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Body mass change and ultraendurance performance: a decrease in body mass is associated with an increased running speed in male 100-km ultramarathoners

Rüst, Christoph A ; Knechtle, Beat ; Knechtle, Patrizia ; Wirth, Andrea ; Rosemann, Thomas

Abstract: We investigated, in 50 recreational male ultrarunners, the changes in body mass, selected hematological and urine parameters, and fluid intake during a 100-km ultramarathon. The athletes lost (mean and SD) 2.6 (1.8) % in body mass ($p < 0.0001$). Running speed was significantly and negatively related to the change in body mass ($p < 0.05$). Serum sodium concentration ($[Na^+]$) and the concentration of aldosterone increased with increasing loss in body mass ($p < 0.05$). Urine-specific gravity increased ($p < 0.0001$). The change in body mass was significantly and negatively related to postrace serum $[Na^+]$ ($p < 0.05$). Fluid intake was significantly and positively related to both running speed ($r = 0.33$, $p = 0.0182$) and the change in body mass ($r = 0.44$, $p = 0.0014$) and significantly and negatively to both postrace serum $[Na^+]$ ($r = -0.42$, $p = 0.0022$) and the change in serum $[Na^+]$ ($r = -0.38$, $p = 0.0072$). This field study showed that recreational, male, 100-km ultramarathoners dehydrated as evidenced by the decrease in >2 % body mass and the increase in urine-specific gravity. Race performance, however, was not impaired because of the loss in body mass. In contrast, faster athletes lost more body mass compared with slower athletes while also drinking more. The concept that a loss of >2% in body mass leads to dehydration and consequently impairs endurance performance must be questioned for ultraendurance athletes competing in the field. For practical applications, a loss in body mass during a 100-km ultramarathon was associated with a faster running speed.

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Body mass change and ultra-endurance performance

A decrease in body mass is associated with an increased running speed in male 100-km ultra-marathoners

ABSTRACT

We investigated in 50 recreational male ultra-runners the changes in body mass, selected haematological and urine parameters as well as fluid intake during a 100-km ultra-marathon. The athletes lost (mean and SD) 2.6 (1.8) % in body mass ($p < 0.0001$). Running speed was significantly and negatively related to the change in body mass ($p < 0.05$). Serum sodium concentration ($[Na^+]$) and the concentration of aldosterone increased with increasing loss in body mass ($p < 0.05$). Urine specific gravity increased ($p < 0.0001$). The change in body mass was significantly and negatively related to post-race serum $[Na^+]$ ($p < 0.05$). Fluid intake was significantly and positively related to both running speed ($r = 0.33$, $p = 0.0182$) and the change in body mass ($r = 0.44$, $p = 0.0014$) as well as significantly and negatively to both post-race serum $[Na^+]$ ($r = -0.42$, $p = 0.0022$) and the change in serum $[Na^+]$ ($r = -0.38$, $p = 0.0072$). This field study showed that recreational male 100-km ultra-marathoners dehydrated as evidenced by the decrease in > 2 % body mass and the increase in urine specific gravity. Race performance, however, was not impaired due to the loss in body mass. In contrast, faster athletes lost more body mass compared to slower athletes while also drinking more. The concept, that a loss of > 2 % in body mass leads to dehydration and consequently impairs endurance performance must be questioned for ultra-endurance athletes competing in the field. For practical applications, a loss in body mass during a 100-km ultra-marathon was associated with a faster running speed.

Key words: fluid metabolism – electrolyte – urine specific gravity – hydration status

INTRODUCTION

Dehydration is reported as a common finding in endurance athletes. Generally, dehydration is defined as a loss of more than 2 % in body mass during endurance performance (10,45,52-54). It is supposed that dehydration leads to a rise in body core temperature and when fluid losses are fully replaced, athletes can lower their core temperature (14) and thus reduce considerably their risk of dehydration (2,18,19).

Several studies showed that dehydration impaired endurance performance (11,45,49,53,61,65). Most of these studies were preferably performed as laboratory experiments under controlled laboratory conditions. Athletes were investigated while cycling on a stationary ergometer (4,6,13,42,48,68), rowing on a stationary ergometer (8,59), or running on a treadmill (20). The temperatures were kept constant during the laboratory trials and varied between 21 °C and 32 °C (4,42,59,68). Generally, the number of investigated subjects in these laboratory settings was rather low between six and eight participants (4,6,13,20,42,48,68). The intensities were rather high between 70 % VO_2max (42) and 80 % VO_2max (6) or even at maximal intensity to exhaustion (48,68). In some instances, the subjects completed a time trial on a cycling (13,42) or on a rowing ergometer (59). Other subjects were running at 70 % VO_2max on a treadmill (20) or rowing on an ergometer at maximum intensity (8).

The performance duration of these laboratory settings was generally no longer than 6 hours, therefore only little is known about the association between dehydration and ultra-endurance performance, defined as an endurance performance lasting for 6 hours or longer (72). The change in body mass has been investigated in ultra-endurance athletes; however, the effect of dehydration on ultra-endurance performance has almost not been explored yet. Sharwood *et* *al.* (55) described no evidence that a loss in body mass was related to an impaired performance in 297 Ironman triathletes. Laursen *et al.* (39) concluded that a body mass loss of up to 3 % was tolerated by 10 male Ironman triathletes and the changes in body mass were not related to Ironman finishing times. Recent studies investigating ultra-marathoners reported that body mass losses were significantly and positively associated with race times in 23 ultra-marathoners in a 24-h run (24). In the 'Marathon des Sables' over 230 km within 7 days in the desert, the athlete with the greatest body mass loss was the fastest one (73).

During the last years, studies were performed to investigate changes in body mass and hydration status in ultra-endurance athletes (24,27,29,30,32-38,73). In some instances, no dehydration was found in ultra-endurance athletes such as in mountain bike ultra-marathoners (33) and Triple Iron ultra-triathletes (32). In a recent study on ultra-runners in a 24-hour ultra-run, it was even questioned whether ultra-runners really dehydrate (38). In general, body mass decreased during an ultra-endurance performance as has been demonstrated for ultra-runners (24,35,36,38,73), ultra-cyclists (33,37) and long-distance triathletes (27,32, 39,55). For male ultra-swimmers, however, no change in body mass was described (30). It must be assumed that the decrease in body mass was not only due to dehydration (33,38) but also due to a decrease in solid masses such as skeletal muscle mass (27,32-36) and fat mass (32,33,36-38,73).

These results on ultra-endurance athletes showed that (*i*) a decrease in body mass such as skeletal muscle mass and fat mass is a common finding in ultra-endurance athletes and (*ii*) a loss in body mass seems not to be associated with a decrease in ultra-endurance performance. For ultra-marathoners, there are few data about the relationship between body mass decreases and ultra-endurance performances (24,73). Although Sharwood *et al.* (55) presented a rather large sample of 297 Ironman triathletes, only small series of ultra-runners have been investigated. Regarding the data of Kao *et al.* (24) and Zouhal *et al.* (73) with rather small samples of 23 and 16 ultra-runners, respectively, we intended to investigate the association between body mass changes and ultra-endurance performance in a larger sample of ultra-marathoners. Apart from body mass changes, we included also parameters of hydration status to better investigate fluid metabolism and dehydration.

The aims of this observational field study on a sample of 50 recreational male 100-km ultra-marathoners were therefore to investigate (*i*) whether ultra-marathoners in a 100-km ultra-marathon undergo a decrease in body mass, (*ii*) whether an eventual decrease in body mass was due to dehydration and (*iii*) whether performance was impaired in case of a decrease in body mass. Based upon present literature, we hypothesized that (*i*) body mass would decrease and (*ii*) a decrease in body mass would be related to a decreased running speed.

METHODS

Experimental Approach to the Problem

The organiser of the ‘100 km Lauf Biel’ in Switzerland, contacted all the participants of the 2010 race before the start via a separate newsletter and informed them about the planned investigation. The race took place on June 11 2010. The ultra-marathoners started the 100-km run at 10:00 p.m. They had to climb a total altitude of 645 metres. During these 100 km, the organiser provided a total of 17 aid stations offering an abundant variety of food and beverages. The athletes were allowed to be supported by a cyclist in order to have additional food and clothing, if necessary. The temperature at the start was at 21.7 °C, dropped to 15.6 °C during the night and rose to 18.1 °C the next day. Humidity was at 52 % at the start, rose to 62 % during the night and to 69 % the following day. Barometric pressure was at 1007.8 hPa at the start, rose to 1011 hPa in the night and was constant at 1011.9 hPa the next day. During the night, the sky was covered but no rain was falling. Body mass, body composition and parameters of hydration status were determined pre- and post-race in order to investigate potential associations between changes in both body mass and body composition with either running speed or parameters of hydration status.

Subjects

Fifty-six male ultra-runners volunteered to participate in the study, 50 athletes finished the ultra-marathon successfully within the time limit of 19 hours. The characteristics of anthropometry and training are represented in **Table 1**. The study was approved by the Institutional Review Board for the use of Human subjects of the Canton of Zurich, Switzerland, and appropriate informed consent has been gained.

Procedures

Upon inscription to the investigation, the participants were instructed to keep a training diary until the start of the race. The investigator provided an EXCEL-file where athletes could record their training. All training units in running until the start of the race were recorded, showing distance in kilometres and duration in minutes.

