

Rapid Weight Loss and the Body Fluid Balance and Hemoglobin Mass of Elite Amateur Boxers

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Context: Dehydration is assumed to be a major adverse effect associated with rapid loss of body mass for competing in a lower weight class in combat sports. However, the effects of such weight cutting on body fluid balance in a real-life setting are unknown.

Objective: To examine the effects of 5% or greater loss of body mass within a few days before competition on body water, blood volume, and plasma volume in elite amateur boxers.

Design: Case-control study.

Setting: Sports medicine laboratory.

Patients or Other Participants: Seventeen male boxers (age = 19.2 ± 2.9 years, height = 175.1 ± 7.0 cm, mass = 65.6 ± 9.2 kg) were assigned to the weight-loss group (WLG; n = 10) or the control group (CON; n = 7).

Intervention(s): The WLG reduced body mass by restricting fluid and food and inducing excessive sweat loss by adhering to individual methods. The CON participated in their usual precompetition training.

Main Outcome Measure(s): During an ordinary training period (t-1), 2 days before competition (t-2), and 1 week after competition (t-3), we performed bioelectrical impedance mea-

surements; calculated total body water, intracellular water, and extracellular water; and estimated total hemoglobin mass (tHb_{mass}), blood volume, and plasma volume by the CO-rebreathing method.

Results: In the WLG, the loss of body mass (5.6% ± 1.7%) led to decreases in total body water (6.0% ± 0.9%), extracellular water (12.4% ± 7.6%), tHb_{mass} (5.3% ± 3.8%), blood volume (7.6% ± 2.1%; *P* < .001), and plasma volume (8.6% ± 3.9%). The intracellular water did not change (*P* > .05). At t-3, total body water, extracellular water, and plasma volume had returned to near baseline values, but tHb_{mass} and blood volume still were less than baseline values (*P* < .05). In CON, we found no changes (*P* > .05).

Conclusions: In a real-life setting, the loss of approximately 6% body mass within 5 days induced hypohydration, which became evident by the decreases in body water and plasma volume. The reduction in tHb_{mass} was a surprising observation that needs further investigation.

Key Words: weight cutting, combat athletes, boxing, blood volume, dehydration

Key Points

- Rapid loss of body mass within 5 days before competition induced hypohydration, which was evident by the point vector displacement of bioelectrical impedance vector analysis and the decreases in body water, blood volume, and plasma volume.
- Bioelectrical impedance analysis might be used with bioelectrical impedance vector analysis to monitor hydration status during weight cutting.
- The reduction in total hemoglobin mass indicates other potentially important adverse effects of weight cutting.

Many athletes in combat sports (eg, wrestling, boxing, judo, karate) reduce their body mass within a few days (range, 5–7 days) by an extreme restriction of fluid and food intake combined with excessive sweat loss (via sauna or exercising with rubber or plastic suits) to compete in a weight class below their usual weight class in order to gain an advantage over a smaller and weaker opponent.^{1–4} The only restrictions concerning rapid loss of body mass in amateur sports are antidoping regulations banning the use of diuretics and special regulations in some sports, such as the minimum wrestling weight in US high school and collegiate wrestling dictating that body fat should not be less than 5% for collegiate male athletes⁵ and not less than 7% for high school male athletes.⁶ Severe dehydration is assumed to be a major adverse effect associated with such weight cutting.³ To our

knowledge, authors of only 2 studies have calculated the changes in body water⁷ or in plasma volume (PV)⁸ resulting from rapid weight loss in combat athletes. However, reductions in PV and body water have not been investigated in a real-life setting where athletes reduce their body mass within several days before competition, adhering to individual regimens while continuing with their regular training.

Therefore, the purpose of our study was to examine the effects of 5% or greater loss of body mass within a few days before competition on body water, blood volume, and PV in elite amateur boxers. We calculated total body water (TBW), intracellular water (ICW), and extracellular water (ECW) by bioelectrical impedance analysis (BIA) and monitored hydration status by bioelectrical impedance vector analysis (BIVA).⁹ Furthermore, changes in PV

Table 1. Anthropometric Data and Maximal Oxygen Consumption in the Weight-Loss Group and Control Groups (Mean ± SD)

Anthropometric Data	Weight-Loss Group (n = 10)			Control Group (n = 7)		
	t-1 ^a	t-2 ^b	t-3 ^c	t-1	t-2	t-3
Age, y	19.7 ± 3.2			18.4 ± 2.2		
Mass, kg	67.4 ± 9.4	63.7 ± 9.3 ^d	66.9 ± 9.5	64.8 ± 8.9	65.0 ± 9.5	64.9 ± 9.4
Height, cm	175.5 ± 7.0			174.6 ± 7.4		
Fat-free mass, kg	61.4 ± 8.1	58.4 ± 8.1 ^d	61.2 ± 8.1	58.5 ± 7.1	58.7 ± 7.5	58.7 ± 7.5
Body fat, %	8.7 ± 1.7	8.2 ± 1.6	8.5 ± 1.6	9.5 ± 2.1	9.5 ± 2.0	9.5 ± 2.1
Maximal oxygen consumption, mL/min/kg	63.3 ± 3.1	Not measured	Not measured	59.9 ± 4.4	Not measured	Not measured

^a t-1 = Ordinary training period and weight maintenance.

^b t-2 = 2 Days before competition for both groups and after a 5-day rapid weight loss period for the weight-loss group.

^c t-3 = 7 Days after competition.

^d Different from t-1 and t-3 ($P < .001$).

