Journal of Sports Sciences
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rjsp20

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Published online: 06 Jun 2012.

Journal of Sports Sciences, July 2012; 30(11): 1131–1140

A faster running speed is associated with a greater body weight loss in 100-km ultra-marathoners

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(Accepted 7 May 2012)

Abstract

In 219 recreational male runners, we investigated changes in body mass, total body water, haematocrit, plasma sodium concentration ($[Na^+]$), and urine specific gravity as well as fluid intake during a 100-km ultra-marathon. The athletes lost 1.9 kg ($s = 1.4$) of body mass, equal to 2.5% ($s = 1.8$) of body mass ($P < 0.001$), 0.7 kg ($s = 1.0$) of predicted skeletal muscle mass ($P < 0.001$), 0.2 kg ($s = 1.3$) of predicted fat mass ($P < 0.05$), and 0.9 L ($s = 1.6$) of predicted total body water ($P < 0.001$). Haematocrit decreased ($P < 0.001$), urine specific gravity ($P < 0.001$), plasma volume ($P < 0.05$), and plasma $[Na^+]$ ($P < 0.05$) all increased. Change in body mass was related to running speed ($r = -0.16$, $P < 0.05$), change in plasma volume was associated with change in plasma $[Na^+]$ ($r = -0.28$, $P < 0.0001$), and change in body mass was related to both change in plasma $[Na^+]$ ($r = -0.36$) and change in plasma volume ($r = 0.31$) ($P < 0.0001$). The athletes consumed 0.65 L ($s = 0.27$) fluid per hour. Fluid intake was related to both running speed ($r = 0.42$, $P < 0.0001$) and change in body mass ($r = 0.23$, $P = 0.0006$), but not post-race plasma $[Na^+]$ or change in plasma $[Na^+]$ ($P > 0.05$). In conclusion, faster runners lost more body mass, runners lost more body mass when they drank less fluid, and faster runners drank more fluid than slower runners.

Keywords: *Fluid metabolism, electrolyte, urine specific gravity, hydration status*

Introduction

Dehydration is a common finding in endurance athletes and is defined as a loss of more than 2% of body weight during an endurance performance (Casa, Clarkson, & Roberts, 2005; Murray, 2007; Sawka & Montain, 2000; Sawka & Noakes, 2007; Sawka et al., 2007). Numerous studies have shown that dehydration leads to an impairment of endurance performance (Casa et al., 2010; Murray, 2007; Sawka & Noakes, 2007; Sawka et al., 2007; Stearns et al., 2009; Von Duvillard, Braun, Markofski, Beneke, & Leithäuser, 2004).

Results showing impaired performance due to dehydration were mainly obtained in laboratory experiments performed under controlled laboratory conditions. The participants were investigated while cycling on a stationary ergometer (Barr, Costill, & Fink, 1991; Below, Mora-Rodriguez, Gonzalez Alonso, & Coyle, 1995; Cheuvront, Carter, Castellani, & Sawka, 2005; McConell, Burge, Skinner, & Hargreaves, 1997; Nybo, Jensen, Nielsen, & Gonzalez Alonso, 2001; Walsh, Noakes, Hawley, & Dennis, 1994), rowing on a stationary ergometer (Burge, Carey, & Payne, 1993; Slater et al., 2005), or running on a treadmill (Fallowfield, Williams, Booth, Choo, & Growns, 1996).

The temperature during these laboratory trials was rather high and kept constant, varying from 21°C (McConell et al., 1997) to 30°C (Barr et al., 1991), to 32°C (Slater et al., 2005; Walsh et al., 1994). The number of participants in these laboratory trials tended to be rather low, at six (Nybo et al., 2001; Walsh et al., 1994), seven (McConell et al., 1997), or eight (Barr et al., 1991; Below et al., 1995; Cheuvront et al., 2005; Fallowfield et al., 1996) participants.

The intensity during endurance performance under laboratory conditions was generally high. The participants cycled on a stationary cycling ergometer at 70% maximum oxygen uptake ($\dot{V}O_{2max}$) (McConell et al., 1997), 80% $\dot{V}O_{2max}$ (Below et al., 1995),

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ISSN 0264-0414 print/ISSN 1466-447X online © 2012 Taylor & Francis
http://dx.doi.org/10.1080/02640414.2012.692479

or even at maximal intensity until exhaustion (Nybo et al., 2001; Walsh et al., 1994). In some instances, the participants completed a time-trial on a cycle ergometer (Cheuvront et al., 2005; McConell et al., 1997) or on a rowing ergometer (Slater et al., 2005). Other participants ran at 70% $\dot{V}O_{2max}$ on a treadmill (Fallowfield et al., 1996) or rowed on a rowing ergometer at maximum intensity (Burge et al., 1993).

