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

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Abstract: 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.

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

Abstract

We investigated in 219 recreational male runners the changes (Δ) 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 ($s = 1.4$) kg of body mass, equal to 2.5 ($s = 1.8$) % in body mass ($P < 0.001$), 0.7 ($s = 1.0$) kg of predicted skeletal muscle mass ($P < 0.001$), 0.2 ($s = 1.3$) kg of predicted fat mass ($P < 0.05$) and 0.9 ($s = 1.6$) L 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 $[Na^+]$ ($P < 0.05$) increased. Δ body mass was related to running speed ($r = -0.16$, $P < 0.05$), Δ plasma volume was associated with Δ plasma $[Na^+]$ ($r = -0.28$, $P < 0.0001$), and Δ body mass was related to both Δ plasma $[Na^+]$ ($r = -0.36$) and Δ plasma volume ($r = 0.31$) ($P < 0.0001$). The athletes consumed 0.65 ($s = 0.27$) L fluid per h. Fluid intake was related to both running speed ($r = 0.42$, $P < 0.0001$) and Δ body mass ($r = 0.23$, $P = 0.0006$), but neither to post-race plasma $[Na^+]$ nor to Δ plasma $[Na^+]$ ($P > 0.05$). To conclude, 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.

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

Introduction

Dehydration is a common finding in endurance athletes and is defined as a loss of > 2% in 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).

These study results of an 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 temperatures were rather high and kept constant during the laboratory trials, varying between 21 °C (McConell, *et al.,* 1997), up to 30 °C (Barr, *et al.,* 1991), or even 32 °C (Slater, *et al.,* 2005, Walsh, *et al.,* 1994). Generally, the number of participants in these laboratory settings was 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.,* 1991; Cheuvront, *et al.,* 2005; Fallowfield, *et al.,* 1996) participants.

The intensity during the endurance performance under laboratory conditions was generally high. The participants cycled on a stationary cycling ergometer at 70% maximum oxygen uptake (VO_2max) (McConell, *et al.,* 1997), at 80% VO_2max (Below, *et al.,* 1995) 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 cycling ergometer (Cheuvront, *et al.,* 2005; McConell, *et al.,* 1997) or on a rowing ergometer (Slater, *et al.,* 2005). Other participants were running at 70% VO_2max on a treadmill (Fallowfield, *et al.,* 1996) or rowing on a rowing ergometer at maximum intensity (Burge *et al.,* 1993).

Apart from 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 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 six hours (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 performance - where ultra-endurance is defined as a performance lasting for six hours or longer (Zaryski & Smith, 2001) - and performance in an ultra-endurance race. The change in body mass has been investigated in ultra-endurance athletes; however, the effect of a loss in body mass on ultra-endurance performance has almost not been explored yet. Sharwood, Collins, Goedecke, Wilson, and Noakes (2002) found no evidence that a loss in body mass or dehydration was related to an impaired performance in 297 Ironman triathletes. In contrast, those athletes who lost the most body weight completed the race in the shortest time. 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 within 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, respectively) was the fastest one (Zouhal, *et al.,* 2009).

In recent years, several studies were performed to investigate the changes in both body mass and hydration status in ultra-endurance athletes (Kao, *et al.,* 2008; Knechtle, Wirth, Knechtle, & Rosemann, 2009d; Knechtle, Knechtle, Rosemann, & Senn, 2009c; Knechtle, Knechtle, Rosemann, & Senn, 2010c; Knechtle *et al.,* 2010d; 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) and 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 an ultra-endurance performance as has been shown for 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 described (Knechtle, Knechtle, Kaul, & Kohler, 2009b). It might be assumed 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 seems 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) 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.* (2008) and Zouhal *et al.* (2009) with 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 100-km ultra-marathoners.

The aims of the present observational field study on a sample of 219 recreational male 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 running speed was impaired in case of a decrease in body mass. Based upon the findings in 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 in a 100-km ultra-marathon, the ‘100-km-Lauf Biel’ in Biel, Switzerland, in order to increase the sample size. The Race Director contacted all the participants, in the years 2007 to 2011, via a separate newsletter at the time of the inscription to the race, in which they were asked to participate in the study. About 1,300 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 five-year period. The participants were informed of the procedures and gave their informed written 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 the night from Friday to Saturday of the first weekend in June. The athletes start the 100-km ultra-marathon on Friday at 10:00 p.m. They have to climb a total altitude of 645 metres. During these 100 km, the organizer provided 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. The athletes were allowed to be supported by a cyclist in order to have additional food and clothing, if necessary. In all five years, the general weather conditions were comparable, with the temperature at the start being 15 °C to 18 °C, night lows of 8 °C to 10 °C, and daily highs of 25 °C to 28 °C the following day. 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 second day.