(Δ PV) were calculated from the estimation of total hemoglobin mass (tHb_{mass}) by the CO-rebreathing method.^{10–13} We hypothesized that after 5 days of weight cutting, PV, ECW, and ICW would be decreased considerably and that dehydration also would become evident in a typical point vector displacement in BIVA. Furthermore, we wanted to determine if fluid compartments would be recovered 1 week after the competition, when the boxers usually have resumed their regular training. We decided to study a common, real-life practice that athletic trainers should understand, so we performed all measurements (anthropometric measurements, BIVA, BIA, CO-rebreathing method) in elite amateur boxers during a period of ordinary training and weight maintenance (t-1), 2 days before a boxing competition (national or international tournament) when the boxers had already reached the desired weight (t-2), and 1 week after the competition (t-3).

METHODS

Participants

Seventeen male elite amateur and junior boxers volunteered for this investigation (Table 1). Their mean boxing experience was 7.5 ± 3.5 years and average training time was 14.1 ± 2.7 hours per week. All of them participated regularly in national and international tournaments. Ten participants who regularly had reduced their body mass before competitions during at least the year before the study were assigned to the weight-loss group (WLG). The remaining 7 participants, who had not engaged in any weight-loss procedure for at least the year before the study, were assigned to the control group (CON). Full physical examination by a physician, electrocardiographs at rest and under exertion, and echocardiography were performed before the study. Participants were not allowed to take any medication or dietary supplements during the study. All participants and their parents or legal guardians if athletes were less than 18 years of age provided written informed consent to participate. The study was approved by the Ethics Committee of the Medical Faculty of the University of Heidelberg, Germany.

Procedures

All tests were performed in our laboratory by the same experienced investigator (D.R.) with the assistance of a second investigator (E.H.) the morning after an overnight fast and after at least 12 hours had elapsed since the last

exercise session. For t-1, the investigation occurred during a period of regular training, eating, and drinking and with the body mass that had been observed consistently by the coaches and an athletic trainer during periods of regular training for at least 1 year. For t-2, the investigation occurred approximately 2 weeks after t-1 and 2 days before competition (after 5 days of weight cutting in the WLG). For t-3, the investigation occurred 1 week after competition. Participants in the WLG reduced their body mass by food and fluid restriction and by excessive sweat loss (eg, daily sauna, exercising with warm or rain clothes), adhering to their individual accustomed regimens. Participants in the CON performed their usual precompetition training.

Anthropometric Measurements. Body mass was measured to the nearest 0.1 kg using a calibrated scale (model 709; Seca, Hamburg, Germany) and with participants barefoot and wearing underwear. Height was determined using a standard stadiometer. Given that the regression equations used to calculate body fat from BIA do not seem to be valid in individuals with altered hydration,⁹ we performed skinfold measurements with a caliper (Holtain, Crymych, UK) at 3 sites (triceps, subscapula, abdomen) as described by Wagner¹⁴ and calculated the percentage of body fat (%BF) and fat-free mass from the mean values of the measurements on both sides of the body using the equation of Lohman.¹⁵

Bioelectrical Impedance Analysis. The TBW, ICW, and ECW were estimated using a single-frequency (50 kHz) bioelectrical impedance analyzer (model BIA-101; Akern-RJL Systems, Florence, Italy) according to the standard tetrapolar, whole-body technique. This noninvasive method has been validated against the accepted criterion standard technique (dilution of deuterium-labeled water), is less laborious and costly than the criterion standard, and has been suggested as a reliable measure of hydration status in the normal condition, hyperhydration, and dehydration.^{9,16,17}

After participants lay in the supine position for 10 minutes, we placed 4 surface electrodes on the right hand and foot after the skin was cleansed with an alcohol swab. The first electrode was placed on the dorsum of the right wrist between the distal prominences of the radius and ulna. The second electrode was placed on the dorsum of the right hand over the third metacarpal proximal to the metacarpophalangeal joint. The third electrode was placed on the dorsum of the right foot between the medial and lateral malleoli at the ankle. The fourth electrode was placed on the dorsum of the right foot over the third metatarsal proximal to the metatarsophalangeal joint. We ensured that

the upper and lower extremities were abducted slightly and did not touch other parts of the bodies. Resistance (R) and reactance (Xc) were measured and were used to calculate TBW, ICW, and ECW according to the following evaluated equations¹⁶:

$$TBW = (1.20 + [0.45 \times \text{height}] / (R + [0.18 \times \text{mass}]),$$

$$ECW = (0.123 \times \text{height}) / (R + [0.0119 \times \text{height}] \div (Xc + [0.08 \times \text{mass}]),$$

$$ICW = TBW - ECW,$$

where height is measured in centimeters squared and mass is measured in kilograms. In addition, we performed a BIVA according to Piccoli⁹ for each individual, which is based on a resistance-reactance graph relating body impedance to body hydration without using equations. Thus, the 2 components of the whole-body impedance vector, resistance, and reactance were standardized by the height (H) of the participants, expressed as both R/H and Xc/H in ohms per meter and plotted on the reference, 50%, 75%, and 95% tolerance ellipses for healthy men. Point vector displacements parallel to the major axis of the tolerance ellipses to upper or lower poles indicate changes in hydration, and point vector displacements to the left or right side of the major axis indicate more or less cell mass. Regular testing of R and Xc with a capacitance circuit according to the manufacturer's instructions showed that the R and Xc values were within calibration specifications.

