.08	20.73 ± 2.04	28.85 ± 3.89	−6.55	–	<0.001
Maturity offset						
Age at peak growth *	13.38 ± 0.57	13.66 ± 0.50	13.04 ± 0.48	3.09	–	0.005
YPHV* (years)	−0.09 ± 0.79	−0.67 ± 0.43	0.61 ± 0.50	0.00	–	<0.001
PAH (cm)	183.15 ± 5.10	181.51 ± 5.33	185.10 ± 4.26	−1.80	–	0.086
%PAH*	90.37 ± 3.24	87.93 ± 1.66	93.26 ± 1.99	−7.14	–	<0.001
Fluid distribution						
ECW (l) *	14.50 ± 2.60	12.64 ± 1.45	16.70 ± 1.78	−6.17	–	<0.001
ICW (l) *	20.21 ± 2.11	18.82 ± 1.02	21.86 ± 1.85	–	7.50	<0.001
TBW (l) *	34.71 ± 4.52	31.45 ± 2.24	38.56 ± 3.30	−6.25	–	<0.001
%TBW	60.29 ± 5.61	60.44 ± 5.32	60.12 ± 6.19	0.14	–	0.893
%ICW*	58.43 ± 2.62	59.89 ± 2.24	56.71 ± 1.94	3.69	–	0.001
ECW:TBW *	41.54 ± 2.60	40.08 ± 2.20	43.27 ± 1.92	−3.75	–	0.001

Table 1. Data are expressed as mean ± standard deviation; t, student's test; U, Mann-Whitney's test; GPNA, growth peak not-achieved; GPA, growth peak achieved; BM, body mass; BM$_{adj}$, body mass adjusted for fluid intake RPE, rating of Perceived Exertion RPE, rating of Perceived Exertion; SH, sitting height; SH/Hr, the sitting height to height ratio; W/Hr, waist-to-height ratio; BMI, body mass index; WC, waist circumference; ΔBM (%), delta values of body mass pre-post training; ΔBM$_{adj}$, delta values of body mass adjusted for fluid intake; R, resistance; Xc, reactance; Z, impedance; PhA, phase angle; R/h, resistance-to-height ratio; Xc/h, reactance-to-height ratio; Z/h, impedance-to-height ratio; ΔR/h, delta values of R/h pre-post training; ΔXc/h, delta values of Xc/h pre-post training; ΔZ/h, delta values of Z/h pre-post training; MUAMA, mid-upper arm muscle area; MUAA, mid-upper arm area; MUAFA, mid-upper arm fat area; AFI, arm fat index; FM$_{sl}$, fat mass by Slaughter equation; %FM$_{sl}$, percentage of fat mass by

Slaughter equation; %FM$_{BIA}$, fat mass by BIA; %FFM$_{BIA}$, fat free mass by BIA; MB, basal metabolism; BCM, body cellular mass; YPHV, distance from peak height velocity in years; PAH, predicted adult height; %PAH, percentage of predicted adult height; ECW, extra-cellular water; ICW, intra-cellular water; TBW, total body water; %TBW, percentage of TBW; %ICW, percentage of ICW; ECW:TBW, ECW-to-TBW; *Indicates statistical significance between GPNA and GPA.

Table 2
Anthropometric and bioelectrical variables before (PRE), after (POST) the acute training session.