In addition to these laboratory studies, two controlled field studies showed that dehydration impaired performance during a 12-km trail-run in the heat (Casa et al., 2010; Stearns et al., 2009). These studies involved the same 17 participants (9 males, 8 females) with repeated measures and controlled numerous factors except the level of hydration. The conclusions of these well-controlled studies were consistent in finding that dehydration impaired performance (Casa et al., 2010; Stearns et al., 2009).

In general, the performance duration of both the laboratory and field studies was less than 6 h (Barr et al., 1991; Casa et al., 2010; Stearns et al., 2009). Little is known about the association between body mass loss in ultra-endurance competition – where ultra-endurance is defined as a performance lasting for 6 h or more (Zaryski & Smith, 2005) – and performance in an ultra-endurance race. Although change in body mass has been investigated in ultra-endurance athletes, the effect of a loss in body mass on ultra-endurance performance has received less attention. Sharwood and colleagues (Sharwood, Collins, Goedecke, Wilson, & Noakes, 2002) found no evidence that a loss in body mass or dehydration was related to impaired performance in 297 Ironman triathletes. Indeed, those athletes who lost the most body weight completed the race in the shortest times. Laursen et al. (2006) 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 finishing times. Recent studies on ultra-marathoners found that body weight loss was positively associated with race performance in 23 ultra-marathoners in a 24-h run (Kao et al., 2008). In the "Marathon des Sables" over 230 km in 7 days in the desert, athletic performance and body weight changes in 16 ultra-marathoners were investigated. The athlete with the greatest body weight changes (i.e. 5% body weight loss on day 3 and 9% body weight loss on day 6) was the fastest competitor (Zouhal et al., 2009).

Several studies have been performed recently to investigate changes in both body mass and hydration status in ultra-endurance athletes (Kao et al., 2008; Knechtle, Knechtle, Rosemann, & Senn, 2009c, 2010c; Knechtle et al., 2010d; Knechtle, Wirth, Knechtle, & Rosemann, 2009d; Knechtle, Wirth, Knechtle, Rosemann, & Senn, 2011b; Zouhal et al., 2009). Regarding dehydration in ultra-endurance athletes, no dehydration was reported for mountain bike ultra-marathoners (Knechtle et al., 2009c) or Triple Iron ultra-triathletes (Knechtle et al., 2010c). In a recent study on ultra-marathoners in a 24-hour ultra-run, it was even questioned whether ultra-runners really dehydrate (Knechtle et al., 2011b).

In general, body mass decreased during ultra-endurance performance, including ultra-distance runners (Kao et al., 2008; Knechtle et al., 2009d, 2010d, 2011a; Zouhal et al., 2009), ultra-distance cyclists (Knechtle, Wirth, Knechtle, & Rosemann, 2009e; Knechtle et al., 2009c), and ultra-distance triathletes (Knechtle, Baumann, Wirth, Knechtle, & Rosemann, 2010a; Knechtle et al., 2010c; Laursen et al., 2006; Sharwood et al., 2002). For male ultra-distance swimmers, however, no change in body mass was reported (Knechtle, Knechtle, Kaul, & Kohler, 2009b). It is possible that the decrease in body mass in ultra-endurance athletes was not only due to dehydration (Knechtle et al., 2010c, 2011b), but also due to a decrease in solid masses such as predicted skeletal muscle mass (Knechtle et al., 2009d, 2009e, 2010a, 2010c) and predicted fat mass (Knechtle et al., 2009d, 2009e, 2010c, 2011a, 2011b; Zouhal et al., 2009).

These data on ultra-endurance athletes show that: (i) a decrease in body mass such as a loss in both predicted skeletal muscle mass and predicted fat mass is a common finding in ultra-endurance athletes; and (ii) a loss in body mass appears not to be associated with a decrease in ultra-endurance performance. For ultra-marathoners, there exist only data on the relationship between body mass decreases and ultra-endurance performance. Although Sharwood et al. (2002) examines a large sample of 297 Ironman triathletes, only small series of ultra-runners have been investigated. Following Kao et al. (2008) and Zouhal et al. (2009), who examined small samples of 23 and 16 ultra-runners, respectively, we wished to investigate the association between body mass changes and ultra-endurance performance in a larger sample of 100-km ultra-marathoners.

The aims of the present observational field study of a sample of 219 recreational male ultra-marathoners were to determine whether: (i) ultra-marathoners in a 100-km ultra-marathon experience a decrease in body mass; (ii) any decrease in body mass was due to dehydration; and (iii) running speed was impaired in the case of a decrease in body mass. Based on the findings on a large sample of Ironman triathletes (Sharwood et al., 2002), we hypothesized that body mass would decrease during a 100-km ultra-marathon but the decrease in body mass would not be related to running speed.

Methods

Participants

Data were collected over five consecutive years of a 100-km ultra-marathon, the "100-km-Lauf Biel" in Biel, Switzerland, in order to increase the sample size. In 2007 to 2011, the Race Director contacted all the participants, via a separate newsletter at the time of acceptance to the race, in which they were asked to participate in the study. About 1300 male ultra-runners finish this race each year (Knechtle, Rüst, Rosemann, & Lepers, 2011c). A total of 239 male ultra-runners volunteered to participate in our investigation over this 5-year period. The participants were informed of the procedures and provided written informed consent. The study was approved by the Institutional Review Board for use of Human Subjects of St. Gallen, Switzerland.