Before the start of the race between 05:00 p.m. and 10:00 p.m. body mass, body height, the circumferences of the limbs and the thicknesses of four skin-folds (mid-upper arm, abdominal, mid-thigh, and mid-calf) were measured on the right side of the body. With this data, fat mass and skeletal muscle mass, using an anthropometric method, were estimated. Body mass was measured using a commercial scale (Beurer BF 15, Beurer GmbH, Ulm, Germany) to the nearest 0.1 kg after voiding of the urine bladder. Body height was determined using a stadiometer to the nearest 1.0 cm. The circumferences and the lengths of the limbs were measured using a non-elastic tape measure (cm) (KaWe CE, Kirchner und Welhelm, Germany) to the nearest 0.1 cm. The circumference of the upper arm was measured at mid-upper arm; the circumference of the thigh was taken at mid-thigh and the circumference of the calf was measured at mid-calf. The skin-fold data were obtained using a skin-fold calliper (GPM-Hautfaltenmessgerät, Siber & Hegner, Zurich, Switzerland) and recorded to the nearest 0.2 mm. The skin-fold measurements were taken following ISAK standard once for all four skin-folds and then the procedure was repeated twice more by the same investigator; the mean of the three times was then used for the analyses. The timing of the taking of the skin-fold measurements was standardised to ensure reliability. According to Becque *et al.* (5), readings were performed 4 s after applying the calliper. One trained investigator took all the skin-fold measurements as inter-tester variability is a major source of error in skin-fold measurements. An intra-tester reliability check was conducted on 27 male athletes prior to testing. The intra-class correlation (ICC) within the two measurers was excellent for all anatomical measurement sites, and various summary measurements of skin-fold thicknesses (ICC > 0.9). Agreement tended to be higher within measurers than between measurers but still reached excellent reliability (ICC > 0.9) for the summary measurements of skin-fold thicknesses (28). For the sum of eight skin-folds for measurer 1, bias (average difference between measure 1 and 2) was -0.515, standard deviation of the average difference was 1.492; and 95% limits of agreement were between -3.439 and 2.409. Fat mass was estimated using the equation following Stewart and Hannan (63) for male athletes: Fat mass (g) = 331.5 * abdominal skin-fold thickness + 356.2 * thigh skin-fold thickness + 111.9 * body mass – 9,108. The coefficient of determination was 0.82 and the standard error of the estimate was 1843 g, equivalent to 2.4% for a typical athlete in the sample. Skeletal muscle mass (kg) was estimated using the anthropometric equation of Lee *et al.* (40) with skeletal muscle mass = Ht * (0.00744 * CAG^2 + 0.00088 * CTG^2 + 0.00441 * CCG^2) + 2.4 * sex – 0.048 * age + race + 7.8 where Ht = height, CAG = skin-fold-corrected upper arm girth, CTG = skin-fold-corrected thigh girth, CCG = skin-fold-corrected calf girth, sex = 1 for male; age is in years; race = 0 for white men and 1 for black men. This equation was validated using magnetic resonance imagining (MRI) to determine skeletal muscle mass. There was a high correlation between the predicted skeletal muscle mass and the MRI-measured skeletal muscle mass ($r^2 = 0.83$, $p < 0.0001$, SEE = 2.9 kg). The correlation between the measured and the predicted skeletal muscle mass difference and the measured skeletal muscle mass was significant ($r^2 = 0.90$, $p = 0.009$).

After the anthropometric measurements, venous blood samples were drawn and urine samples were collected. Two Sarstedt S-Monovettes (plasma gel, 7.5 ml) for chemical and one Sarstedt S-Monovette (EDTA, 2.7 ml) (Sarstedt, Nümbrecht) for hematological analysis were drawn. Monovettes for plasma were centrifuged at 3,000 g for 10 min at 4 °Celsius. Plasma was collected and stored on ice. Urine was collected in Sarstedt monovettes for urine (10 ml).

Blood and urine samples were transported immediately after collection to the laboratory and were analysed within six hours. Immediately after arrival at the finish line, identical measurements were applied.

In the venous blood samples, hemoglobin, hematocrit, [Na^+], [K^+], creatinine, urea, glucose, aldosterone and osmolality were measured. Hematologic parameters were determined using ADVIA® 120 (Siemens Healthcare Diagnostics, Deerfield, IL, USA). Plasma parameters were measured using COBAS INTEGRA® 800 (Roche, Mannheim, Germany). The concentration of aldosterone was measured using RIA (Radio Immuno Assay) with Gamma-Counter 1277 (DRG Instruments GmbH, Germany). In the urine samples, creatinine, urea, [Na^+], [K^+], urine specific gravity and osmolality were determined. Urine specific gravity was analysed using Clinitek Atlas® Automated Urine Chemistry Analyzer (Siemens Healthcare Diagnostics, Deerfield, IL, USA). Creatinine and urea in urine were measured using COBAS INTEGRA® 800. Electrolytes in urine were determined using ISE IL 943 Flame Photometer (GMI, Inc., Ramsey, MN, USA). The osmolality of in plasma and urine was determined using Fiske® Modell 210 Mikro-Osmometer (IG Instrumenten-Gesellschaft AG, Zurich, Switzerland). Fractional sodium excretion was calculated using the equation fractional excretion of sodium $= ((\text{sodium}_{\text{urine}} * \text{creatinine}_{\text{plasma}})/(\text{sodium}_{\text{plasma}} * \text{creatinine}_{\text{urine}})) * 100$ according to Steiner (62). Fractional urea excretion was calculated using the equation fractional urea excretion $= ((\text{urea}_{\text{urine}} * \text{creatinine}_{\text{plasma}}) /(\text{urea}_{\text{plasma}} * \text{creatinine}_{\text{urine}})) * 100$ following Dole (15). Transtubular potassium gradient was calculated using the equation transtubular potassium gradient $= ((\text{potassium}_{\text{urine}} * \text{osmolality}_{\text{plasma}})/(\text{potassium}_{\text{plasma}} * \text{osmolality}_{\text{urine}})$ according to West *et al.* (67). Creatinine clearance was calculated according Gault *et al.* (22). Percentage change in plasma volume was determined following Strauss *et al.* (64).

Between the pre- and the post-race measurements, all athletes recorded their intake of solid food and fluids using paper and pencil. The investigator provided a prepared paper with all aid stations and the food and drinks provided there. At each aid station, they marked the kind as well as the amount of food and fluid ingested. At these aid stations, liquids and food were prepared in a standardized manner, i.e. beverages and food were provided in standardized size portions. The drinking cups were filled to 0.2 l, the energy bars and the fruits were halved. The athletes had only to mark at which station they consumed liquids and food. They also recorded additional food and fluid intake provided by the support crew as well as the intake of salt tablets and other supplements. The composition of fluids and solid food were determined according to the reports of the athletes using a food table (26).

Statistical Analyses

Data are presented as mean and standard deviation (SD). Pre- and post-race results were compared using a paired *t*-test. Pearson correlation analyses were used to check for associations between parameters with statistically significant changes between pre- and post-race results. Analysis of variance (one way) was used to determine differences between groups. A Tukey's post-hoc test was performed when the overall *F* value of the model was significant to detect differences. Statistical significance was accepted with $p < 0.05$ (two-sided hypothesis).

RESULTS

Pre-race, the 50 subjects reported 11.8 (7.9) years of experience as long-distance runners. During training, they were running for 8.6 (10.8) hours per week, completed 66.5 (27.6) weekly running kilometres and were running at a speed of 10.7 (1.3) km/h. The finishers completed the 100-km ultra-marathon within 734 (119) min, running at a speed of 8.4 (1.2) km/h. The weekly running kilometres ($r = -0.28$; $p = 0.0473$), the running speed during training ($r = -0.58$; $p < 0.0001$), the personal best time in a marathon ($r = 0.61$, $p < 0.0001$) and the personal best time in a 100-km ultra-marathon ($r = 0.80$; $p < 0.0001$) were related to their 100-km race time.

During the run, the subjects lost 1.9 (1.4) kg of body mass ($p < 0.0001$) and 0.7 (2.0) kg of skeletal muscle mass ($p < 0.05$) whereas fat mass remained unchanged ($p > 0.05$) (see **Table 2**). Expressed in percent, the athletes lost 2.6 (1.8) % in body mass. The change in body mass varied between a loss of - 8 % body mass to an increase in 1.3 % body mass (see **Figure 1**). The decrease in body mass was not related to the decrease in skeletal muscle mass ($p > 0.05$). However, the change in body mass was associated with the change in fat mass ($r = 0.44$, $p = 0.0014$). Race time was significantly and positively related to the change in body mass; faster runners lost more body mass than slower runners (see **Figure 2**).

Hemoglobin, hematocrit, serum glucose and serum [K^+] remained unchanged; calculated plasma volume increased by 1.0 (7.8) %. The concentration of aldosterone, serum [Na^+], serum creatinine, serum urea, and plasma osmolality increased ($p < 0.0001$) (see **Table 2**). In urine, urine specific gravity and urine osmolality increased ($p < 0.0001$). Fractional sodium excretion, fractional urea excretion and creatinine clearance decreased ($p < 0.0001$); fractional potassium excretion, transtubular potassium gradient and the potassium-to-sodium ratio in urine increased ($p < 0.0001$).

The changes in body mass were significantly and negatively related to post-race serum [Na^+] (see **Figure 3**). The increase in plasma osmolality was highly significantly associated with the increase in both serum urea ($r = 0.71$, $p < 0.0001$) and serum [Na^+] ($r = 0.51$, $p < 0.0001$). For urine, the increase in osmolality was highly significantly related to the increase in urea ($r = 0.77$, $p < 0.0001$) and to the decrease in [Na^+] ($r = 0.57$, $p < 0.0001$).