	All players (n = 24)		Growth peak not reached (n = 13)		Growth peak reached (n = 11)	
	Pre	Post	Pre	Post	Pre	Post
Anthropometric						
BM (Kg)[a],[b]	58.07 ± 10.41	57.67 ± 10.34	52.37 ± 6.27	52.09 ± 6.37	64.81 ± 10.48	64.26 ± 10.43
BM$_{adj}$ (Kg)[a],[b]	58.07 ± 10.41	56.64 ± 10.39	52.37 ± 6.27	51.02 ± 6.27	64.81 ± 10.48	63.28 ± 10.55
Bioelectrical						
R/h (Ω/m)[a],[b]	373.82 ± 51.83	366.63 ± 56.40	410.23 ± 36.29	405.24 ± 40.77	330.80 ± 28.96	321.00 ± 33.08
Xc/h (Ω/m)[b],[c]	41.82 ± 3.88	42.17 ± 4.68	43.41 ± 3.64	44.35 ± 4.64	39.94 ± 3.39	39.58 ± 3.32
Z/h (Ω/m)[a],[b]	229.15 ± 42.41	224.96 ± 44.92	259.37 ± 30.77	256.36 ± 33.27	193.44 ± 20.26	187.84 ± 22.72
PhA(°)[a],[b]	6.45 ± 0.63	6.63 ± 0.62	6.05 ± 0.40	6.26 ± 0.44	6.91 ± 0.52	7.07 ± 0.51
Fluid distribution						
ECW:TBW[a],[b]	41.54 ± 2.60	41.94 ± 2.87	40.08 ± 2.20	40.29 ± 2.52	43.27 ± 1.92	43.90 ± 1.88

Table 2. Data are expressed as mean ± standard deviation; GPNA: growth peak not-achieved, GPA: growth peak achieved; BM, body mass; R/h, resistance-to-height ratio; Xc/h, reactance-to-height ratio; Z/h, impedance-to-height ratio; PhA, phase angle; ECW:TBW, extra cellular water-to-total body water.

[a] Express a significant effect per time.
[b] Indicates a significant effect per group.
[c] Indicates a significant interaction effect.

reference, comprising individuals aged 14–15 years. This trend was especially pronounced among GPNA players, who exhibited longer vectors compared to both their GPA counterparts and the reference group. Conversely, GPA players clustered in the top-left quadrant, indicative of individuals with an athletic body composition. Therefore, our study indicates that 13-year-old water polo players who have reached biological maturity exhibit bioelectrical characteristics similar to their 14-15-year-old peers. This is an advantage for GPA players that could play a significant role in gameplay performance and the selection of sports talents, which should be taken into account. Currently, BIVA stands as a widely utilized method for evaluating body composition and health status. Since coaches need to consider the maturity level of young athletes when evaluating their performances, using bioelectrical impedance vector analysis alongside maturation assessment can be helpful for understanding their performance in relation to their potential [33,34].

BIA vector migration enables examining body fluids and tissue health changes [14]. While its established role in assessing clinical and various physiological conditions is well-documented [14], the application of BIVA in training and competition is not as widely recognized. Some studies investigated chronic effects of training or changes during a competitive season [35,36] while others examined acute pre-post-changes after training [16,37]. The latter category of studies is more sensitive to factors that mainly generate bioelectrical signal errors. For this reason, it is crucial to control several features such as: previous hydration status and consumption of food and beverages, body position and posture, electrode impedance, position and placement, time dedicated to body fluids stabilization, cutaneous blood flow and temperature, exercise-induced electrolyte accumulation over the skin, biological intra-day and inter-day variation of bioelectrical measurements, environmental conditions, and injuries occurrence [38].

This study adopted an ecological design. Apart from their low cost and simplicity of analysis, ecological designs allow the recognition of environmental (both physical and social) determinants operating at a real-world level. On the other hand, it is not always possible to control all the confounding factors. In the present study, the ingestion of food and beverages could have influenced BIVA measurements. For this reason, breakfast and *ad libitum* water intake were strictly controlled because they may affect Z length (about −3%), over a period of 2- to 4-h after a meal [39]. In the present study, the ingestion of water during training is expected to have affected BIVA measurements (Fig. 1). Indeed, only recent ingestion of meals and beverages (less than 1 h) did not affect the bioelectrical signal [40]. Consequently, Z shortened despite a BM reduction which denotes fluids loss. While training tends to lengthen the vector due to the loss of fluids, the consumption of water shortens it. In the present study, it is possible that the impact of beverage ingestion, given its electrical relevance as it occurred more than 1 h before post-training measurements, outweighed the effect of the training session that was performed. This finding could imply that water consumed during training is biologically available to the body, indicating effective rehydration. Thus, the application of BIVA may serve as a valuable tool in evaluating the efficacy of fluid replacement during training.