Race

The "100-km-Lauf Biel" generally takes place during Friday night into Saturday of the first weekend in June. The athletes start the 100-km ultra-marathon on Friday at 22.00 h. They have to climb a total altitude of 645 m. During the study years, they were provided with a total of 17 aid stations offering an abundant variety of food and beverages such as hypotonic sports drinks, tea, soup, caffeinated drinks, water, bananas, oranges, energy bars, cakes, and bread. Each runner was allowed the support of a cyclist who carried additional food and clothing. In all 5 years, the general weather conditions were comparable, with the temperature at the start being 15–18°C, nighttime lows of 8–10°C, and daytime highs of 25–28°C. There was no rain or wind from 2007 to 2010. In 2011, there were rain showers during the night and the temperature rose only to 18°C the following day.

Measurements and calculations

Upon agreeing to participate in the study, the participants were instructed to keep a comprehensive training diary until the start of each race. All units of run training were recorded, showing distance in kilometres and duration in minutes per unit. Before the start of the race on Friday and upon arrival at the finish line on Saturday, body mass, the circumferences of the limbs, and the thickness of four skinfolds (i.e. mid-upper arm, abdominal, mid-thigh, and mid-calf) on the right side of the body were measured. From these anthropometric measurements, skeletal muscle mass and fat mass were estimated.

Body mass was measured to the nearest 0.1 kg after voiding of the bladder using a commercial scale (Beurer BF 15, Beurer GmbH, Ulm, Germany). The participants were weighed in their running clothes without shoes; pre- and post-race the scale was in the same location. Height was determined using a stadiometer to the nearest 0.01 m (Tanita HR 001 Portable Height Measure, Tanita Europe, Amsterdam, Netherlands). The circumferences of upper arm, thigh, and calf were measured using a non-elastic tape measure (KaWe CE, Kirchner und Welhelm, Germany), at mid-upper arm, mid-thigh, and mid-calf to the nearest 0.1 cm. The skinfold data were obtained using a skinfold calliper (GPM-Hautfaltenmessgerät, Siber & Hegner, Zurich, Switzerland) and recorded to the nearest 0.2 mm. The skinfold calliper measures with a constant pressure of 0.1 MPa $\pm$ 5% over the whole measuring range. One trained investigator took all the anthropometric measurements. The skinfold measurements were taken three times and the mean value used for the analyses. The skinfold measurements were standardized to ensure reliability and readings were performed 4 s after applying the calliper, in line with Becque and colleagues (Becque, Katch, & Moffatt, 1986). An intra-tester reliability check was conducted on 27 male ultra-runners prior to testing (Knechtle et al., 2010b). The intra-class correlation (ICC) between the two measurers was excellent for all anatomical measurement sites, and various summary measurements of skinfold 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 the skinfold thicknesses.

Skeletal muscle mass was estimated using the formula of Lee et al. (2000), with skeletal muscle mass $=$ Height $\times$ (0.00744 $\times$ CAG^2 + 0.00088 $\times$ CTG^2 + 0.00441 $\times$ CCG^2) + 2.4 $\times$ sex $-$ 0.048 $\times$ age + race + 7.8, where CAG $=$ skinfold-corrected upper arm girth, CTG $=$ skinfold-corrected thigh girth, CCG $=$ skinfold-corrected calf girth, sex $=$ 1 for male and 0 for female, and race $= -2.0$ for Asian, 1.1 for African-American, and 0 for white or Hispanic. This anthropometric method was evaluated using 189 non-obese participants and cross-validated using magnetic resonance imagining. Fat mass was estimated using the anthropometric method of Stewart and Hannan (2000), with fat mass (g) $=$ 331.5 $\times$ (abdominal) + 356.2 $\times$ (thigh) + 111.9 m $-$ 9108, where abdominal is the thickness of the abdominal skinfold in millimetres, thigh is the thickness of the thigh skinfold in millimetres, and m is body mass in kilograms. Changes (Δ) in total body water were estimated using the equation Δ total body water $= \Delta$ body mass $-$ (Δ skeletal muscle mass + Δ fat mass) following Weschler (2005).

At the same time as the anthropometric measurements, samples of blood and urine were collected.

Capillary blood samples were taken from the fingertip and both plasma sodium concentration ($[Na^+]$) and haematocrit were analysed using the i-STAT® 1 System (Abbott Laboratories, Abbott Park, IL, USA). Athletes were seated for blood sampling and standardization of posture prior to blood collection was ensured, since postural changes can influence blood volume and therefore haemoglobin concentration and haematocrit. The percentage change in plasma volume was calculated from pre- and post-race concentrations of haematocrit following the equation of Beaumont (1972). Urine specific gravity was analysed using a Clinitek Atlas® Automated Urine Chemistry Analyzer (Siemens Healthcare Diagnostics, Deerfield, IL, USA).