While running, the athletes consumed 7.2 (2.2) L of fluids, equal to 0.60 (0.20) L/h. Considering the intake of electrolytes, they ingested 4.2 (3.7) g of sodium and 0.6 (0.3) g of potassium, respectively. This was equal to 353 (319) mg of sodium per race hour and 52 (30) mg of potassium per race hour, respectively. Fluid intake was significantly and positively related to the change in body mass ($r = 0.40$, $p = 0.004$) (see **Figure 4**). Furthermore, fluid intake was significantly and positively related to running speed ($r = 0.33$, $p = 0.0182$) where faster runners were drinking more fluids per hour (see **Figure 5**). Additionally, fluid intake was significantly and negatively related to both post-race serum [Na^+] ($r = -0.34$, $p = 0.0142$) and the change in serum [Na^+] ($r = -0.38$, $p = 0.0072$). Sodium intake was neither related to post- race serum [Na^+] nor to the change in serum [Na^+] ($p > 0.05$).

The concentration of aldosterone increased highly significantly ($p < 0.0001$). The change in aldosterone concentration was highly significantly and positively associated with the change in transtubular potassium gradient ($r = 0.37$, $p = 0.0078$) and the change in potassium-to-sodium ratio in urine ($r = 0.68$, $p < 0.0001$). Post-race aldosterone concentration was not related to post-race serum [Na^+] ($p > 0.05$); also the change in aldosterone concentration was not associated with the change in serum [Na^+] ($p > 0.05$). Post-race aldosterone concentration (see **Figure 6**) and the change in aldosterone concentration (see **Figure 7**) were significantly and positively related to running speed. The faster the athletes were running the more the aldosterone concentration increased. Furthermore, the change in aldosterone concentration was significantly and negatively associated with the increase in plasma volume (r = -0.40, p = 0.0037). Fluid intake was neither related to post-race aldosterone concentration nor to the change in aldosterone (p > 0.05). Also, fluid intake correlated neither to post-race aldosterone concentration nor to the change in aldosterone concentration (p > 0.05).

The subjects were divided in athletes with > 2% loss of body mass and athletes with ≤ 2 % of body mass (see **Table 3**). Of the 50 subjects, 31 finishers (62%) showed a loss of > 2 % body mass and 19 finishers (38 %) a loss of ≤ 2 % body mass. The finishers with a loss of > 2 % body mass completed the race within 729 (109) min and were not slower compared to the finishers with a loss of ≤ 2 % body mass, finishing within 744 (137) min (p > 0.05). The finishers with > 2 % loss of body mass showed a higher increase in aldosterone concentration (p < 0.001). In addition, they showed a higher increase in fractional potassium excretion, in transtubular potassium gradient and in the potassium-to-sodium ratio in urine (p < 0.05).

Further, we divided the subjects in three groups (see **Table 4**); athletes with ≤ 2 % loss of body mass (group 1), athletes with a decrease between 2% and 4% of body mass (group 2) and athletes with a loss of > 4 % body mass (group 3). Race time was not different between the three groups (p > 0.05). The athletes in group 1 consumed significantly more fluids than the athletes in the other groups (p < 0.05). The finishers with the highest decrease in body mass (group 3) showed a significantly greater change in aldosterone concentration, in hemoglobin, in hematocrit, in serum [Na$^+$], in serum urea, in plasma osmolality, and in fractional urea excretion compared to the other groups (p < 0.05).

DISCUSSION

This study aimed to investigate whether (*i*) ultra-marathoners in a 100-km ultra-marathon undergo a decrease in body mass, (*ii*) an eventual decrease in body mass was due to dehydration and (*iii*) race performance was impaired in case of a decrease in body mass. We hypothesized that (*i*) body mass would decrease and (*ii*) a decrease in body mass would be related to an impaired race performance.

A main finding in these male 100-km ultra-marathoners was that the faster runners lost more body mass than the slower runners did (see **Figure 2**). One might assume that the decrease in body mass would be related to a decreased fluid intake. However, the faster runners were drinking more than the slower runners (see **Figure 5**). Although the faster runners were drinking more each hour, they were losing more body mass during the race presumably due to more sweating but they were still drinking appropriately at a relatively lesser rate than were the slower runners. The goal of drinking during endurance exercise is to prevent excessive (> 2 % body weight loss from water deficit) dehydration and excessive changes in electrolyte balance to avert compromised performance. Because there is a considerable variability in sweating rates and sweat electrolyte content between individuals, customized fluid replacement programs are recommended (14,52). However, this behaviour may lead to fluid overload (7). When athletes drink too much in order to prevent dehydration, fluid overload with consequent exercise-associated hyponatremia may occur (60). Instead of a full replacement of body weight loss through fluid ingestion, drinking to thirst seems to prevent from fluid overload (46). Therefore, *ad libitum* fluid ingestion is optimal as it prevents athletes from ingesting too little or too much fluid (16).

In an actual study of Zouhal *et al.* (74) using 643 marathoners and investigating the association between a loss in body mass and race performance, the degree in the loss of body mass was inversely and linearly related to the marathon race time. Fifty-five % of their subjects lost > 2 % of body mass during the marathon and runners with that extent of body mass loss ran significantly faster than those runners who lost less body mass. Their findings confirmed recent findings where a loss of body mass seems to be 'ergogenic' regarding an endurance performance. In marathon runners (74), in cyclists (17), in Ironman triathletes (56,69), in 24-h ultra-marathoners (24) and in ultra-runners in the ‚Marathon des Sables' (73), an inverse relationship between body mass changes and race performance has been demonstrated.

Regarding the association between a loss of body mass and race performance in ultra-endurance athletes, Kao *et al.* (24) investigated both 12-h and 24-h ultra-marathoners. Their ultra-runners were competing at a temperature between 11.5 °C and 14.6 °C. In the 18 participants in the 12-h run, body mass change was not related to running performance. However, in the 23 runners in the 24-h run, the loss in body mass was positively associated with the completed kilometres. All runners with a loss of > 7 % body mass ran more than 200 km during the 24 hours. Their findings were in accordance to studies in Ironman triathletes where athletes exhibiting the most dramatic changes in body mass during an Ironman were among the fastest to finish (55,56). High levels of body mass losses did also not affect performance in the 'Marathon des Sables' (73). These findings that faster athletes lost more body mass during an endurance performance compared to slower athletes were, however, no new findings. Already the early studies on marathoners of both Pugh *et al.* (50) and Wyndham and Strydom (71) showed that the winners were those who lost the most body mass and usually showed the highest post-race core body temperatures (9,50,71). In the study of Pugh *et al.* (50) using 77 marathon runners, the winner finished the marathon race with a core temperature of 41.1 °C, having lost 6.7 % of body mass. The winner of the 1970 Commonwealth Games Marathon in near world-record time did not drink during the race and lost 3.9 % of body mass (44).

We must, however, be aware that the change in body mass is not always a reliable measure of the change in hydration status (41,47) although a recent laboratory study concluded that measuring pre- to post-exercise changes in body mass was an accurate and reliable method to assess the change in total body water (3). In 181 male Ironman triathletes, plasma volume and serum [Na^+] were maintained despite a significant loss of 5 % body mass. It was concluded that body mass was not an accurate surrogate of body fluid homeostasis during prolonged endurance performance (23). In addition, ultra-endurance performance may lead to a decrease in solid masses such as fat mass (32,33,36-38,73) and skeletal muscle mass (27,32-36). In the present ultra-marathoners, skeletal muscle mass was significantly reduced and the change in body mass was related to the change in fat mass. The change in body mass is only one potential variable to determine a change in hydration status among different other possibilities (25,57,58). Armstrong recently presented a list of 13 different methods to assess hydration status (1). A major problem is that a single gold standard, including plasma osmolality, is not possible for all hydration assessment requirements. For a field study such as an ultra-endurance race, techniques to assess hydration status should be easy-to-use, safe, portable, and inexpensive such as body mass changes, urine specific gravity, 24-h urine volume, urine colour, and thirst (1). Therefore, we determined apart from the body mass changes also the change in urine specific gravity. The decrease of 2.6 % body mass means minimal dehydration and the post-race urine specific gravity of 1.026 g/mL significant dehydration, following Kavouras (25). Presumably, the combination of blood indices such as plasma osmolality, hemoglobin concentration and hematocrit together with urine indices such as urine osmolality and urine specific gravity would be best method to define dehydration instead of using only body mass changes as a single parameter of hydration status (25,57,58). Clinical signs thought to indicate dehydration such as altered skin turgor, dry oral mucous membranes, sunken eyes, an inability to spit and the sensation of thirst were not able to identify runners with a total body mass loss of > 3 % at the end of a marathon (43).

A further important finding was that plasma [Na^+] increased with an increasing loss of body mass. The group with > 4 % loss of body mass showed an increase in plasma [Na^+] of 3.75 (2.86) mmol/L ($p < 0.05$). In Ironman triathletes, Sharwood *et al.* (56) described that serum [Na^+] was significantly higher in athletes with the greatest percent body mass loss. This increase in plasma [Na^+] might be due to endocrine regulation during dehydration (35). In a case study in a multi-stage ultra-triathlon with one Ironman triathlon per day for five consecutive days, body mass decreased and plasma [Na^+] increased after each stage (29). In marathoners, Whiting *et al.* (70) showed a decrease in body mass and an increase in plasma [Na^+]. The increase in plasma [Na^+] in marathoners might not be due to dehydration but rather due to endocrine regulation by hormones such as aldosterone, renin and atrial natriuretic peptide which are increased after a marathon (49). After an endurance performance, sodium excretion in urine is reduced (21,49) presumably due to the increased activity of aldosterone (21). An endocrine regulation of plasma [Na^+] is quite possible since fluid intake was neither related to the change in body mass nor to the change in plasma [Na^+] in the present ultra-marathoners. In the present ultra-marathoners, both post-race aldosterone concentration and the change in aldosterone concentration were significantly and negatively related to race time; the faster the athlete, the higher the aldosterone concentration. Wade *et al.* (66) described chronically elevated plasma aldosterone levels in multi-stage runners with a decreased urine excretion rate. This might explain why plasma [Na^+] increased in the present 100-km ultra-marathoners.