In a previous study, Carrasco et al. [16] found that a synchronized swimming training session in comen and junior female athletes determined a lengthening of the BIA vector that was in line with BM changes evoked by training. They concluded that, from a methodological perspective, BIVA seems to be sensitive enough to detect small hydration changes, although they underlined the need for further studies to ensure its validity and reliability. Although our results differ from this conclusion, there are some differences between the present study and that of Carrasco et al. that are worthy of consideration: first, synchronized swimmers were females while water polo players in the present study were males and younger; secondly, their competitive levels were different (elite vs.
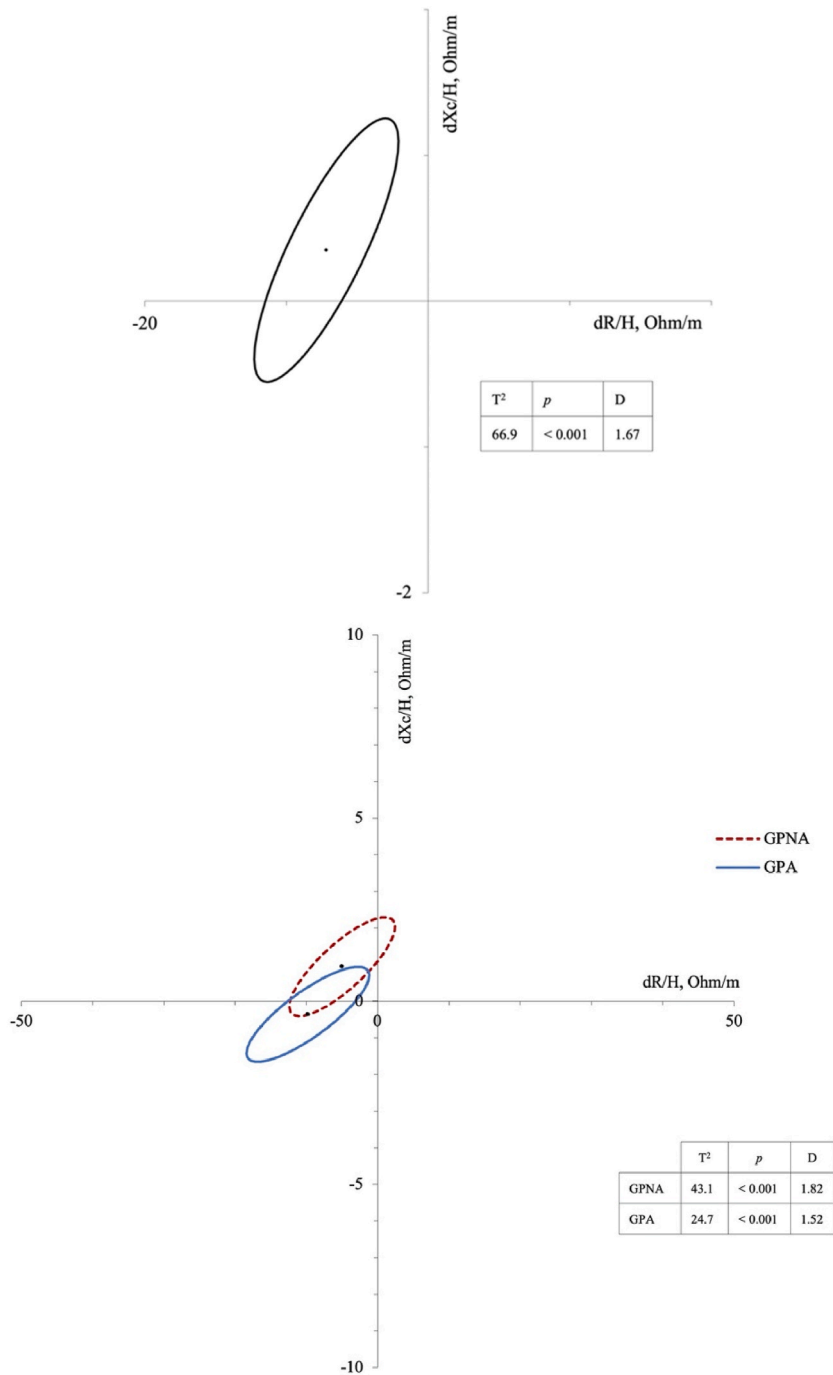
Fig. 2. a. Mean vector displacements of the whole sample of water polo players from pre-to post-training. R/h, height-adjusted resistance; Xc/h, height-adjusted reactance; T^2, Hotelling's T^2 test; p-value (significance at $p < 0.05$); D, Mahalanobis distance.
b. Mean vector displacements of GPNA and GPA from pre-to post-training. GPNA, growth peak not-achieved, GPA, growth peak achieved; R/h, height-adjusted resistance; Xc/h, height-adjusted reactance; T^2, Hotelling's T^2 test; p-value (significance at $p < 0.05$); D, Mahalanobis distance.