During the race, the athletes recorded their fluid intake on a sheet of paper they carried with them during the run. At each aid station, they marked the number of cups consumed. The cups were prepared at each aid station in the same manner with 0.2 L per cup. In addition, all supplemental fluid intake provided by the support crew was recorded, including pre- and post-race fluids. Total fluid intake was estimated according to the reports of the athletes.

Statistical analysis

Results are presented as means ± standard deviations (s). Pre- and post-race results were compared using paired t-tests. Associations between both anthropometric and laboratory variables with running speed were investigated using Pearson correlation analysis. Statistical significance was set at $P < 0.05$.

Results

Of the 239 participants who started the investigation, 20 participants dropped out due to over-use injuries of the lower limbs. The 219 successful finishers completed the 100-km ultra-marathon within 713 min ($s = 123$), running at an average speed of 8.6 km $\cdot$ h^{-1} ($s = 1.4$). Table I provides the ages, anthropometric and training characteristics of the participants.

During the run, the successful finishers lost 1.9 kg ($s = 1.4$) of body mass ($P < 0.001$), 0.7 kg ($s = 1.0$) of predicted skeletal muscle mass ($P < 0.001$), 0.2 kg ($s = 1.3$) of predicted fat mass ($P < 0.05$), and 0.9 L ($s = 1.6$) of predicted total body water ($P < 0.001$) (Table II). Expressed as a percentage, the athletes lost 2.5% ($s = 1.8$) of body mass. The change in body mass varied between an 8% loss in body mass and a 3% gain in body mass (Figure 1). The change in body mass was significantly and positively related to both the change in predicted skeletal muscle mass ($r = 0.21$, $P = 0.0017$) and to the change in predicted fat mass ($r = 0.41$, $P < 0.0001$). Also, change in body mass was significantly and negatively related to running speed (Figure 2). The changes in predicted fat mass, predicted skeletal muscle mass, and predicted total body water were not associated, however, with running speed ($P > 0.05$).

Urine specific gravity increased ($P < 0.001$) (Table II). The change in urine specific gravity showed no association with change in body mass, change in predicted skeletal muscle, or running speed. Haematocrit decreased ($P < 0.001$), plasma volume increased by 5.1% ($s = 12.3$) ($P < 0.05$), and plasma $[Na^+]$ increased ($P < 0.05$). The change in plasma volume was significantly and negatively associated with the change in plasma $[Na^+]$ (Figure 3). The change in total body water was significantly and positively associated with the change in body mass (Figure 4), but showed no association with either change in plasma $[Na^+]$ or change in plasma volume ($P > 0.05$). The change in body mass was significantly and negatively related to the change in plasma $[Na^+]$ (Figure 5) and significantly and positively related to the change in plasma volume (Figure 6).

While running, the athletes consumed a total of 7.6 L ($s = 2.6$) of fluids during the ultra-marathon, equal to 0.65 L $\cdot$ h^{-1} ($s = 0.27$). Fluid intake was significantly and positively related to both running speed (Figure 7) and the change in body mass (Figure 8), but not to post-race plasma $[Na^+]$ or to change in plasma $[Na^+]$ ($P > 0.05$).

Discussion

The aim of this study was to determine whether a 100-km ultra-marathon leads to a decrease in body mass and whether a loss in body mass impairs running speed. We hypothesized that body mass would decrease but the decrease in body mass would not be related to running speed. We found several significant correlations. However, we must

Table I. Age, anthropometric and training characteristics of the participants ($n = 219$).

Variable	Mean value (s)
Age (years)	46.2 (9.3)
Body mass (kg)	75.0 (9.4)
Height (m)	1.78 (0.06)
Body mass index (kg $\cdot$ m^{-2})	23.4 (2.2)
Weekly running time (h)	8.2 (8.1)
Weekly running distance (km)	69.6 (27.6)
Running speed during training (km $\cdot$ h^{-1})	10.3 (2.1)
Number of completed marathons ($n = 214$)	34.6 (69.4)
Personal best marathon time (min) ($n = 214$)	208 (31)
Number of completed 100-km ultra-marathons ($n = 148$)	8.9 (6.5)
Personal best 100-km ultra-marathon time (min) ($n = 148$)	648 (166)

Table II. Changes in anthropometric and laboratory parameters ($n = 219$).