Venous Blood Draw. After participants rested for 15 minutes in the supine position, blood samples were drawn from an antecubital vein via an indwelling cannula (Venflon Pro Safety model 20GA; BD, Franklin Lakes, NJ). Hemoglobin concentrations, hematocrit, erythrocyte count, mean corpuscular volume, mean corpuscular hemoglobin concentration, and mean corpuscular hemoglobin were determined using a hematology analyzer (ADVIA 2120; Siemens Healthcare, Erlangen, Germany). Plasma ferritin concentrations were measured by chemiluminescence immunoassay (ADVIA Centaur; Siemens Healthcare). Plasma concentrations of sodium (Na⁺) and potassium (K⁺) were measured with an ion-selective electrode; plasma concentrations of calcium (Ca⁺⁺) and magnesium (Mg⁺⁺) were determined photometrically (ADVIA 2400; Siemens Healthcare).

Determination of Total Hemoglobin Mass, Blood Volume, and Plasma Volume. The tHb_{mass} was measured according to the CO-rebreathing method as described by Burge and Skinner⁹ and modified by Prommer and Schmidt¹⁰ and Schmidt and Prommer.¹² Briefly, after the athletes had spent 15 minutes in a sitting position, they were connected to a glass spirometer (Blood Tec GbR; Bayreuth, Germany) with a 3-L anesthetic bag filled with oxygen. Subsequently, the participants inhaled an individualized amount of pure CO (1.0 mL/kg), which was administered by a 100-mL plastic syringe (Omnifix; B. Braun, Melsungen, Germany) connected to the spirometer. After the first deep inspiration, the participants held their breath for 10 seconds, after which they continued to respire in the closed system for 1 minute, 50 seconds. During the rebreathing procedure, a portable CO analyzer (Fluke; CO-

220, Everett, WA) was used to check for possible CO leakage at the apparatus, mouthpiece, and nose clip. The same analyzer also was used to measure the remaining CO concentration in the anesthetic bag and the CO concentration exhaled after disconnecting the participant from the spirometer to quantify the amount of CO that had not been absorbed by the body. Venous blood samples were drawn via the indwelling cannula twice before and at 6 and 8 minutes after the start of CO rebreathing. After blood collection, the tubes (PICO50 Arterial Blood Sampler; Radiometer, Copenhagen, Denmark) were vented immediately, closed, and stored in a blood rocker. To measure the percentage of carboxyhemoglobin (%HbCO), an OSM3 hemoximeter (Radiometer) was used. All samples were analyzed in triplicate, and the mean value was recorded for further calculations. As recommended by Hütler et al,¹⁸ %HbCO was adjusted for oxygen saturation effects.

The tHb_{mass} was determined using the software SpiCO (Blood Tec GbR, Bayreuth, Germany) based on the formula:

$$tHb_{\text{mass}} = K_{\text{baro}} \times VCO \times 100 \times 1.39 \text{ mL/g} \times \Delta\%HbCO^{-1},$$

where K_{baro} is the current ambient barometric pressure in millimeters mercury $\times 760^{-1}$ mmHg $\times (1 + [0.003661 \times \text{ambient temperature in degrees kelvin}^{-1}])$, VCO is the volume of CO in milliliters bound to hemoglobin at minute 7, 1.39 mL/g is Hüfners number in milliliters of carbon monoxide per gram of hemoglobin, and $\Delta\%HbCO^{-1}$ is the difference between %HbCO before CO administration (mean %HbCO of the 2 initial blood samples) and maximal %HbCO (average value of minutes 6 and 8) after CO rebreathing. The typical error in our hands is 1.8%, which is comparable with the typical error reported by others.¹³

The BV and PV were calculated as follows¹²:

$$RCV = tHb_{\text{mass}} / (MCHC \times 100),$$

$$BV = RCV \times (100 / [Hct \times F]),$$

$$PV = BV - RCV,$$

where RCV is red cell volume, MCHC is the mean corpuscular hemoglobin concentration, Hct is hematocrit determined with the hematology analyzer, and F is cell factor (correction of hematocrit to whole body Hct by the body/venous hematocrit ratio of 0.91).

Statistical Analysis

Descriptive data are presented as means \pm standard deviations. Unpaired *t* tests were performed to compare values of the WLJ and CON after testing for normal distribution. An analysis of variance (ANOVA) with repeated measures was applied to evaluate the changes of the variables in the WLJ. For non-normally distributed data (tHb_{mass} related to body mass, tHb_{mass} related to fat-free mass, and %BF in WLJ), a repeated-measures ANOVA on ranks was applied. If main effects were found, an all pairwise multiple-comparisons procedure (Holm-Sidak method or Tukey test) was performed. Linear