regional); thirdly, the exercise duration in the study of Carrasco et al. was about double the duration of the session in the present investigation; Fourthly, synchronized swimmers ingested fluids within the last hour before post-training assessment, whereas in the present study, free water drinking was permitted during training but not within the hour preceding post-training assessment. A longer vector after training was also found in a recent study on rink hockey players performing a high-intensity training session for both whole body and muscle-localized BIVA in the rectus femoris muscle [37]. In both studies, authors failed to find a correlation between BM changes and bioelectrical raw parameters. On the other hand, we found a moderate inverse correlation between ΔBM_{adj} and $\Delta Xc/h$, as

well as a tendency for a weak correlation with ΔR/h, ΔZ/h, and ΔPhA. This result suggests that players who experienced a higher loss of BM after training, net of ingested water, had longer vectors, while the opposite occurred for those players showing smaller BM changes. Therefore, despite a generally shorter vector post-training, our results indicate that the greater the loss of body mass due to fluid loss, the relatively longer the vector post-training.

When we examined the impact of maturation on training-induced changes in BIA vector, we observed a significant difference between the groups, primarily attributable to the contribution of Xc/h (Fig. 2b). Specifically, while both groups decreased R/h, the Xc/h showed a different behavior according to the achievement of peak grow. Although we did not find difference in perceived exertion between groups, one possible explanation could be that GPNA players had a higher relative training session intensity. Indeed, they exhibited a body composition and structure significantly less performing than their more mature counterparts. Furthermore, the time dedicated to training differed between the two groups, with GPNA players having fewer weekly training hours than GPA players (Table 1). Therefore, it is possible that the training workload resulted in a greater water shift from the intracellular to the extracellular compartment in GPNA players than in GPA players. It has been suggested that as cell size decreases, cell membrane shrinkage occurs, modifying dielectric mass and cell capacitance, resulting in higher Xc [41]. Notably, although not statistically significant, GPNA players experienced higher training-induced BM loss after adjusting for water intake. This suggests that they relatively suffered a greater water loss, likely affecting the intracellular compartment, leading to higher Xc/h values. Additionally, the inverse correlation between changes in BM_{adj} and changes in Xc/h supports this hypothesis.

Importantly, previous studies [16] did not consider fluid replacement when assessing BM changes after training. Considering that the ingestion of water and other fluids affects BM, the volume of fluids ingested should be subtracted from the BM after training when evaluating its effect on hydration. In the present study, the evaluation of hydration based on body mass (BM) saw significant changes when considering ingested fluids. Specifically, players transitioned from a water loss initially deemed insignificant (<2 % of BM) to one considered significant in relation to endurance capacity (>2 % of BM) [1]. Thus, our results underline the importance of replacing fluids while training to preserve a good hydration state. Another significant finding of the present study is that, after controlling for water ingested, the RM-ANCOVA did not detect significant changes in bioelectrical parameters. This outcome implies that the observed BIA vector migration (shortening of the vector) may be primarily attributed to fluid ingestion. This evidence could also suggest that BIVA can be adopted to determine if water replacement is enough during training because the shortening of the BIA vector seems indicate that the ingested water is available in the body, despite training resulted in fluid loss.