	Pre-race	Post-race	Change absolute	Change in %
Body mass (kg)	75.0 (9.4)	73.1 (9.3)	−1.9 (1.4) ***	−2.5 (1.8) ***
Predicted skeletal muscle mass (kg)	38.9 (3.8)	38.2 (3.7)	−0.7 (1.0) ***	−1.8 (2.5) ***
Predicted fat mass (kg)	8.8 (4.7)	8.6 (4.2)	−0.2 (1.3) *	−1.4 (8.1) *
Predicted total body water (L)	27.3 (4.6)	26.4 (4.4)	−0.9 (1.6) ***	−3.1 (6.1) ***
Haematocrit (%)	45.1 (3.9)	43.9 (3.3)	−1.2 (3.1) ***	−2.3 (6.3) ***
Plasma sodium ($\text{mmol} \cdot \text{L}^{-1}$)	137.7 (2.3)	138.6 (2.7)	+0.9 (3.4) *	+0.7 (2.4) *
Urine specific gravity ($\text{g} \cdot \text{mL}^{-1}$)	1.014 (0.008)	1.024 (0.007)	+0.009 (0.007) ***	+0.9 (0.8) ***

Note: Results are presented as mean (s). * $P < 0.05$, *** $P < 0.001$.

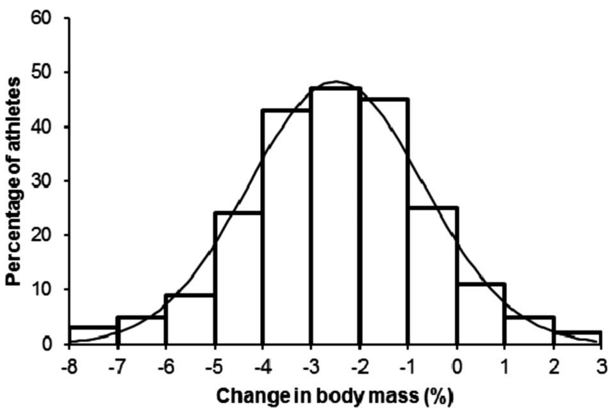

Figure 1. Distribution of percent changes in body mass ($n = 219$).

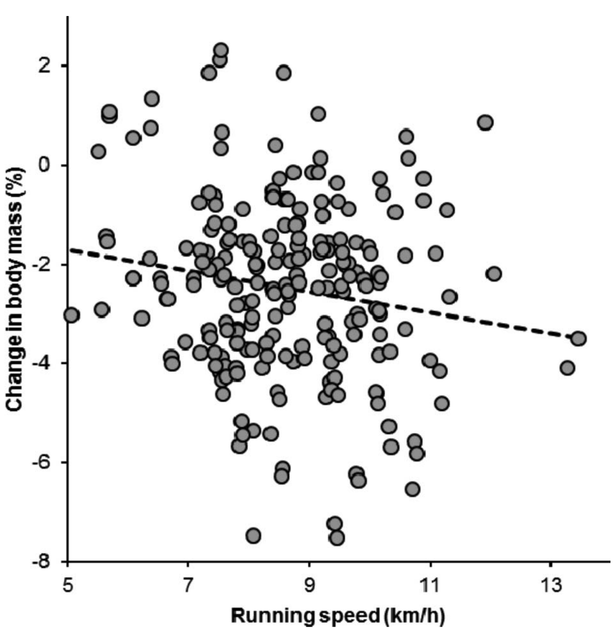

Figure 2. Change in body mass was significantly and negatively related to running speed ($n = 219$) ($r = -0.16$, $P < 0.05$).

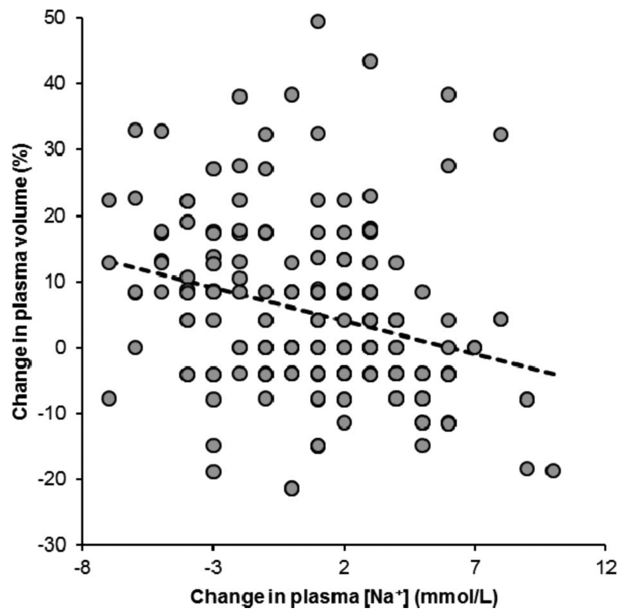

Figure 3. Change in plasma volume was significantly and negatively associated with change in plasma [Na^+] ($n = 219$) ($r = -0.28$, $P < 0.0001$).

acknowledge that (i) a significant correlation does not prove cause and effect and (ii) the r-values for the present correlations were rather weak, ranging from 0.16 to 0.42. The main findings were: (i) faster runners lost more body mass, (ii) runners lost more body mass when they drank less fluid, and (iii) faster runners drank more fluid than slower runners.