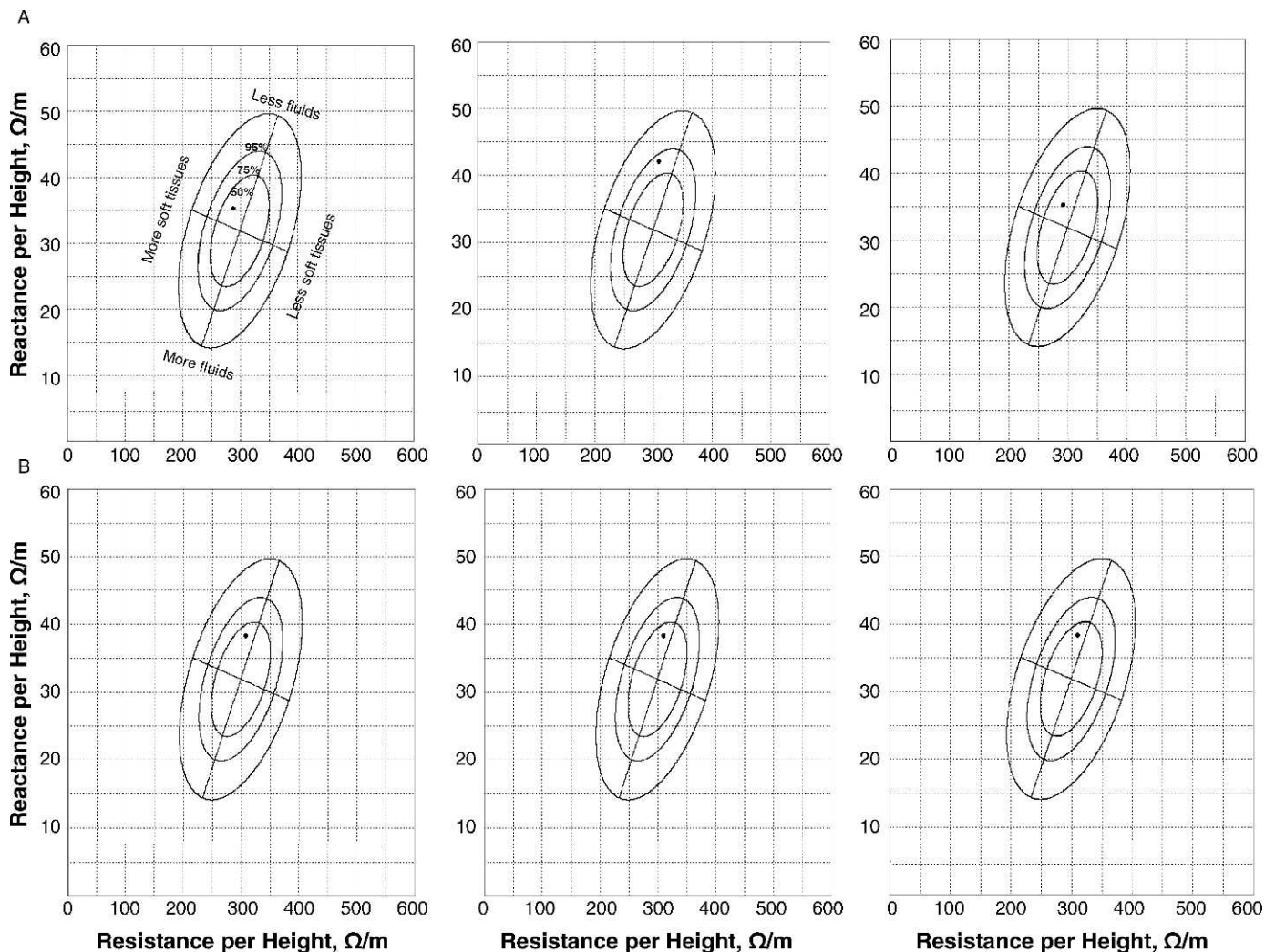


Figure 1. Resistance-reactance graph with the 50%, 75%, and 95% tolerance ellipses indicating reference intervals for healthy men and the mean point vector at 50 kHz in the weight-loss group, A, and in the control group, B, at t-1 (ordinary training period and weight maintenance), t-2 (2 days before competition for both groups and after a 5-day rapid weight-loss period for the weight-loss group), and t-3 (7 days after competition).

regression and subsequent Pearson product moment correlation analysis were used to determine the relationships between selected variables. For all statistical analyses, the α level was set at .05. All analyses were performed using the software programs SigmaStat 3.5 and SigmaPlot 10.0 for Windows (Jandel Scientific, San Rafael, CA).

RESULTS

Body Mass and Fat-Free Mass

We found no group differences in body mass and composition (t_{15} range = 0.15–1.15, $P > .05$). In the WLG, body mass ($F_{2,18} = 60.60$, $P < .001$) and fat-free mass ($F_{2,18} = 69.51$, $P < .001$) were different among time points. We observed reductions in body mass by $5.6\% \pm 1.7\%$ and fat-free mass by $4.9\% \pm 1.3\%$ from t-1 to t-2 ($P < .001$). At t-3, body mass and fat-free mass had increased again by $4.9\% \pm 1.9\%$ and by $4.6\% \pm 1.7\%$, respectively ($P < .001$). We noted only a weak tendency for a precompetition decrease in %BF in the WLG, which

was not statistically significant ($F_{2,18} = 2.45$, $P = .09$; Table 1).

Body Water

We found no differences between the 2 groups in any body water variable (t_{15} range = 0.27–0.94, all P values $> .05$). In the WLG, we saw a vector displacement parallel to the major axis of the tolerance ellipses from the 50% to the 75% tolerance ellipse at t-2 (Figure 1). Concomitantly, pairwise comparisons demonstrated changes in TBW ($F_{2,18} = 79.32$, $P < .001$) and ECW ($F_{2,18} = 32.45$, $P < .001$). At t-2, TBW was decreased ($P < .001$) by $6.0\% \pm 0.9\%$, mainly due to a reduction in ECW ($-12.4\% \pm 7.6\%$; $P < .001$; Figure 2). At t-3, body impedance measurements were similar to the measurements at t-1, and TBW ($P = .09$) and ECW ($P = .10$) were not different from the baseline values after increases of $4.9\% \pm 1.6\%$ and $11.9\% \pm 5.6\%$, respectively. The ICW did not change throughout the observation period ($F_{2,18} = 2.56$, $P = .11$). In the CON, no changes in the point vector, TBW, ICW, or ECW occurred