An important finding was that the faster runners were drinking more than the slower runners (see **Figure 5**). Although the faster runners were drinking more each hour, they were losing more body mass during the race (see **Figure 2**). Also, drinking more while running was associated with an increase in body mass (see **Figure 4**). The faster runners – although drinking more – lost more body mass during the race presumably due to more sweating but they were still drinking less than were the slower runners. We assume that the faster runners had a support crew to provide drinks also between the aid stations in contrast to the slower runners with no support crew. Most probably, the faster runners were not stopping at the aid stations to get food and drinks. We must also be aware that intensity drives sweat rate (51). The fact that they were more dehydrated is likely due to the greater sweat rate at a higher intensity more so than it being ergogenic. The better performance in the faster runners is also due to numerous reasons where one main reason is certainly the motivation to achieve a fast race time (31).

Limitations and implications for future research

This study is limited due to the design. We do not know how the athletes would have consumed fluids with an enhanced hydration plan. Two field studies using a randomized, cross-over design showed that dehydration impaired performance during a 12-km trail-run in the heat (11,61). These studies involved the same 17 subjects (9 males, 8 females) with repeated measures and controlled numerous factors except the level of hydration. The conclusions of these two well-controlled studies were consistent that dehydration impaired performance (11,61). An ultra-marathon of 100 km will produce a substantial protein catabolism, leading to a decrease in skeletal muscle mass (36,38) and thus leading to an increase in urine urea concentration, which will increase urine specific gravity independent of a changing water fraction. Therefore, the hydration parameter urine specific gravity for fluid and hydration status is limited under the present circumstances. The faster ultra-marathoners were running through the night at rather low temperatures and finished early in the morning. The slower ultra-marathoners had to continue on the second day while the ambient temperature started to rise. This change in temperature from the cool night to the hot day for the slower runners might have influenced our results. Future studies may investigate whether ultra-marathoners competing for hours or days run faster during the night with lower temperatures than during the day with higher temperatures and how they consume fluids depending upon the ambient temperature.

PRACTICAL APPLICATIONS

This field study showed that recreational male 100-km ultra-marathoners dehydrated as evidenced by the decrease in 2.6 % body mass and the increase in urine specific gravity. Race performance, however, was not impaired due to the loss of body mass. In contrast, faster athletes lost more body mass compared to slower athletes. The concept, that a loss of > 2 % body mass leads to dehydration and consequently impairs endurance performance must be questioned for ultra-endurance athletes competing in the field. For practical application, a loss in body mass was associated with a faster running speed during a 100-km ultra-marathon in recreational male ultra-runners.

REFERENCES

1. Armstrong LE. Assessing hydration status: the elusive gold standard. *J Am Coll Nutr* 26: 575S-584S, 2007.
2. Baker LB, Munce TA, Kenney WL. Sex differences in voluntary fluid intake by older adults during exercise. *Med Sci Sports Exerc* 37: 789-796, 2005.
3. Baker LB, Lang JA, Kenney WL. Change in body mass accurately and reliably predicts change in body water after endurance exercise. *Eur J Appl Physiol* 105: 959-967, 2009.
4. Barr SI, Costill DL, Fink WJ. Fluid replacement during prolonged exercise: effects of water, saline, or no fluid. *Med Sci Sports Exerc* 23: 811-817, 1991.
5. Becque MD, Katch VL, Moffatt RJ. Time course of skin-plus-fat compression in males and females. *Hum Biol* 58: 33-42, 1986.
6. Below PR, Mora-Rodríguez R, González-Alonso J, Coyle EF. Fluid and carbohydrate ingestion independently improve performance during 1 h of intense exercise. *Med Sci Sports Exerc* 27: 200-210, 1995.
7. Beltrami FG, Hew-Butler T, Noakes TD. Drinking policies and exercise-associated hyponatraemia: is anyone still promoting overdrinking? *Br J Sports Med* 42: 796-501, 2008.
8. Burge CM, Carey MF, Payne WR. Rowing performance, fluid balance, and metabolic function following dehydration and rehydration. *Med Sci Sports Exerc* 25: 1358-1364, 1993.
9. Buskirk ER, Beetham WPJ. Dehydration and body temperature as a result of marathon running. *Med Sport* XIV: 493-506, 1969.
10. Casa DJ, Clarkson PM, Roberts WO. American College of Sports Medicine roundtable on hydration and physical activity: consensus statement. *Curr Sports Med Rep* 4: 115-127, 2005.
11. Casa DJ, Stearns RL, Lopez RM, Ganio MS, McDermott BP, Walker Yeargin S, Yamamoto LM, Mazerolle SM, Roti MW, Armstrong LE, Maresh CM. Influence of hydration on physiological function and performance during trail running in the heat. *J Athl Train* 45: 147-156, 2010.
12. Cheuvront SN, Carter R 3rd, Sawka MN. Fluid balance and endurance exercise performance. *Curr Sports Med Rep* 2: 202-208, 2003.
13. Cheuvront SN, Carter R 3rd, Castellani JW, Sawka MN. Hypohydration impairs endurance exercise performance in temperate but not cold air. *J Appl Physiol* 99: 1972-1976, 2005.
14. Convertino VA, Armstrong LE, Coyle EF, Mack GW, Sawka MN, Senay LC, Sherman WM. American College of Sports Medicine position stand - exercise and fluid replacement. *Med Sci Sports Exerc* 28: R1-R7, 1996.
15. Dole VP. Back diffusion of urea in the mammalian kidney. *Am J Physiol* 139: 504-519, 1943.
16. Dugas JP, Ossthuizen U, Tucker R, Noakes TD. Rates of fluid ingestion alter pacing but not thermoregulatory responses during prolonged exercise in hot and humid conditions with appropriate convective cooling. *Eur J Appl Physiol* 105: 69-80, 2009.

17. Ebert TR, Martin DT, Stephens B, McDonald W, Withers RT. Fluid and food intake during professional men's and women's road-cycling tours. *Int J Sports Physiol Perform* 2: 58-71, 2007.
18. Eichner ER. Treatment of suspected heat illness. *Int J Sports Med* 19: S150-S153, 1998.
19. Epstein Y, Armstrong LE. Fluid-electrolyte balance during labor and exercise: concepts and misconceptions. *Int J Sport Nutr* 9: 1-12, 1999.
20. Fallowfield JL, Williams C, Booth J, Choo BH, Growns S. Effect of water ingestion on endurance capacity during prolonged running. *J Sports Sci* 14: 497-502, 1996.
21. Fellmann N, Sagnol M, Bedu M, Falgairette G, Van Praagh E, Gaillard G, Jouanel P, Coudert J. Enzymatic and hormonal responses following a 24 h endurance run and a 10 h triathlon race. *Eur J Appl Physiol* 57: 545-553, 1988.
22. Gault MH, Longerich LL, Harnett JD, Wesolowski C. Predicting glomerular function from adjusted serum creatinine (editorial). *Nephron* 62: 249-256, 1992.
23. Hew-Butler T, Collins M, Bosch A, Sharwood K, Wilson G, Armstrong M, Jennings C, Swart J, Noakes T. Maintenance of plasma volume and serum sodium concentration despite body weight loss in ironman triathletes. *Clin J Sport Med* 17: 116-122, 2007.
24. Kao WF, Shyu CL, Yang XW, Hsu TF, Chen JJ, Kao WC, Polun-Chang, Huang YJ, Kuo FC, Huang CI, Lee CH. Athletic performance and serial weight changes during 12- and 24-hour ultra-marathons. *Clin J Sport Med* 18: 155-158, 2008.
25. Kavouras SA. Assessing hydration status. *Curr Opin Clin Nutr Metab Care* 5: 519-524, 2002.
26. Kirchhoff E. Online-Publication of the German Food Composition Table 'Souci–Fachmann–Kraut' on the Internet. *J Food Comp Anal* 15: 465-472, 2002.
27. Knechtle B, Baumann B, Wirth A, Knechtle P, Rosemann T. Male Ironman triathletes lose skeletal muscle mass. *Asia Pac J Clin Nutr* 19: 91-97, 2010.
28. Knechtle B, Joleska I, Wirth A, Knechtle P, Rosemann T, Senn O. Intra- and inter-judge reliabilities in measuring the skin-fold thicknesses of ultra-runners under field conditions. *Percept Mot Skills* 111: 105-106, 2010.
29. Knechtle B, Knechtle P, Andonie JL, Kohler G. Body composition, energy, and fluid turnover in a five-day multistage ultratriathlon: a case study. *Res Sports Med* 17: 104-120, 2009.
30. Knechtle B, Knechtle P, Kaul R, Kohler G. No change of body mass, fat mass, and skeletal muscle mass in ultraendurance swimmers after 12 hours of swimming. *Res Q Exerc Sport* 80: 62-70, 2009.
31. Knechtle B, Knechtle P, Rosemann T, Lepers R. Predictor variables for a 100-km race time in male ultra-marathoners. *Percept Mot Skills* 111: 681-693, 2010.
32. Knechtle B, Knechtle P, Rosemann T, Oliver S. A Triple Iron triathlon leads to a decrease in total body mass but not to dehydration. *Res Q Exerc Sport* 81: 319-327, 2010.
33. Knechtle B, Knechtle P, Rosemann T, Senn O. No dehydration in mountain bike ultra-marathoners. *Clin J Sport Med* 19: 415-420, 2009.