These findings need to be viewed in a common context. Faster runners lost more body mass although they drank more. Also, the decrease in body mass was associated with a decrease in both the predicted skeletal muscle mass and the predicted fat mass. Therefore, the loss in body mass was due to a loss in solid mass than a loss in fluid. Body mass changes are not a reliable measure of changes in hydration status (Maughan, Shirreffs, & Leiper, 2007; Nolte, Noakes, & Van Vuuren, 2011). An ultra-endurance performance may lead to a decrease in solid mass such as predicted fat mass (Knechtle, Knechtle, Andonie, & Kohler, 2009a; Knechtle et al., 2009d, 2009e, 2010c, 2011a) and predicted

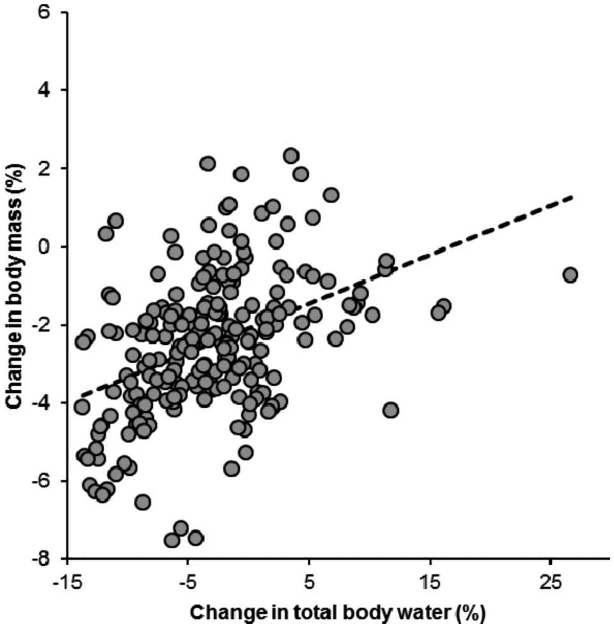

Figure 4. Change in body mass was significantly and positively associated with change in predicted total body water ($n = 219$) ($r = 0.42$, $P < 0.0001$).

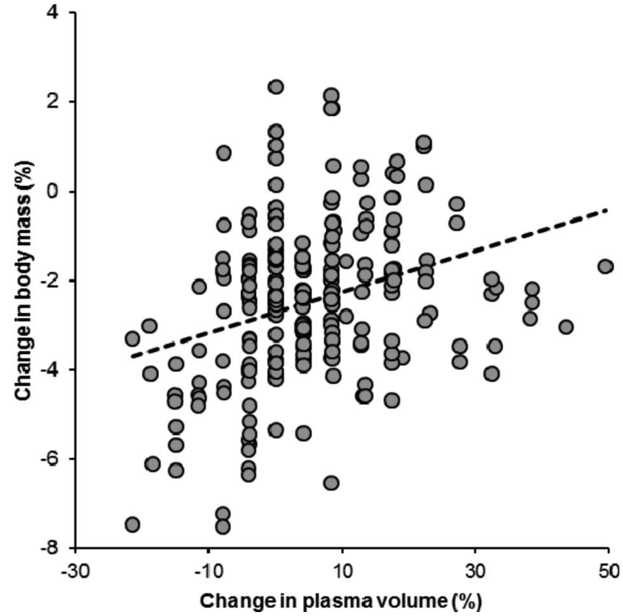

Figure 6. Change in plasma volume was significantly and positively associated with change in body mass ($r = 0.31$, $P < 0.0001$).

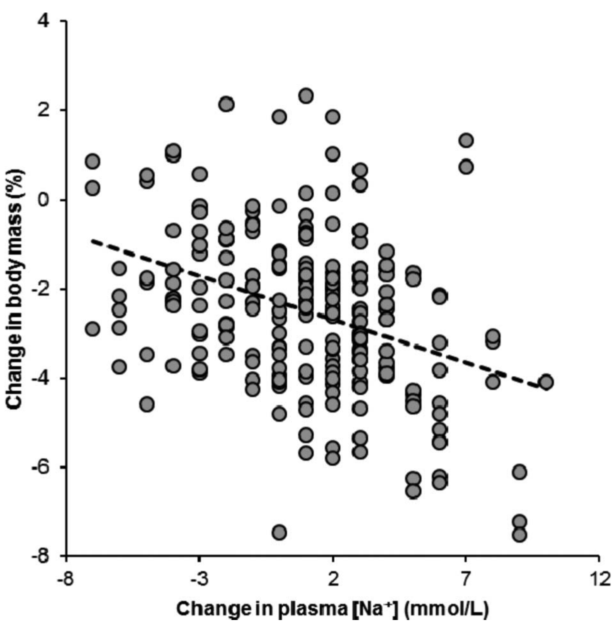

Figure 5. Change in body mass was significantly and negatively associated with change in plasma [Na^+] ($n = 219$) ($r = -0.36$, $P < 0.0001$).