Measurements and Calculations

Upon inscription to the investigation, the participants were instructed to keep a comprehensive training diary until the start of the race. All training units in running 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 skin-folds (*i.e.* mid-upper arm, abdominal, mid-thigh, and mid-calf) on the right side of the body were measured. With these anthropometric measurements, skeletal muscle mass and fat mass were estimated.

Body mass was measured after voiding of the urinary bladder using a commercial scale (Beurer BF 15, Beurer GmbH, Ulm, Germany) to the nearest 0.1 kg. The participants were weighed in their running dress without shoes; the scale was pre- and post-race at the same place. Body 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 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 calliper measures with a constant pressure of 0.1 Mpa ± 5% over the whole measuring range. One trained investigator took all the anthropometric measurements. The skin-fold measurements were taken three times and the mean was then used for the analyses. The skin-fold measurements were standardized to ensure reliability and readings were performed 4 s after applying the calliper, according to Becque, Katch, and Moffat (1986). An intra-tester reliability check was conducted on 27 male ultra-runners prior to testing (Knechtle *et al.,* 2010b). 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 the skin-fold thicknesses.

Skeletal muscle mass was estimated using the formula following Lee *et al.* (2000) with skeletal muscle mass = Ht x ($0.00744 \times CAG^2 + 0.00088 \times CTG^2 + 0.00441 \times CCG^2$) + 2.4 x sex – 0.048 x age + race + 7.8 where Ht = body height, CAG = skin-fold-corrected upper arm girth, CTG = skin-fold-corrected thigh girth, CCG = skin-fold-corrected calf girth, sex = 1 for male and 0 for female, 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 MRI (magnetic resonance imagining) evaluation. Fat mass was estimated using the anthropometric method of Stewart and Hannan (2000) with fat mass (g) = 331.5 x (abdominal) + 356.2 x (thigh) + 111.9 m – 9108 where abdominal is the thickness of abdominal skin-fold in mm, thigh is the thickness of thigh skin-fold in mm and m is body mass in kg. Changes (Δ) in total body water were estimated using the equation Δ total body water = Δ body mass – (Δ skeletal muscle mass + Δ fat mass) following Weschler (2005).

At the same time of the anthropometric measurements, samples of blood and urine were collected. Capillary blood samples were taken from the fingertip and both plasma [Na^+] and haematocrit were analysed using the i-STAT® 1 System (Abbott Laboratories, Abbott Park, IL, USA). Athletes were sitting for blood sampling and standardisation of posture prior to blood collection was respected 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 levels of haematocrit following the equation of Beaumont (1972). Urine specific gravity was analysed using 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 which they carried with them during the run. At each aid station, they marked the number of the consumed cups. 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 deviation (*s*). Pre- and post-race results were compared using paired t-test. 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

A total of 239 participants started the race, 20 participants dropped out during the ultra-marathon due to over-use injuries of the lower limbs. The 219 successful finishers completed the 100-km ultra-marathon within 713 (*s* = 123) min, running at an average speed of 8.6 (*s* = 1.4) km/h. Table 1 shows the age, anthropometric and training characteristics of the participants.

During the run, the successful finishers lost 1.9 (*s* = 1.4) kg of body mass ($P < 0.001$), 0.7 (*s* = 1.0) kg of predicted skeletal muscle mass ($P < 0.001$), 0.2 (*s* = 1.3) kg of predicted fat mass ($P < 0.05$) and 0.9 (*s* = 1.6) L of predicted total body water ($P < 0.001$) (Table 2). Expressed in percent, the athletes lost 2.5 (*s* = 1.8) % in body mass. The change in body mass varied between – 8 % loss in body mass to + 3 % increase 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, the 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 showed, however, no association with running speed ($P > 0.05$).

Urine specific gravity increased ($P < 0.001$) (Table 2). The change in urine specific gravity showed no association with the change in body mass, the change in predicted skeletal muscle and 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 both the change in plasma [Na^+] and 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 to the change in plasma volume (Figure 6).

While running, the athletes consumed a total of 7.6 ($s = 2.6$) L of fluids during the ultra-marathon, equal to 0.65 ($s = 0.27$) L/h. Fluid intake was significantly and positively related to both running speed (Figure 7) and the change in body mass (Figure 8), but neither to post-race plasma [Na^+] nor to the change in plasma [Na^+] ($P > 0.05$).

Discussion

This study aimed to investigate whether a 100-km ultra-marathon leads to a decrease in body mass and whether a loss in body mass would impair 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 acknowledge that (*i*) a significant correlation does not prove cause and effect and (*ii*) the *r*-values in the presented correlations were rather weak with a range of *r*-values from 0.16 to 0.42. The main findings 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.