34. Knechtle B, Senn O, Imoberdorf R, Joleska I, Wirth A, Knechtle P, Rosemann T. Maintained total body water content and serum sodium concentrations despite body mass loss in female ultra-runners drinking ad libitum during a 100 km race. *Asia Pac J Clin Nutr* 19: 83-90, 2010.
35. Knechtle B, Senn O, Imoberdorf R, Joleska I, Wirth A, Knechtle P, Rosemann T. No fluid overload in male ultra-runners during a 100 km ultra-run. *Res Sports Med* 19: 14-27, 2011.
36. Knechtle B, Wirth A, Knechtle P, Rosemann T. Increase of total body water with decrease of body mass while running 100 km nonstop--formation of edema? *Res Q Exerc Sport* 80: 593-603, 2009.
37. Knechtle B, Wirth A, Knechtle P, Rosemann T. An ultra-cycling race leads to no decrease in skeletal muscle mass. *Int J Sports Med* 30: 163-167, 2009.
38. Knechtle B, Wirth A, Knechtle P, Rosemann T, Senn O. Do ultra-runners in a 24-h run really dehydrate? *Ir J Med Sci* 180: 129-134, 2011.
39. Laursen PB, Suriano R, Quod MJ, Lee H, Abbiss CR, Nosaka K, Martin DT, Bishop D. Core temperature and hydration status during an Ironman triathlon. *Br J Sports Med* 40: 320-325, 2006.
40. Lee RC, Wang Z, Heo M, Ross R, Janssen I, Heymsfield SB. Total-body skeletal muscle mass: Development and cross-validation of anthropometric prediction models. *Am J Clin Nutr* 72: 796-803, 2000.
41. Maughan RJ, Shirreffs SM, Leiper JB. Errors in the estimation of hydration status from changes in body mass. *J Sports Sci* 25: 797-804, 2007.
42. McConell GK, Burge CM, Skinner SL, Hargreaves M. Influence of ingested fluid volume on physiological responses during prolonged exercise. *Acta Physiol Scand* 160: 149-156, 1997.
43. McGarvey J, Thompson J, Hanna C, Noakes TD, Stewart J, Speedy D. Sensitivity and specificity of clinical signs for assessment of dehydration in endurance athletes. *Br J Sports Med* 44: 716-719, 2010.
44. Muir AL, Percy-Robb IW, Davidson IA, Walsh EG, Passmore R. Physiological aspects of the Edinburgh commonwealth games. *Lancet* 28: 1125-1288, 1970.
45. Murray B. Hydration and physical performance. *J Am Coll Nutr* 26: 542S-548S, 2007.
46. Noakes TD. Is drinking to thirst optimum? *Ann Nutr Metab* 57: 9-17, 2010.
47. Nolte HW, Noakes TD, van Vuuren B. Protection of total body water content and absence of hyperthermia despite 2% body mass loss ('voluntary dehydration') in soldiers drinking ad libitum during prolonged exercise in cool environmental conditions. *Br J Sports Med* Epub ahead of print, 2010
48. Nybo L, Jensen T, Nielsen B, González-Alonso J. Effects of marked hyperthermia with and without dehydration on VO_2kinetics during intense exercise. *J Appl Physiol* 90: 1057-1064, 2011.
49. Pastene J, Germain M, Allevard AM, Gharib C, Lacour JR. Water balance during and after marathon running. *Eur J Appl Physiol* 73: 49-55, 1996.
50. Pugh LG, Corbett JL, Johnson RH. Rectal temperatures, weight losses, and sweat rates in marathon running. *J Appl Physiol* 23: 347-352, 1967.
51. Rehrer NJ. Fluid and electrolyte balance in ultra-endurance sport. *Sports Med* 31: 701-715, 2001.

52. Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS, American College of Sports Medicine. American College of Sports Medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc* 39: 377-390, 2007.
53. Sawka MN, Noakes TD. Does dehydration impair exercise performance? *Med Sci Sports Exerc* 39: 1209-1217, 2007.
54. Sawka MN, Montain SJ. Fluid and electrolyte supplementation for exercise heat stress. *Am J Clin Nutr* 72: 564S-572S, 2000.
55. Sharwood K, Collins M, Goedecke J, Wilson G, Noakes T. Weight changes, sodium levels, and performance in the South African Ironman Triathlon. *Clin J Sport Med* 12: 391-399, 2002.
56. Sharwood KA, Collins M, Goedecke JH, Wilson G, Noakes TD. Weight changes, medical complications, and performance during an Ironman triathlon. *Br J Sports Med* 38: 718-724, 2004.
57. Shirreffs SM. Markers of hydration status. *Eur J Clin Nutr* 57: S6-S9, 2003.
58. Shirreffs SM. Markers of hydration status. *J Sports Med Phys Fitness* 40: 80-84, 2000.
59. Slater GJ, Rice AJ, Sharpe K, Tanner R, Jenkins D, Gore CJ, Hahn AG. Impact of acute weight loss and/or thermal stress on rowing ergometer performance. *Med Sci Sports Exerc* 37: 1387-1394, 2005.
60. Speedy DB, Noakes TD, Schneider C. Exercise-associated hyponatremia: a review. *Emerg Med (Fremantle)* 13: 17-27, 2011.
61. Stearns RL, Casa DJ, Lopez RM, McDermott BP, Ganio MS, Decher NR, Scruggs IC, West AE, Armstrong LE, Maresh CM. Influence of hydration status on pacing during trail running in the heat. *J Strength Cond Res* 23: 2533-2541, 2009.
62. Steiner RW. Interpreting the fractional excretion of sodium. *Am J Med* 77: 699-702, 1984.
63. Stewart AD, Hannan WJ. Prediction of fat mass and fat-free mass in male athletes using dual X-ray absorbtiometry as the reference method. *J Sports Sci* 18: 263-274, 2000.
64. Strauss MB, Davies RK, Rosenbaum JD, Rossmeisl EC. Water diuresis produced during recumbency by the intravenous infusion of isotonic saline solution. *J Clin Invest* 30: 862-868, 1951.
65. Von Duvillard SP, Braun WA, Markofski M, Beneke R, Leithäuser R. Fluids and hydration in prolonged endurance performance. *Nutrition* 20: 651-666, 2004.
66. Wade CE, Hill LC, Hunt MM, Dressendorfer RH. Plasma aldosterone and renal function in runners during a 20-day road race. *Eur J Appl Physiol* 54: 456-460, 1985.
67. West ML, Marsden PA, Richardson RM, Zettle RM, Halperin ML. New clinical approach to evaluate disorders of potassium excretion. *Miner Electrolyte Metab* 12: 234-238, 1986.
68. Walsh RM, Noakes TD, Hawley JA, Dennis SC. Impaired high-intensity cycling performance time at low levels of dehydration. *Int J Sports Med* 15: 392-398, 1994.
69. Wharam PC, Speedy DB, Noakes TD, Thompson JM, Reid SA, Holtzhausen LM. NSAID use increases the risk of developing hyponatremia during an Ironman triathlon. *Med Sci Sports Exerc* 38: 618-622, 2006.
70. Whiting PH, Maughan RJ, Miller JD. Dehydration and serum biochemical changes in marathon runners. *Eur J Appl Physiol* 52: 183-187, 1984.

71. Wyndham CH, Strydom NB. The danger of an inadequate water intake during marathon running. *S Afr Med J* 43: 893-896, 1969.
72. Zaryski C, Smith DJ. Training principles and issues for ultra-endurance athletes. *Curr Sports Med Rep* 4: 165-170, 2005.
73. Zouhal H, Groussard C, Vincent S, Jacob C, Abderrahman AB, Delamarche P, Gratas-Delamarche A. Athletic performance and weight changes during the "Marathon of Sands" in athletes well-trained in endurance. *Int J Sports Med* 30: 516-521, 2009.
74. Zouhal H, Groussard C, Minter G, Vincent S, Cretual A, Gratas-Delamarche A, Delamarche P, Noakes TD. Inverse relationship between percentage body weight change and finishing time in 643 forty-two-kilometre marathon runners. *Br J Sports Med* Epub ahead of print, 2010

	n	***Result***
Age (years)	50	47.9 (8.7)
Body height (m)	50	1.79 (0.07)
Body mass (kg)	50	74.9 (9.6)
Body mass index (kg/m^2)	50	23.2 (2.3)
Pre-race experience as an ultra-runner (years)	50	11.8 (7.9)
Training volume (h/week)	50	8.6 (10.8)
Training volume (km/week)	50	66.5 (27.6)
Training speed (km/h)	50	10.7 (1.3)
Pre-race completed marathons (number)	48	33 (55)
Pre-race completed 100-km ultra-marathons (number)	35	5.6 (5.7)
Personal best time in a marathon (min)	48	210 (30)
Personal best time in a 100-km ultra-marathon (min)	35	682 (119)

Table 1: Characteristics age, anthropometry, training and previous experience of the subjects (*n*=50). Results are presented as mean and SD.