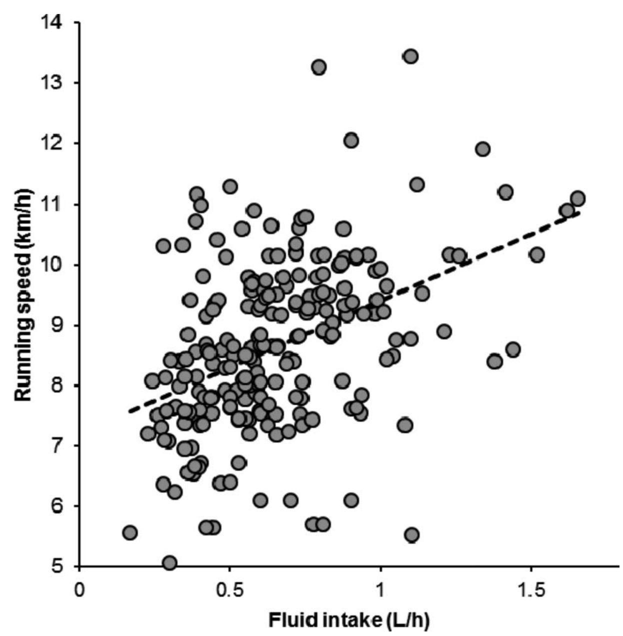

Figure 7. Fluid intake was significantly and positively related to running speed ($n = 219$) ($r = 0.42$, $P < 0.0001$).

skeletal muscle mass (Knechtle et al., 2009c, 2009d, 2010a, 2010c), as in the present participants. In a recent study of half-marathoners and ultra-marathoners, the change in body mass for both disciplines exceeded the change in total body water, indicating that water losses alone did not explain the body mass lost during the races (Tam, Nolte, & Noakes, 2011). The authors reported a correlation between the change in body mass and the change in total body water, as we did.

In another study of 181 male Ironman triathletes, plasma volume and serum [Na^+] were maintained

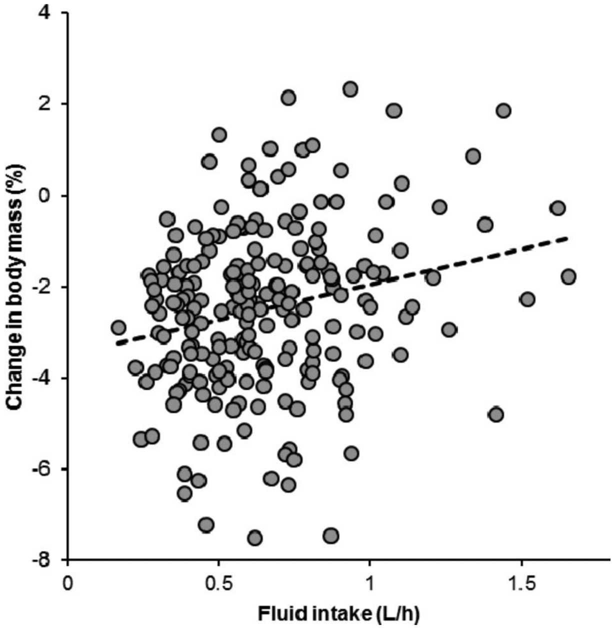

Figure 8. Fluid intake was significantly and positively related to change in body mass ($n = 219$) ($r = 0.23$, $P = 0.0006$).

despite a significant body mass loss of 5% (Hew-Butler et al., 2007). These authors concluded that body mass was not an accurate ''absolute'' surrogate of fluid balance homeostasis during prolonged endurance exercise. Furthermore, body mass change is only one of several variables responsible for changes in hydration status. There is no evidence to support the concept that body mass is a physiologically regulated parameter during prolonged exercise (Tam et al., 2011). The regulation of body mass occurs over months and years and is related to the regulation of both protein and fat mass rather than to acute changes in fluid balance (Harris, 1990).

Faster runners drank more than slower runners. Although faster runners drank more fluids each hour, they lost more body mass during the race. Also, drinking more while running was associated with an increase in body mass. This finding is in contrast to reports on marathoners, where faster athletes drank less (Muir, Percy-Robb, Davidson, Walsh, & Passmore, 1970; Noakes, 1995). Recent studies investigating fluid intake and exercise-associated hyponatremia in marathoners undertook no correlation analyses between fluid intake and running speed (Almond et al., 2005; Kipps, Sharma, & Pedoe, 2011; Mettler et al., 2008). Chorley and colleagues (Chorley, Cianca, & Divine, 2007) reported a significant interaction between gender and finish time that affected the total amount of fluid consumed. Slower males drank more cups than faster males, a relationship not seen in females. In the present ultra-marathoners, the faster runners – although they drank more – lost more body mass during the race presumably due to greater perspiration but they still drank appropriately at a relatively lesser rate than the slower runners. We assume that the faster runners had a support crew to provide drinks between the aid stations in contrast to the slower runners with no support crew.