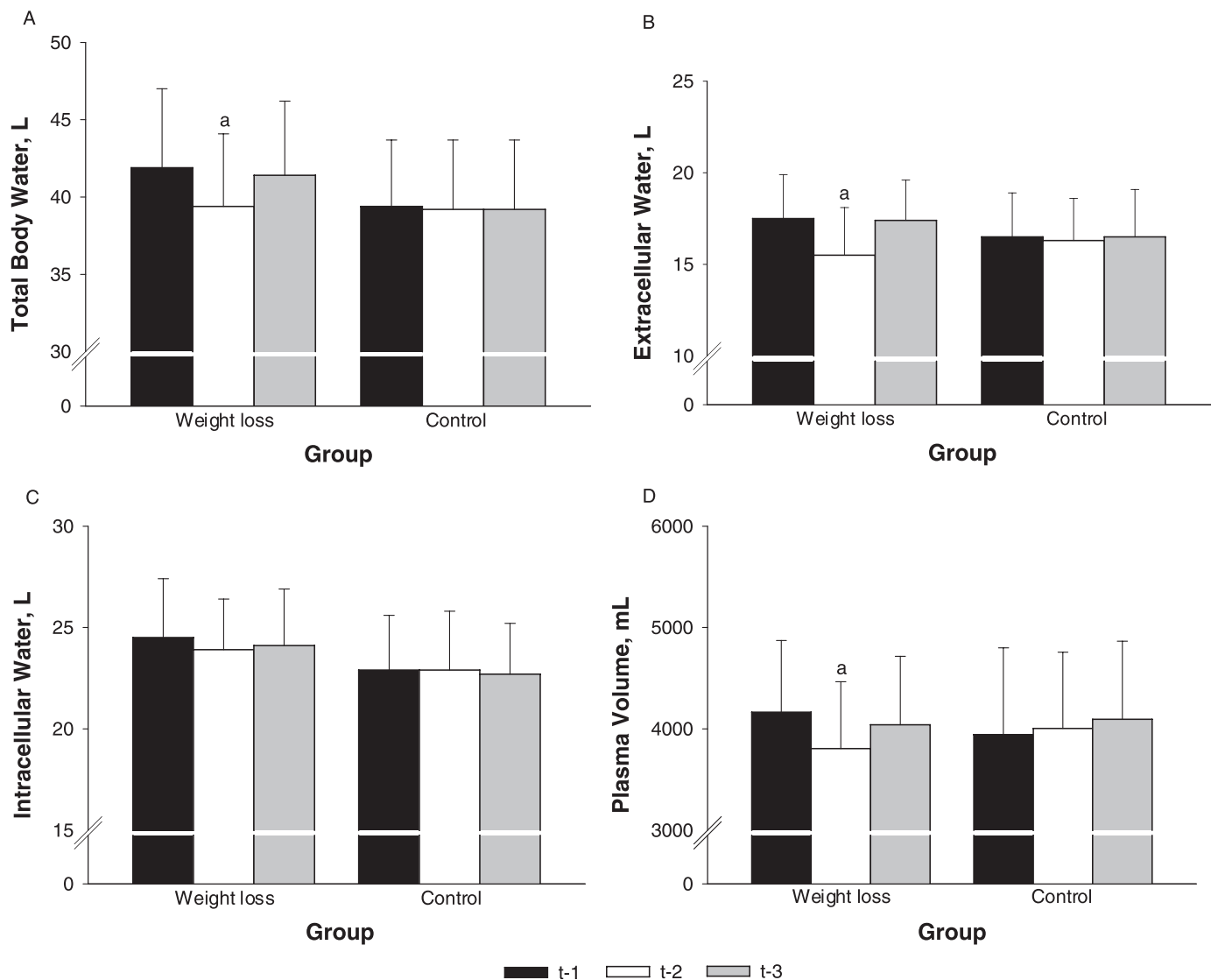


Figure 2. Total body water, A, extracellular water, B, and intracellular water, C, measured by bioelectrical impedance analysis and plasma volume determined by the CO-rebreathing method, D, in the weight-loss group and in the control group at t-1 (ordinary training period and weight maintenance), t-2 (2 days before competition for both groups and after a 5-day rapid weight-loss period for the weight-loss group), and t-3 (7 days after competition) (mean \pm SD). ^aIndicates different from t-1 and t-3 ($P < .001$).

($F_{2,12}$ range = 0.25–0.79, all P values $> .05$; Figures 1 and 2).

Red Blood Cell Count and Plasma Electrolytes

The Hb did not change during the observation period in the WLJ ($F_{2,18} = 2.14$, $P = .15$) or CON ($F_{2,12} = 1.19$, $P = .85$). In the WLJ, hematocrit values were different among the 3 time points ($F_{2,18} = 12.20$, $P < .001$). The hematocrit value was greater at t-2 than at baseline ($P < .001$) and at t-3 ($P = .003$). The Hct value was still higher at t-3 than at baseline ($P = .049$). The erythrocyte count, mean corpuscular volume, mean corpuscular hemoglobin concentration, and mean corpuscular hemoglobin did not change in the WLJ ($F_{2,18}$ range = 0.24–1.92, $P > .05$) and CON ($F_{2,12}$ range = 0.84–2.13, all P values $> .05$). Only in the WLJ did we find a time effect for plasma ferritin ($F_{2,18} = 7.14$, $P = .005$), which was greater at t-2 than at t-1 ($P = .009$) or t-3 ($P = .005$; Table 2). No changes

in the plasma concentrations of Na^+ , K^+ , Ca^{++} , and Mg^{++} were observed in either group.