The findings of the present study provide practical insights for managing rehydration and assessing physical status in young water polo athletes. Specifically, the use of BIVA can be integrated into the regular monitoring of athletes to identify changes in hydration status and body composition. This approach can support coaches in planning personalized rehydration strategies during and after training and competition, ensuring that athletes maintain adequate hydration levels and minimizing health risk and performance declines associated with dehydration. Furthermore, the present study suggests that biological age and maturation level could have a role in dehydration process after training in young water polo players, highlighting the importance of assessing maturation offset. Therefore, the combined monitoring of maturity offset, bioelectrical parameters and training workload, along with careful hydration management, can enhance athletic preparation, optimize recovery, and promote the well-being of young athletes. Finally, this is the first study reporting BIA Vector of youth water polo players and could be used as a reference by practitioners and scholars.

The present study has strengths and limitations. The ecological design is, on one hand, a strength because allows to investigate the effect of water polo training and water replacement on BM and raw bioelectrical parameters changes in field conditions. On the other hand, this type of design makes it difficult to distinguish between confounding factors and training effects. In the conditions of the present study, it seems that fluid ingestion affects BIA vector length more than training. Furthermore, the present sample was younger than the reference population [31], complicating comparisons and played at the regional level making difficult generalization of the results.

5. Conclusion

In conclusion, our study found that young water polo players experienced dehydration exceeding the 2 % threshold, impacting endurance capacity [1]. Partial compensation through *ad libitum* water intake shortened the BIA vector despite training. Significant differences between GPNA and GPA groups, as well as the reference population, indicated that age and maturation influenced BIVA. Integration with pubertal growth spurt data could enhance the understanding of the body composition of young athletes. Despite challenges in controlling factors, our ecological study highlights the importance of fluid replacement in training and suggests BIVA for assessing hydration after sessions. The present study investigated dehydration in young water polo players after training in an ecological setting, providing valuable insights into real-world conditions. Future research should address this process in a more controlled environment to minimize confounding factors. Moreover, the development of new specific ellipses for water polo players stratified by age and level would be necessary for both researchers and practitioners. These ellipses would establish useful and comparable reference values for the field of sport sciences. Longitudinal studies tracking bioelectrical changes across training seasons and maturation stages would also be critical for understanding the interactions between hydration, maturation, and performance over time.

CRediT authorship contribution statement

Sofia Serafini: Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Andrea Di Blasio:** Writing – review & editing, Supervision, Resources, Project administration. **Iris Prestanti:** Writing – review & editing,

Visualization, Investigation, Data curation. **Andrea Di Credico:** Writing – review & editing, Visualization, Investigation, Data curation. **Andrea Fusco:** Writing – review & editing, Methodology, Formal analysis. **Jacopo Cilli:** Writing – review & editing, Visualization, Investigation. **Gabriele Mascherini:** Writing – review & editing, Supervision, Conceptualization. **Ruggero D'Anastasio:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Pascal Izzicupo:** Writing – original draft, Supervision, Resources, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Consent to publish

All participants gave their assent to participate in the study voluntarily and delivered written informed consent to parents for permission to participate and publish.

Data availability statement

All data generated analyzed during the current study are available from Serafini, Sofia; D'Anastasio, Ruggero; Mascherini, Gabriele; Izzicupo, Pascal (2024), "BIVA and anthropometric assessment of youth water polo players ", Mendeley Data, V1, https://doi.org/10.17632/8677by7j68.1.