	Pre-race	Post-race	Absolute change	Percent change	*p*-value
Body mass (kg)	74.9 (9.6)	73.0 (9.6)	- 1.9 (1.4)	- 2.6 (1.8)	<0.0001
Fat mass (kg)	8.8 (4.8)	8.4 (4.6)	- 0.4 (1.6)	- 2.1 (21.1)	
Skeletal muscle mass (kg)	38.8 (3.8)	37.9 (3.6)	- 0.7 (2.0)	- 1.6 (6.5)	< 0.05
Plasma aldosterone (ng/l)	90.4 (41.1)	423.7 (255.4)	+ 333.3 (252.9)	+ 454 (425)	<0.0001
Hemoglobin (g/dl)	14.5 (0.9)	14.5 (1.0)	- 0.0 (0.6)	- 0.3 (4.5)	
Hematocrit (%)	43.4 (2.7)	43.3 (3.0)	- 0.1 (2.0)	- 0.3 (4.5)	
Serum sodium (mmol/l)	136.0 (2.2)	138.2 (2.2)	+ 2.2 (2.8)	+ 1.6 (2.1)	<0.0001
Serum potassium (mmol/l)	4.1 (0.3)	4.2 (0.4)	+ 0.1 (0.5)	+ 3.9 (13.2)	
Serum glucose (mmol/l)	5.3 (1.1)	5.4 (1.2)	+ 0.1 (1.6)	+ 7.1 (31.5)	
Serum creatinine (µmol/l)	77.8 (11.6)	100.4 (25.0)	+ 22.4 (23.4)	+ 30.1 (32.0)	<0.0001
Serum urea (mmol/l)	5.7 (1.1)	9.1 (2.4)	+ 3.4 (2.2)	+ 6.1 (42.24)	<0.0001
Plasma osmolality (mosmol/kgH_2O)	296.4 (4.3)	302.0 (7.4)	+ 5.6 (7.9)	+ 1.9 (2.7)	<0.0001
Urine specific gravity (g/ml)	1.017 (0.007)	1.026 (0.006)	+ 0.009 (0.007)	+ 0.92 (0.69)	<0.0001
Urine osmolality (mosmol/kgH_2O)	648.3 (278.7)	850.7 (214.5)	+ 202.5 (256.6)	+ 61.6 (95.5)	<0.0001
Fractional sodium excretion (%)	0.91 (0.36)	0.37 (0.31)	- 0.54 (0.43)	- 50.6 (56.5)	<0.0001
Fractional potassium excretion (%)	11.3 (5.5)	19.1 (8.1)	+ 7.8 (9.1)	+ 100.0 (126.9)	<0.0001
Fractional urea excretion (%)	52.7 (12.9)	31.0 (14.5)	- 21.7 (19.4)	- 38.9 (30.8)	<0.0001
Transtubular potassium gradient (ratio)	28.3 (22.7)	99.7 (52.2)	+71.4 (52.2)	+ 828 (1,582)	<0.0001
Potassium-to-sodium in urine (ratio)	0.46 (0.42)	3.26 (3.57)	+ 2.80 (3.64)	+ 11.2 (27.7)	<0.0001
Creatinine clearance (ml/min)	111.5 (24.5)	87.3 (26.5)	- 24.1 (21.4)	- 33.6 (32.8)	<0.0001

Table 2: Results of the physical, hematological and urine parameters before and after the race (*n*=50). Results are presented as mean and SD.

	Finishers with > 2% body mass loss (*n*=31; 62%)			**Finishers with ≤ 2% body mass loss (*n*=19; 38%)**			**Difference between Δ**
	Pre-race	**Post-race**	**Δ Post-race – Pre-race**	**Pre-race**	**Post-race**	**Δ Post-race – Pre-race**	**Δ > 2% – Δ ≤ 2 %**
Body mass (kg)	75.3 (7.7)	72.5 (7.6)	- 3.7 (0.9) ***	74.3 (12.2)	73.7 (12.3)	- 0.6 (0.7) ***	3.0 (0.3) ***
Fat mass (kg)	8.3 (4.1)	7.9 (4.0)	- 0.4 (1.1) *	9.4 (5.8)	9.3 (5.4)	- 0.1 (2.1)	0.3 (1.0)
Skeletal muscle mass (kg)	39.3 (3.7)	38.3 (3.6)	- 1.0 (0.8) ***	38.0 (3.2)	37.2 (3.4)	- 0.8 (0.9) **	0.2 (0.8)
Plasma aldosterone (ng/l)	90.4 (34.8)	509.6 (266.0)	+ 419.2 (262.3) ***	90.4 (50.8)	283.5 (161.6)	+ 193.1 (161.4) ***	226.0 (100.9) ***
Hemoglobin (g/dl)	14.5 (1.0)	14.6 (0.1)	+ 0.1 (0.6)	14.5 (1.0)	14.2 (1.0)	- 0.3 (0.6) *	0.37 (0.06) **
Hematocrit (%)	43.5 (2.6)	43.9 (2.8)	+ 0.4 (1.8)	43.4 (2.9)	42.3 (3.1)	- 1.1 (2.0) *	1.35 (0.22) **
Serum sodium (mmol/l)	136.2 (2.2)	138.7 (2.3)	+ 2.5 (2.9) ***	135.7 (2.1)	137.4 (1.7)	+ 1.7 (2.6) *	0.83 (0.37)
Serum potassium (mmol/l)	4.2 (0.3)	4.3 (0.4)	+ 0.1 (0.4)	4.1 (0.3)	4.2 (0.3)	+ 0.1 (0.6)	0.02 (0.14)
Serum glucose (mmol/l)	5.5 (1.2)	5.6 (1.1)	+ 0.1 (1.6)	5.0 (0.8)	5.2 (1.3)	+ 0.2 (1.6)	0.10 (0.05)
Serum creatinine (µmol/l)	78.7 (10.0)	106.4 (28.0)	+ 27.7 (26.2) ***	76.3 (13.9)	90.4 (15.1)	+ 14.1 (14.9) ***	13.6 (11.3)
Serum urea (mmol/l)	5.7 (1.1)	9.8 (2.4)	+ 4.1 (2.0) ***	5.6 (1.1)	8.0 (2.2)	+ 2.4 (2.2) ***	1.7 (0.2) *
Plasma osmolality (mosmol/kgH_2O)	206.5 (4.1)	304.2 (7.1)	+ 7.7 (7.4) ***	296.1 (4.6)	298.4 (6.5)	+ 2.3 (7.6)	5.4 (0.2) *
Urine specific gravity (g/ml)	1.016 (0.007)	1.028 (0.004)	+ 0.011 (0.006) ***	1.017 (0.008)	1.023 (0.007)	+ 0.006 (0.006) **	0.006 (0.000) *
Urine osmolality (mosmol/kgH_2O)	651.3 (277.9)	894.7 (177.3)	+ 243.4 (281.6) ***	643.2 (287.5)	779.0 (253.1)	+ 135.8 (198.7) **	107.5 (92.9)
Fractional sodium excretion (%)	0.90 (0.28)	0.26 (0.18)	- 0.64 (0.33) ***	0.94 (0.46)	0.55 (0.39)	- 0.39 (0.53) **	0.25 (0.20)
Fractional potassium excretion (%)	11.0 (4.7)	20.4 (8.9)	+ 9.4 (9.8) ***	11.8 (6.6)	16.8 (5.8)	+ 5.0 (7.1) **	4.4 (2.7) *
Fractional urea excretion (%)	54.1 (14.4)	25.8 (11.2)	- 28.3 (19.0) ***	50.5 (10.0)	39.4 (15.7)	- 11.1 (14.9) **	17.2 (4.1) **
Transtubular potassium gradient (ratio)	27.6 (20.3)	116.4 (48.5)	+ 88.8 (50.1) ***	29.4 (26.7)	72.4 (47.2)	+ 43.0 (43.0) **	45.8 (7.8) **
Potassium-to-sodium in urine (ratio)	0.42 (0.29)	4.26 (4.13)	+ 3.84 (4.19) ***	0.53 (0.59)	1.64 (1.32)	+ 1.01 (1.43) **	2.7 (2.7) **
Creatinine clearance (ml/min)	110.1 (23.2)	82.7 (28.2)	- 27.4 (22.4) ***	113.9 (26.9)	94.9 (22.3)	- 19.0 (19.1) **	8.4 (3.2)

Table 3: Comparison of the changes in anthropometric and laboratory parameters between the finishers with > 2 % decrease in body mass and the finishers with ≤ 2 % loss in body mass. Results are presented as mean (SD). * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

	Finishers with decrease in body mass ≤ 2% (Group 1; *n*=15)	**Finishers with decrease in body mass 2 - ≤ 4% (Group 2; *n*=19)**	**Finishers with decrease in body mass > 4% (Group 3; *n*=12)**	***p*-value**
Race time (min)	713 (113)	764 (109)	670 (89)	
Fluid intake (L/h)	8.1 (1.6)	6.8 (1.9) †	6.3 (2.4) §	0.04
Change in body mass (kg)	- 0.87 (0.42)	- 2.20 (0.51) †	- 3.69 (0.73) §, #	< 0.0001
Change in fat mass (kg)	- 0.54 (2.12)	- 0.26 (0.99)	- 0.75 (1.30)	
Change in skeletal muscle mass (kg)	- 0.89 (0.90)	- 0.99 (0.89)	- 0.99 (0.85)	
Change in plasma aldosterone (ng/l)	231.98 (159.67)	371.07 (255.81)	495.32 (265.15) §	0.02
Change in hemoglobin (g/dl)	- 0.26 (0.53)	- 0.14 (0.56)	+ 0.44 (0.61) §	0.04
Change in hematocrit (%)	- 0.66 (1.79)	- 0.42 (1.21)	+ 1.58 (1.92) §	0.04
Change in serum sodium (mmol/l)	+ 1.60 (2.02)	+ 1.73 (2.80)	+ 3.75 (2.86) §, #	0.04
Change in serum potassium (mmol/l)	+ 0.28 (0.56)	+ 0.00 (0.41)	+ 0.32 (0.44)	
Change in serum glucose (mmol/l)	+ 0.28 (1.69)	- 0.28 (1.06)	+ 0.77 (2.05)	
Change in serum creatinine (µmol/l)	+ 15.80 (15.19)	+ 22.63 (17.51)	+ 35.75 (35.44)	
Change in serum urea (mmol/l)	+ 2.62 (2.36)	+ 3.40 (1.55)	+ 5.00 (2.35) §	0.02
Change in plasma osmolality (mosmol/kgH_2O)	+ 3.06 (7.99)	+ 4.73 (5.44)	+ 12.33 (7.99) §, #	0.04
Change in urine specific gravity (g/ml)	+ 0.006 (0.006)	+ 0.010 (0.005)	+ 0.012 (0.007)	
Change in urine osmolality (mosmol/kgH_2O)	+ 130.46 (186.89)	+ 234.73 (206.31)	+ 256.91 (382.62)	
Change in fractional sodium excretion (%)	- 0.54 (0.46)	- 0.64 (0.38)	- 0.64 (0.24)	
Change in fractional potassium excretion (%)	+ 5.91 (7.02)	+ 6.21 (4.67)	+ 14.47 (13.49)	
Change in fractional urea excretion (%)	- 14.05 (12.97)	- 24.98 (13.60) †	- 33.54 (25.26) §	0.02
Change in transtubular potassium gradient (ratio)	+ 50.99 (44.01)	+ 85.36 (47.87)	+ 94.27 (55.15)	
Change in potassium-to-sodium in urine (ratio)	+ 1.52 (1.29)	+ 3.28 (4.04)	+ 4.72 (4.45)	
Change in creatinine clearance (ml/min)	- 22.17 (19.58)	- 26.00 (17.01)	- 29.55 (29.78)	

Table 4: Comparison of changes in anthropometric and laboratory parameters between groups separated by the degree of the changes in body mass. The four athletes with an increase in body mass were not considered due to the small sample size. Results are presented as mean (SD). † = significant difference between group 1 and 2; § = significant difference between group 1 and 3; # = significant difference between group 2 and 3.