The environmental conditions are most probably an important variable for both body mass loss and fluid intake. The ambient temperature might affect whether a decrease in body mass is associated with running speed. It is possible that in those field studies reporting no effect of body weight loss on race performance (Byrne, Lee, Chew, Lim, & Tan, 2006; Knechtle et al., 2010d; Laursen et al., 2006; Nolte, Noakes, & Van Vuuren, 2010), the exercise task may not have been long enough or intense enough, or the ambient temperature may not have been high enough to compromise endurance performance. In the field studies of Stearns et al. (2009) and Casa et al. (2010), who investigated 17 trail runners competing over 12 km in the heat at $\sim 26^{\circ}$C, dehydration impaired endurance performance. Ely and colleagues (Ely, Cheuvront, Roberts, & Montain, 2007) investigated the impact of weather on marathon performance times for different populations of runners at different marathon races. Marathon performance times increased as temperature increased from 5°C to 25°C, with performance being impaired more for the slower runners. Vihma (2010) also reported a significant association between ambient temperature and marathon race time. For ultra-marathoners, Wegelin and Hoffman (2011) reported that warmer weather was associated with slower finish times with the effect being more marked in faster runners.

The ambient temperature might have been responsible for the association we found between body mass losses and running speed in 100-km ultra-marathoners while running during the night at mean temperatures of $\sim 10^{\circ}$C. Laboratory (Galloway & Maughan, 1997) and field data (Trapasso & Cooper, 1989; Zhang, Meng, Wang, & Li, 1992) support an ''optimal'' ambient air temperature threshold of $\sim 12^{\circ}$C; above or below this temperature, performance is relatively impaired (Galloway & Maughan, 1997). Higher temperatures are detrimental to endurance performance compared with lower temperatures (Casa et al., 2010; Stearns et al., 2009). It has been demonstrated that hypohydration impairs performance in temperate but not cold air (Cheuvront et al., 2005). Furthermore, pacing strategy in ultra-endurance athletes may be influenced by environmental temperature (Abbiss et al., 2010).

Regarding the association between a loss in body mass and running speed in ultra-endurance athletes, Kao et al. (2008) 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 weight changes were not related to running speed, whereas in the 23 participants in the 24-h race, body weight loss was significantly and positively associated with running speed. All their runners with a body mass loss of more than 7% ran more than 200 km in the 24 h. Their findings are in accordance with studies in Ironman triathletes, where athletes exhibiting the most dramatic changes in body weight during an Ironman were among the fastest to finish (Sharwood et al., 2002, 2004). Also, in the ''Marathon des Sables'', marked body weight loss did not affect performance (Zouhal et al., 2009).

Limitations and implications for future research

We collected data in five successive years in which the environmental conditions were not identical. Variables such as age, previous ultra-events, years of racing experience, training background, wind speed, acclimatization to the weather, radiant energy loads, nutritional preparation prior to the event, nutritional strategies during the race, body core temperature, $\dot{V}O_{2max}$, exercise economy, exercise efficiency, and muscle fibre types were not controlled. Several of these variables might have influenced the performance of these athletes in a different manner. Also, the determination of body mass was limited, since it was measured to the nearest 0.1 kg only. Body mass changes are influenced by fluid intake, sweat loss, urine loss, and food consumption. Although the athletes voided prior to weighing, we were not able to account for faecal losses during the race and before body weight measurements. An ultra-marathon of 100 km will produce a substantial protein catabolism and elevate urine urea levels, which will increase urine specific gravity ''independent'' of a changing water fraction. Therefore, the use of urine specific gravity for hydration status is limited under these circumstances (Armstrong, 2007; Armstrong et al., 2010). The faster ultra-marathoners ran through the night at lower temperatures, while the slower ultra-marathoners had to continue into the next day when the ambient temperature started to rise. This change in temperature from cool night to hot day might have affected our results. Future studies should investigate whether ultra-marathoners competing for hours or days run faster during the night with lower temperatures than during the day with higher temperatures. The decrease in both estimated skeletal muscle mass and estimated fat mass requires future confirmations using DEXA (dual-emission X-ray absorptiometry) scans.

Conclusions

The main findings of this study were that (i) faster runners lost more body mass, (ii) runners lost more body mass when they drank less fluid, and (iii) faster runners drank more fluid than slower runners. We assume that the loss in body mass is explained by the loss in solid mass such as predicted fat mass and predicted muscle mass. Furthermore, faster runners, who probably had a higher sweating rate, lost more fluids and consequently drank more fluids. The concept that a loss of in body mass of more than 2% leads to dehydration and consequently impairs running speed must be questioned for ultra-marathoners competing in the field at ambient temperatures of 15–25°C. The determination of water- and electrolyte-regulating hormones such as vasopressin and aldosterone before and after an ultra-marathon (Bürge et al., 2011) might explain why the change in body mass was associated with the change in plasma $[Na^+]$ and why plasma $[Na^+]$ increased. Future studies should also investigate whether ultra-marathoners competing for hours or days run faster during the night with lower temperatures than during the day with higher temperatures.

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