Ethical approval

This research protocol has been approved by the Institutional Review Board of the Department of Human Sciences, Society and Health of the University of Cassino and Lazio Meridionale (Approval No.: 16259; dated July 15, 2024). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Funding

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

References

[1] S.N. Cheuvront, R.W. Kenefick, Dehydration: physiology, assessment, and performance effects, in: R. Terjung (Ed.), Comprehensive Physiology, first ed., Wiley, 2014, pp. 257–285, https://doi.org/10.1002/cphy.c130017.
[2] B. Murray, Hydration and physical performance, J. Am. Coll. Nutr. 26 (2007) 542S–548S, https://doi.org/10.1080/07315724.2007.10719656.
[3] D. Boening, H.V. Ulmer, U. Meier, W. Skipka, J. Stegemann, Effects of a multi-hour immersion on trained and untrained subjects. I. Renal function and plasma volume, Aero. Med. 43 (1972) 300–305.
[4] E.R. Nadel, I. Holmér, U. Bergh, P.O. Astrand, J.A. Stolwijk, Energy exchanges of swimming man, J. Appl. Physiol. 36 (1974) 465–471, https://doi.org/10.1152/jappl.1974.36.4.465.
[5] I. Holmér, U. Bergh, Metabolic and thermal response to swimming in water at varying temperatures, J. Appl. Physiol. 37 (1974) 702–705, https://doi.org/10.1152/jappl.1974.37.5.702.
[6] R. Soler, M. Echegaray, M.A. Rivera, Thermal responses and body fluid balance of competitive male swimmers during a training session, J. Strength Condit Res. 17 (2003) 362, https://doi.org/10.1519/1533-4287(2003)017<0362:TRABFB>2.0.CO;2.
[7] G. Cox, E. Broad, M. Riley, L. Burke, Body mass changes and voluntary fluid intakes of elite level water polo players and swimmers, J. Sci. Med. Sport 5 (2002) 183–193, https://doi.org/10.1016/S1440-2440(02)80003-2.
[8] F. Meyer, K.A. Volterman, B.W. Timmons, B. Wilk, Fluid balance and dehydration in the young athlete: assessment considerations and effects on health and performance, Am. J. Lifestyle Med. 6 (2012) 489–501, https://doi.org/10.1177/1559827612444525.
[9] W.C. Chumlea, C.M. Schubert, N.V. Reo, S.S. Sun, R.M. Siervogel, Total body water volume for white children and adolescents and anthropometric prediction equations: the Fels Longitudinal Study, Kidney Int. 68 (2005) 2317–2322, https://doi.org/10.1111/j.1523-1755.2005.00692.x.
[10] T. Rowland, Fluid replacement requirements for child athletes, Sports Med. 41 (2011) 279–288, https://doi.org/10.2165/11584320-000000000-00000.
[11] R.L. Mirwald, A.D.G. Baxter-Jones, D.A. Bailey, G.P. Beunen, An assessment of maturity from anthropometric measurements, Med. Sci. Sports Exerc. 34 (2002) 689–694, https://doi.org/10.1097/00005768-200204000-00020.
[12] R.M. Malina, C. Bouchard, O. Bar-Or, Chapter 5: body Composition (Changes in body density and total-body water during growth), in: Growth, Maturation, and Physical Activity, second ed., Human Kinetics, 2004.
[13] F. Campa, G. Coratella, G. Cerullo, S. Stagi, S. Paoli, S. Marini, A. Grigoletto, A. Moroni, C. Petri, A. Andreoli, C. Ceolin, R. Degan, P. Izzicupo, G. Sergi, G. Mascherini, M. Micheletti Cremasco, E. Marini, S. Toselli, T. Moro, A. Paoli, New bioelectrical impedance vector references and phase angle centile curves in 4,367 adults: the need for an urgent update after 30 years, Clin. Nutr. 42 (2023) 1749–1758, https://doi.org/10.1016/j.clnu.2023.07.025.