Figure 1: The distribution of percent changes in body mass (*n*=50).

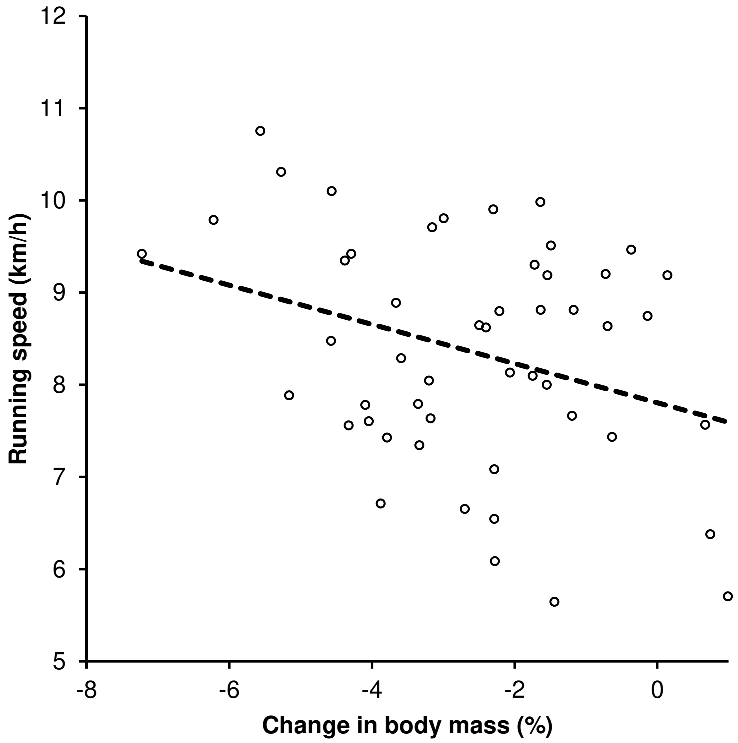

Figure 2: Running speed was significantly and negatively related to the change in body mass (*n*=50) (*r* = -0.31, *p* = 0.026).

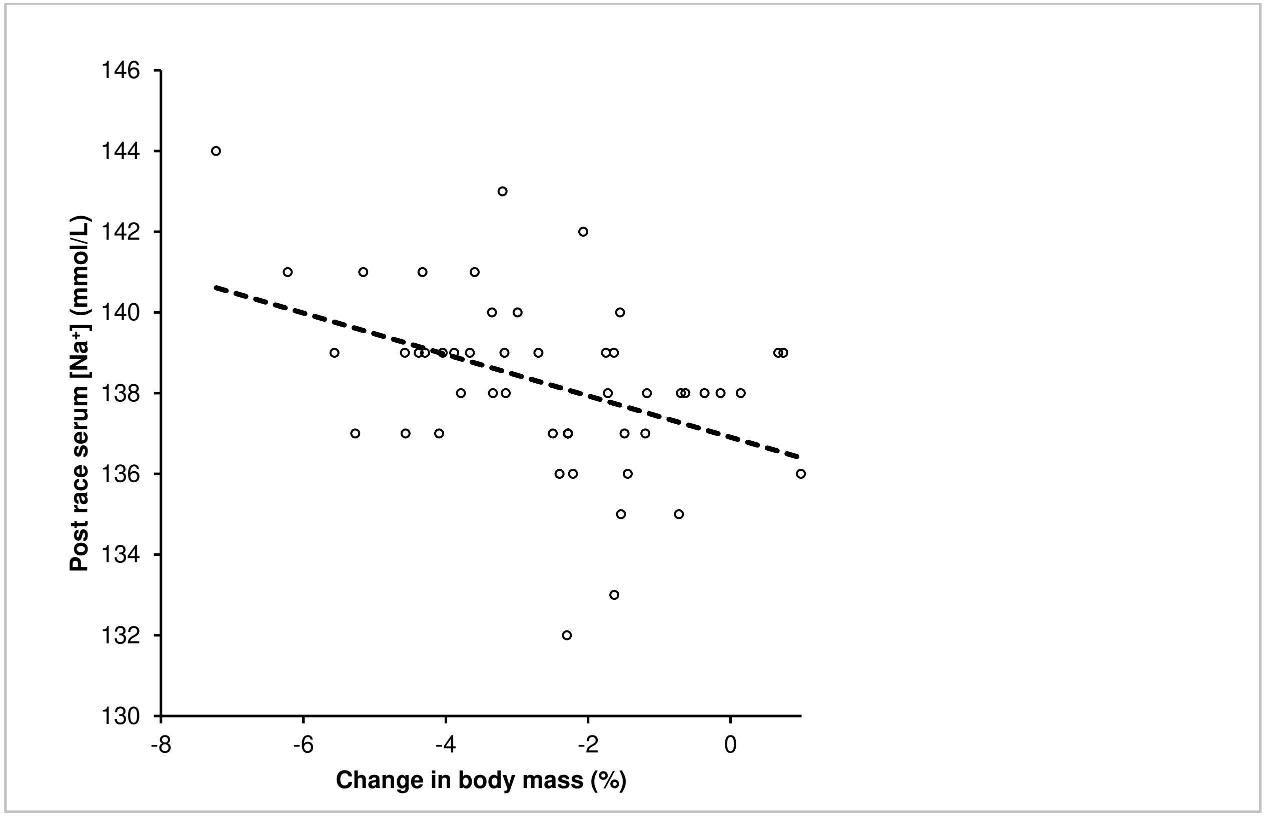

Figure 3: The change in body mass was significantly and negatively related to post-race serum [Na$^+$] (*n*=50) (*r* = -0.42, *p* = 0.0022).

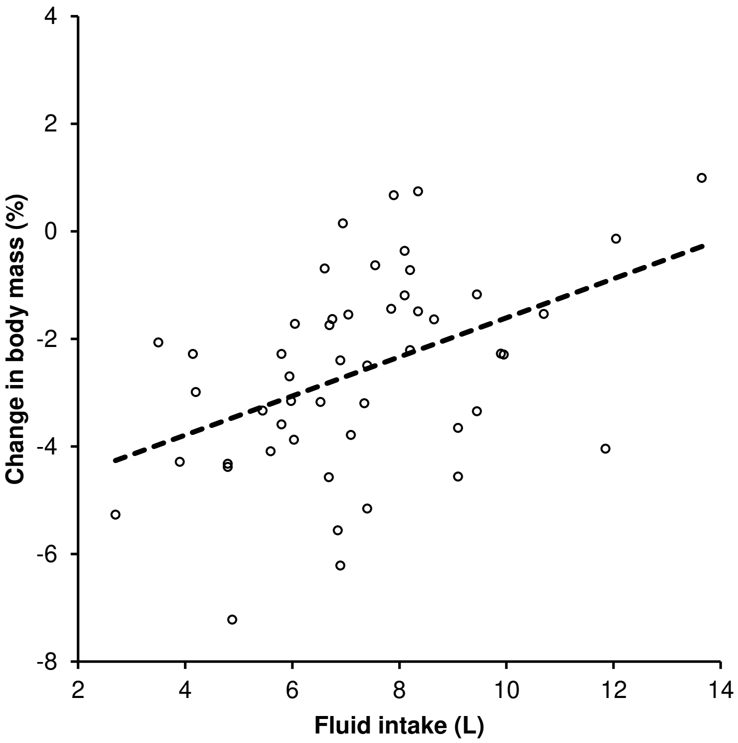

Figure 4: Fluid intake was significantly and positively related to the change in body mass (*n*=50) ($r = 0.44$, $p = 0.0014$).