Total Hemoglobin Mass, Blood Volume, and Plasma Volume

We did not observe differences between the WLJ and CON for tHb_{mass}, blood volume, or PV (t_{15} range = 0.04–0.93, all P values $> .05$). In the WLJ, we observed changes in PV ($F_{2,18} = 23.12$, $P < .001$). At t-2, PV had decreased by $8.6\% \pm 3.9\%$ ($P < .001$). At t-3, PV had increased again by $5.6\% \pm 3.2\%$ ($P < .001$) and was not different from the baseline value ($P = .08$; Figure 2D). We noted strong correlations between Δ PV (t-1 – t-2) derived from the CO-rebreathing method and Δ TBW (t-1 – t-2) measured by BIA ($r = 0.69$, $P < .001$) and between Δ PV (t-1 – t-2) and Δ ECW (t-1 – t-2; $r = 0.64$, $P < .001$) in the WLJ.

Comparisons of the 3 time points demonstrated changes in tHb_{mass} ($F_{2,18} = 11.87$, $P < .001$) and BV ($F_{2,18} = 56.13$, $P < .001$), respectively, in the WLJ. At t-2, we observed

Table 2. Red Blood Cell Count and Plasma Electrolyte Concentrations in the Weight-Loss Group and Control Group (Mean ± SD)

Variable	Weight-Loss Group (n = 10)			Control Group (n = 7)		
	t-1 ^a	t-2 ^b	t-3 ^c	t-1	t-2	t-3
Hemoglobin concentration, g/dL	14.1 ± 1.0	14.4 ± 1.0	14.1 ± 1.0	13.5 ± 0.9	13.7 ± 0.7	13.6 ± 0.8
Hematocrit, %	40.1 ± 2.7	42.4 ± 2.5 ^{d,e}	41.2 ± 3.1 ^f	40.7 ± 2.9	39.6 ± 2.0	39.7 ± 2.0
Erythrocyte count, ×10 ⁶ /μL	4.8 ± 0.5	4.9 ± 0.4	4.8 ± 0.5	4.9 ± 0.4	4.7 ± 0.3	4.7 ± 0.4
Mean corpuscular volume, fL (μm ³)	86.2 ± 5.1	85.2 ± 4.0	85.5 ± 4.6	84.9 ± 5.5	82.4 ± 2.4	82.7 ± 2.6
Mean corpuscular hemoglobin concentration, pg/cell	30.0 ± 1.8	(85.2 ± 4.0)	(85.5 ± 4.6)	(84.9 ± 5.5)	(82.4 ± 2.4)	(82.7 ± 2.6)
Mean corpuscular hemoglobin concentration, g/dL	34.9 ± 1.1	29.4 ± 1.7	29.6 ± 1.7	29.1 ± 1.1	29.4 ± 1.0	29.7 ± 1.0
Plasma ferritin, μg/L (ng/mL)	47 ± 22	34.6 ± 1.1	34.7 ± 0.8	35.0 ± 0.6	35.6 ± 0.5	35.9 ± 0.7
	(47 000 ± 22 000)	54 ± 27 ^g	42 ± 21	45 ± 17	41 ± 12	43 ± 22
Sodium, mmol/L (mEq/L)	140 ± 1	(54 000 ± 27 000)	(42 000 ± 21 000)	(45 000 ± 17 000)	(41 000 ± 12 000)	(43 000 ± 22 000)
	(140 ± 1)	141 ± 1	141 ± 1	140 ± 1	140 ± 1	141 ± 1
Potassium, mmol/L (mEq/L)	3.9 ± 0.2	4.0 ± 0.3	3.9 ± 0.3	3.8 ± 0.3	3.8 ± 0.3	3.8 ± 0.2
	(3.9 ± 0.2)	(4.0 ± 0.3)	(3.9 ± 0.3)	(3.8 ± 0.3)	(3.8 ± 0.3)	(3.8 ± 0.2)
Calcium, mmol/L (mg/dL)	2.4 ± 0.1	2.4 ± 0.1	2.3 ± 0.1	2.5 ± 0.4	2.4 ± 0.1	2.3 ± 0.1
	(9.6 ± 0.4)	(9.6 ± 0.4)	(9.2 ± 0.4)	(10.0 ± 1.6)	(9.6 ± 0.4)	(9.2 ± 0.4)
Magnesium, mmol/L (mEq/L)	0.8 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.1
	(1.6 ± 0.2)	(1.8 ± 0.2)	(1.8 ± 0.2)	(1.8 ± 0.2)	(1.8 ± 0.2)	(1.8 ± 0.2)

^a t-1 = Ordinary training period and weight maintenance.

^b t-2 = 2 Days before competition for both groups and after a 5-day rapid weight-loss period for the weight-loss group.

^c t-3 = 7 Days after competition.

^d Different from t-3 ($P < .01$).

^e Different from t-1 ($P < .001$).

^f Different from t-1 ($P < .05$).

^g Different from t-1 and t-3 ($P < .01$).