[14] A. Piccoli, B. Rossi, L. Pillon, G. Bucciante, A new method for monitoring body fluid variation by bioimpedance analysis: the RXc graph, Kidney Int. 46 (1994) 534–539, https://doi.org/10.1038/ki.1994.305.

[15] J.F. Reis, C.N. Matias, F. Campa, J.P. Morgado, P. Franco, P. Quaresma, N. Almeida, D. Curto, S. Toselli, C.P. Monteiro, Bioimpedance vector patterns changes in response to swimming training: an ecological approach, IJERPH 17 (2020) 4851, https://doi.org/10.3390/ijerph17134851.

[16] M. Carrasco-Marginet, J. Castizo-Olier, L. Rodríguez-Zamora, X. Iglesias, F.A. Rodríguez, D. Chaverri, D. Brotons, A. Irurtia, Bioelectrical impedance vector analysis (BIVA) for measuring the hydration status in young elite synchronized swimmers, PLoS One 12 (2017) e0178819, https://doi.org/10.1371/journal.pone.0178819.

[17] G. Melchiorri, E. Padua, F. Sardella, V. Manzi, V. Tancredi, M. Bonifazi, Physiological profile of water polo players in different competitive levels, J. Sports Med. Phys. Fit. 50 (2010) 19–24.

[18] H.K. Smith, Applied physiology of water polo, Sports Med. 26 (1998) 317–334, https://doi.org/10.2165/00007256-199826050-00003.

[19] D.G. Higham, G.A. Naughton, L.A. Burt, X. Shi, Comparison of fluid balance between competitive swimmers and less active adolescents, Int. J. Sport Nutr. Exerc. Metabol. 19 (2009) 259–274, https://doi.org/10.1123/ijsnem.19.3.259.

[20] J.D. Adams, S.A. Kavouras, J.I. Robillard, C.N. Bardis, E.C. Johnson, M.S. Ganio, B.P. McDermott, M.A. White, Fluid balance of adolescent swimmers during training, J. Strength Condit Res. 30 (2016) 621–625, https://doi.org/10.1519/JSC.0000000000001132.

[21] C. Foster, J.A. Florhaug, J. Franklin, L. Gottschall, L.A. Hrovatin, S. Parker, P. Doleshal, C. Dodge, A new approach to monitoring exercise training, J. Strength Condit Res. 15 (2001) 109–115.

[22] F. Esparza Ros, R. Vaquero-Cristóbal, M. Marfell-Jones, International Standars for Anthropometric Assessment, 2019, p. 2019.

[23] A.R. Frisancho, Anthropometric Standards for the Assessment of Growth and Nutritional Status, University of Michigan Press, Ann Arbor, 1990.

[24] M.H. Slaughter, T.G. Lohman, R.A. Boileau, C.A. Horswill, R.J. Stillman, M.D. Van Loan, D.A. Bemben, Skinfold equations for estimation of body fatness in children and youth, Hum. Biol. 60 (1988) 709–723.

[25] L.B. Sherar, R.L. Mirwald, A.D.G. Baxter-Jones, M. Thomis, Prediction of adult height using maturity-based cumulative height velocity curves, J. Pediatr. 147 (2005) 508–514, https://doi.org/10.1016/j.jpeds.2005.04.041.

[26] O. Di Vincenzo, M. Marra, L. Scalfi, Bioelectrical impedance phase angle in sport: a systematic review, Sports Nutr. Rev. J. 16 (2019) 49, https://doi.org/10.1186/s12970-019-0319-2.

[27] S. Mendt, M.A. Maggioni, M. Nordine, M. Steinach, O. Opatz, D. Belavý, D. Felsenberg, J. Koch, P. Shang, H.-C. Gunga, A. Stahn, Circadian rhythms in bed rest: monitoring core body temperature via heat-flux approach is superior to skin surface temperature, Chronobiol. Int. 34 (2017) 666–676, https://doi.org/10.1080/07420528.2016.1224241.