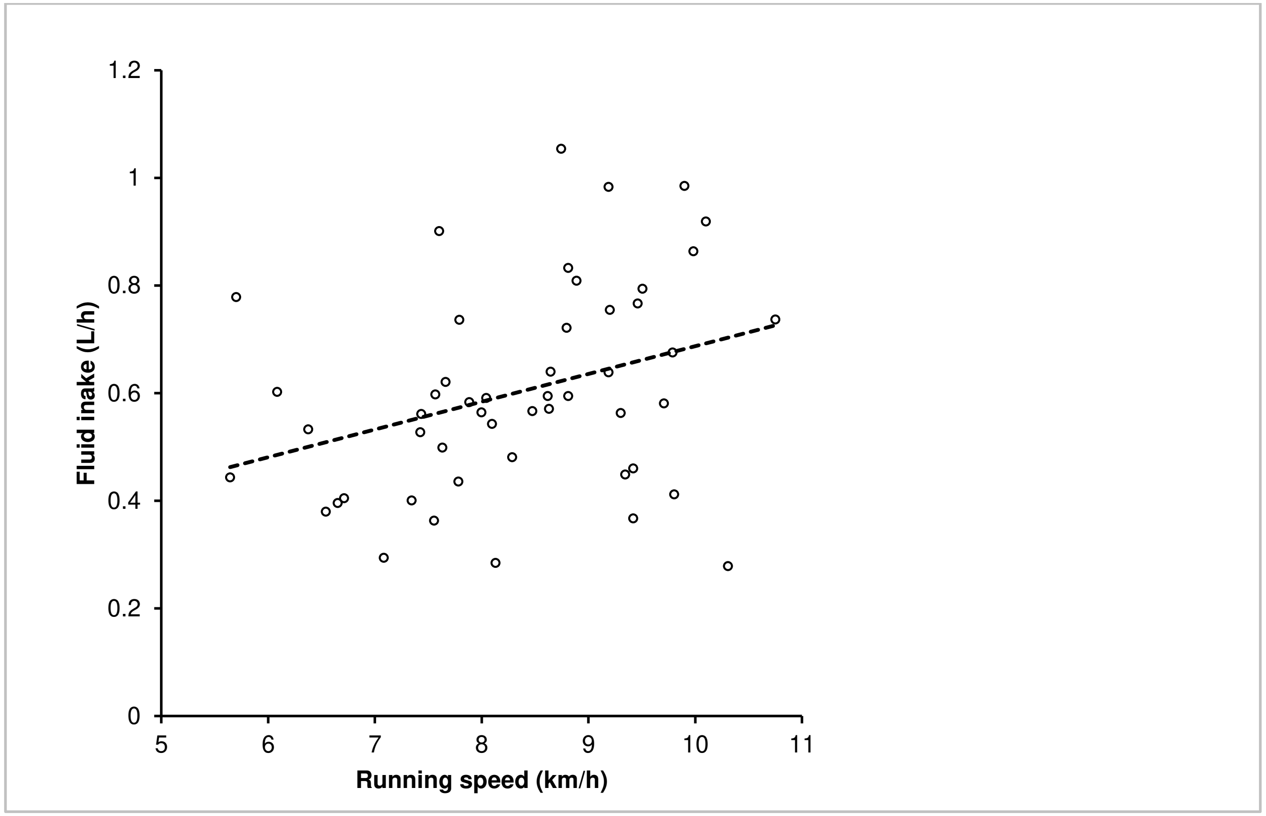

Figure 5: Fluid intake was significantly and positively related to running speed where faster runners were drinking more fluids per hour ($r = 0.33$, $p = 0.0182$)

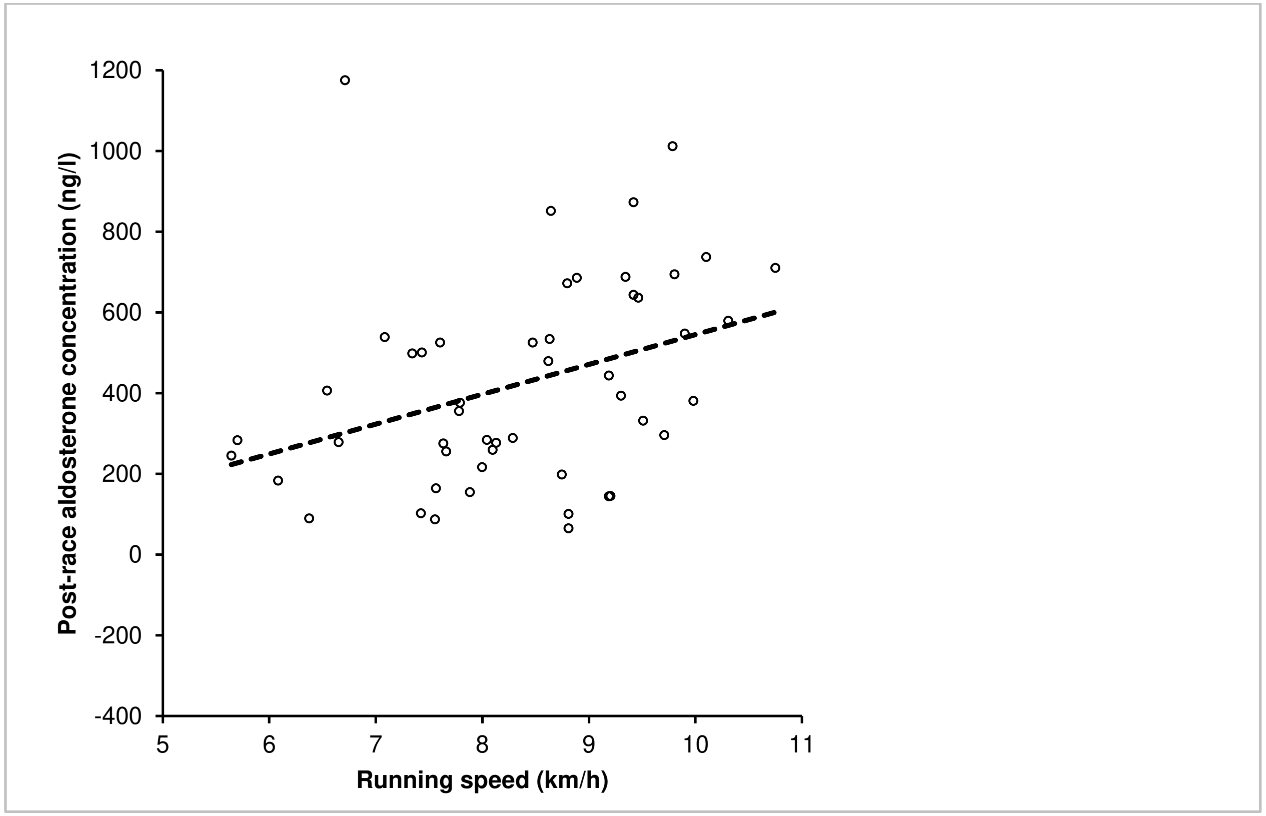

Figure 6: Post-race aldosterone was significantly and positively related to running speed (*n*=50) (*r* = 0.36, *p* = 0.011).

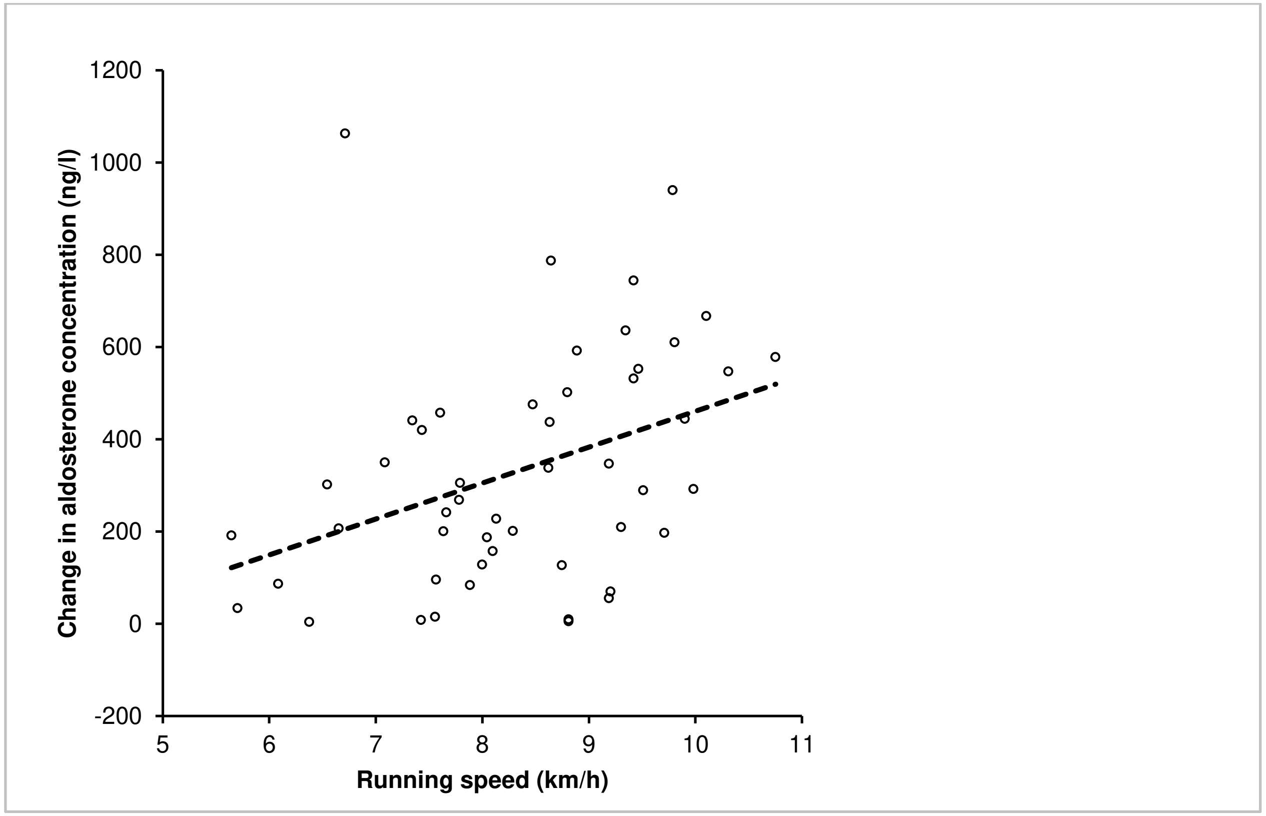

Figure 7: The change in aldosterone was significantly and positively related to running speed (*n*=50) ($r = 0.35$, $p = 0.0122$).