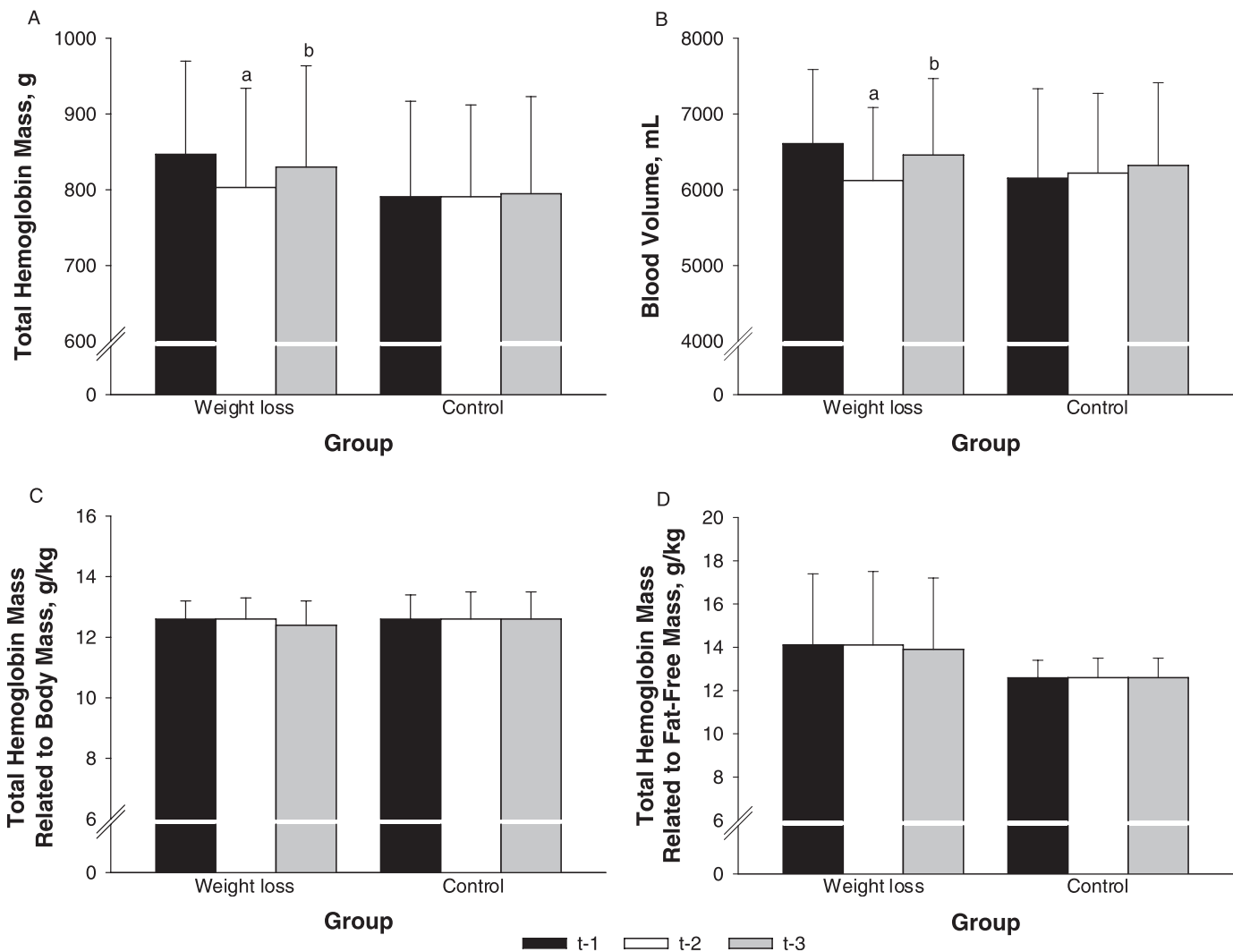


Figure 3. Total hemoglobin mass, A, blood volume, B, tHb_{mass} related to body mass, C, and tHb_{mass} related to fat-free mass, D, in the weight-loss group and in the control group at t-1 (ordinary training period and weight maintenance), t-2 (2 days before competition for both groups and after a 5-day rapid weight-loss period for the weight-loss group), and t-3 (7 days after competition) (mean \pm SD). ^aIndicates different from t-1 and t-3 ($P < .001$). ^bIndicates different from t-1 ($P < .05$).

decreases in tHb_{mass} and BV by $5.3\% \pm 3.8\%$ and $7.6\% \pm 2.1\%$, respectively, in the WLG ($P < .001$). At t-3, tHb_{mass} and BV had increased again by $3.2\% \pm 1.7\%$ ($P = .009$) and $5.3\% \pm 1.5\%$ ($P < .001$), respectively, but remained at a lower level ($P < .05$) than the baseline value (Figure 3). We found strong relationships between changes in tHb_{mass} and changes in body mass ($r = 0.82$, $P < .001$) and fat-free mass ($r = 0.79$, $P < .001$), respectively. For tHb_{mass} as related to body mass ($F_{2,18} = 1.48$, $P = .26$) and fat-free mass ($F_{2,18} = 1.26$, $P = .31$), no changes occurred. In the CON, no changes in PV, BV, or absolute or relative tHb_{mass} were found ($F_{2,12}$ range = 0.80–2.26, all P values $> .05$; Figure 2).

DISCUSSION

In a real-life setting, we examined the hypohydration that results from the rapid loss of approximately 6% body mass achieved during a few days before competition in elite amateur and junior boxers. After 5 days of weight reduction (t-2), when the athletes had already reached the desired mass, they experienced an average 6% (approximately 2.5

L) decrease in TBW mainly due to an average 12% (approximately 2 L) loss of ECW. At the same time point, BIVA revealed a vector displacement, indicating hypohydration without substantial loss of soft tissue mass. The reductions in TBW and ECW were correlated strongly with the decrease in PV by approximately 9% as estimated by the CO-rebreathing method. Surprisingly, we also found a decrease of approximately 5% in tHb_{mass} after the mass reduction; and at t-3, when baseline body mass, TBW, ECW, and PV were reached again, tHb_{mass} was still decreased by approximately 3%.