[28] C. O'Brien, A.J. Young, M.N. Sawka, Bioelectrical impedance to estimate changes in hydration status, Int. J. Sports Med. 23 (2002) 361–366, https://doi.org/10.1055/s-2002-33145.

[29] H.H. Carter, A.L. Spence, C.L. Atkinson, C.J.A. Pugh, N.T. Cable, D.H.J. Thijssen, L.H. Naylor, D.J. Green, Distinct effects of blood flow and temperature on cutaneous microvascular adaptation, Med. Sci. Sports Exerc. 46 (2014) 2113–2121, https://doi.org/10.1249/MSS.0000000000000349.

[30] A. Piccoli, G. Pastori, BIVA Software, 2002.

[31] T. De Palo, G. Messina, A. Edefonti, F. Perfumo, L. Pisanello, L. Peruzzi, B. Di Iorio, M. Mignozzi, A. Vienna, G. Conti, R. Penza, A. Piccoli, Normal values of the bioelectrical impedance vector in childhood and puberty, Nutrition 16 (2000) 417–424, https://doi.org/10.1016/s0899-9007(00)00269-0.

[32] P. Schober, C. Boer, L.A. Schwarte, Correlation coefficients: appropriate use and interpretation, Anesth. Analg. 126 (2018) 1763–1768, https://doi.org/10.1213/ANE.0000000000002864.

[33] S. Toselli, E. Marini, P. Maietta Latessa, L. Benedetti, F. Campa, Maturity related differences in body composition assessed by classic and specific bioimpedance vector analysis among male elite youth soccer players, IJERPH 17 (2020) 729, https://doi.org/10.3390/ijerph17030729.

[34] F. Campa, A.M. Silva, V. Iannuzzi, G. Mascherini, L. Benedetti, S. Toselli, The role of somatic maturation on bioimpedance patterns and body composition in male elite youth soccer players, IJERPH 16 (2019) 4711, https://doi.org/10.3390/ijerph16234711.

[35] G. Mascherini, H. Gatterer, H. Lukaski, M. Burtscher, G. Galanti, Changes in hydration, body-cell mass and endurance performance of professional soccer players through a competitive season, J. Sports Med. Phys. Fit. 55 (2015) 749–755.

[36] Á. Cebrián-Ponce, C. Petri, P. Izzicupo, M.L. Micheli, C. Cortis, A. Fusco, M. Carrasco-Marginet, G. Mascherini, In-season longitudinal hydration/body cell mass ratio changes in elite rugby players, Sports 11 (2023), https://doi.org/10.3390/sports11080142.

[37] Á. Cebrián-Ponce, M.V. Garnacho-Castaño, M. Castellano-Fàbrega, J. Castizo-Olier, M. Carrasco-Marginet, N. Serra-Paya, A. Irurtia, Bioelectrical impedance vector and creatine phosphokinase changes induced by a high-intensity training session in rink hockey players, Appl. Sci. 12 (2022) 751, https://doi.org/10.3390/app12020751.

[38] E. Marini, S. Toselli, Bioelectrical impedance analysis of body composition Applications in sports science. https://doi.org/10.13125/UNICAPRESS.978-88-3312-033-1, 2021.

[39] R. Kushner, R. Gudivaka, D. Schoeller, Clinical characteristics influencing bioelectrical impedance analysis measurements, Am. J. Clin. Nutr. 64 (1996) 423S–427S, https://doi.org/10.1093/ajcn/64.3.423S.

[40] W.D. Evans, H. McClagish, C. Trudgett, Factors affecting the in vivo precision of bioelectrical impedance analysis, Appl. Radiat. Isot. 49 (1998) 485–487, https://doi.org/10.1016/S0969-8043(97)00061-4.

[41] J. Castizo-Olier, A. Irurtia, M. Jemni, M. Carrasco-Marginet, R. Fernández-García, F.A. Rodríguez, Bioelectrical impedance vector analysis (BIVA) in sport and exercise: systematic review and future perspectives, PLoS One 13 (2018) e0197957, https://doi.org/10.1371/journal.pone.0197957.