The loss of 5% to 7% of body mass within 1 week before competition is a common practice in combat sports.^{1–4,19} Some athletes even report a rapid weight loss of up to 10% of their usual body mass.¹ The decrease of approximately 6% in the initial body mass in our study was due to a reduction of fat-free mass by approximately 5%. The displacement of the point vector (BIVA) indicates that this reduction in fat-free mass was achieved nearly exclusively by a loss in body water without substantial change in soft tissue mass.⁹ The decrease in %BF by 0.5% (approximately

0.7 kg) that was not statistically significant contributed only marginally to the weight loss and was similar to the loss of body fat reported in a study¹⁹ of judo athletes who also reduced body mass in a real-life setting within 7 days. In contrast to the studies of Bartok et al⁷ and Smith et al,⁸ who found a decrease of approximately 3% to 4% in body mass, which was achieved within a few hours by excessive sweat loss due to exercise in a hot environment, the boxers in the real-life setting of our study presumably reduced their body mass within 5 days by fluid and food restriction and excessive sweat loss (daily sauna, exercising with warm clothes or rain clothes). The slower but greater weight reduction had different effects on body water and fluid compartments; compared with the approximately 3% loss of mass within a few hours, a similar decrease in TBW (approximately 6%) was observed when nearly double the weight loss (5.4%) was achieved during a much longer period (within 5 days). Similar to Kozlowski and Saltin,²⁰ Bartok et al⁷ observed a decrease in ECW (approximately 6%) that was about 2 times the decrease in ICW (approximately 3%) after dehydration, developing within a few hours; however, we noted a 6-fold greater decrease in ECW than in ICW. After 5 days of weight reduction mainly due to dehydration, the boxers might have reached a new steady state of decreased body water content (ie, hypohydration as indicated by unchanged plasma electrolytes compared with the baseline measurements). In agreement with this observation, Caldwell et al²¹ suggested that the effects of body fluid loss on performance might be less detrimental if the deficit in body fluid develops slowly. Furthermore, because they found no relationship between Δ PV (−8% on average) and boxing-related tasks in collegiate boxers who had reduced their body mass by 3% to 4% within a few hours by excessive sweat loss, Smith et al⁸ assumed that some athletes might be predisposed to cope effectively with the effects of dehydration, and sporting performance might remain unaffected. A limitation of our study is that, in the real-life setting, we could not subject the boxers to performance measurements immediately before competition because the athletes feared that such testing would impair their competitive performance.

The decrease in tHb_{mass} with a concomitant increase in plasma ferritin after rapid weight reduction is a surprising finding. Even at t-3, when body mass and PV had increased again toward the baseline values, tHb_{mass} still was lower than at baseline. Given that boxing performance depends on aerobic fitness (maximal oxygen consumption),²² an approximately 5% decrease in the tHb_{mass} with a concomitant decrease in maximal oxygen consumption²³ is important. We can only speculate on the reasons for this finding. We showed that tHb_{mass} estimation with the CO-rebreathing method is not influenced by recent or dramatic shifts in fluid compartments.^{24,25} Therefore, the tHb_{mass} decrement could be the result of impaired erythropoiesis or hemolysis. Reduced erythropoiesis resulting from drastic food and fluid deprivation has been observed in animal studies.^{26–28} In addition, Gunga et al²⁹ reported a decrease in erythropoietin in humans after 5 days of survival training (ie, food and fluid restriction combined with heavy physical exercise), causing an approximately 9% reduction in body mass. The mechanism responsible for the decrease in red cell production due to food and fluid restriction is not

completely understood. A direct relationship with increased hematocrit or blood viscosity as a consequence of dehydration might exist.^{27,28} Furthermore, the assumption was that the negative energy balance might be mainly responsible for erythropoietic changes during food restriction.^{26,29} The strong correlations of decreased body mass and fat-free mass with the reduced tHb_{mass} in our investigation point in this direction. However, considering a mean erythrocyte survival time of approximately 120 days after release from the bone marrow and an approximately 1% loss of erythrocytes per day to senescence,³⁰ the rapid decrease in tHb_{mass} cannot be explained entirely by decreased erythropoiesis. Therefore, neocytolysis should be considered as a cause for the observed decrease in tHb_{mass} . Alfrey et al³¹ described neocytolysis as a physiologic mechanism to down-regulate red cell mass by selective destruction of young circulating red blood cells (neocytes) when erythropoietin production is suppressed. In our study, the rapid weight reduction mainly achieved by dehydration might have caused a decrease in erythropoietin with consequent reduction in erythropoiesis and neocytolysis, resulting in decreased tHb_{mass} and increased plasma ferritin. However, because we had not expected these changes, we did not measure markers for erythropoiesis or hemolysis. In the future, researchers should investigate this phenomenon by thoroughly monitoring food and fluid uptake, the loss of body water, and changes in aerobic performance capacity.

CONCLUSIONS

Rapid loss of body mass within a few days before competition was achieved nearly exclusively by dehydration as evident from the point vector displacement in BIVA and the decreases in plasma volume, blood volume, and body water (in particular, extracellular water), probably resulting in a new steady state of decreased body water content (hypohydration). Although BIA is not a suitable method for determining body fat, it might be used with BIVA to monitor hydration status during the weight cutting that is not limited in amateur sports, except high school and collegiate wrestling. The reduction in tHb_{mass} after rapid weight loss was surprising and indicates further important adverse effects of weight cutting. More research is needed to explore the responsible mechanisms.

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