These findings are concurrent and 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 rather 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, Shireffs, & Leiper, 2007; Nolte, Noakes, & Van Buuren, 2011). An ultra-endurance performance may lead to a decrease in solid mass such as predicted fat mass (Knechtle, *et al.,* 2009a; 2009d; 2009e; 2010c; 2011a) and predicted skeletal muscle mass (Knechtle, *et al.,* 2009c; 2009d; 2010a; 2010c) as has been confirmed in the present participants. In a very recent study on half-marathoners and ultra-marathoners, the change in body mass in both distances exceeded the change in total body water, indicating that water losses alone did not explain all 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 on 181 male Ironman triathletes, plasma volume and serum [Na^+] were maintained 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 variable to determine changes in hydration status among different other possibilities. 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 rather 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 were drinking more than slower runners. Although faster runners were drinking more each hour, they were losing 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, *et al.,* 1970; Noakes, 1995). Recent studies investigating fluid intake and exercise-associated hyponatremia in marathoners performed no correlation analyses between fluid intake and running speed (Almond, *et al.,* 2005; Kipps, Sharma, & Pedoe, 2011; Mettler, *et al.,* 2008). Chorley, Cianca, and Divine (2007) reported a significant interaction between gender and finish time that affects the total number of cups of fluid consumed. Slower males drank more cups than faster males, a relationship not present in females. In the present ultra-marathoners, the faster runners – although drinking more – lost 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. 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.

The environmental conditions are most probably an important variable for both body mass loss and fluid intake. The ambient temperature might be responsible whether a decrease in body mass is associated with running speed. It is possible that in those field studies with no effect of increasing losses in body weight on race performance (Byrne, *et al.,* 2006; Knechtle, *et al.,* 2010d; Laursen, *et al.,* 2006; Nolte, Noakes, and 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) investigating 17 trail runners competing for 12 km in the heat at ~26 °C, dehydration impaired endurance performance. Ely, Cheuvront, Roberts, and 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 where performance was more negatively affected for the slower runners. Also Vihma (2010) 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 where the effect was more marked in faster runners.

The ambient temperature might therefore be responsible that we found an association between body mass losses and running speed in these 100-km ultra-marathoners while running during the night at mean temperatures of ~10 °C. Laboratory (Galloway & Maughan, 1997) and field data (Trapasso & Cooper, 1989; Zhang, Meng, Wang, & Li, 1992) support an ‘optimal’ ambient air temperature threshold of ~12°C; above or below this temperature, performance is relatively impaired (Galloway & Maughan, 1997). Higher temperatures are detrimental to endurance performance compared to 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 temperatures (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-hour and 24-hour 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-hour run, body weight changes were not related to running speed whereas in the 23 participants in the 24-hour race, body weight loss was significantly and positively associated with running speed. All their runners with a body weight loss of > 7 % body mass ran more than 200 km in the 24 hours. Their findings were in accordance to 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', high levels of body weight loss did not affect performance (Zouhal, *et al.,* 2009).

Limitations and implications for future research

We collected data in five subsequent years where 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, VO_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. The determination of body mass is limited since we measured only to the nearest 0.1 kg. Body mass changes are influenced by fluid intake, sweat loss, urine loss and food consumption. Although the athletes voided their urinary bladder prior to weighing, we were not able to account for faecal losses during the race and prior to 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 parameter urine specific gravity for hydration status is limited under these circumstances (Armstrong, 2007; Armstrong, *et al.,* 2010). The faster ultra-marathoners were running through the night with rather low temperatures and 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 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. The decrease in both estimated skeletal muscle mass and estimated fat mass requires future confirmations using DEXA (Dual-emission X-ray absorptiometry) scans.

Conclusions

To summarize, the main findings 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 had most probably a higher sweat rate, lost therefore more fluids and drank consequently more fluids. The concept that a loss of > 2 % in body mass leads to dehydration and consequently impairs running speed must be questioned for ultra-marathoners competing in the field at ambient temperatures of 15 °C to 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 may 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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Variable	**Result**
Age (years)	46.2 (9.3)
Body mass (kg)	75.0 (9.4)
Body height (m)	1.78 (0.06)
Body mass index (kg/m^2)	23.4 (2.2)
Weekly running hours (h)	8.2 (8.1)
Weekly running kilometres (km)	69.6 (27.6)
Running speed during training (km/h)	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 1: Age, anthropometric and training characteristics of the participants (n=219). Results are presented as mean (s).

	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 (mmol/L)	137.7 (2.3)	138.6 (2.7)	+ 0.9 (3.4) *	+ 0.7 (2.4) *
Urine specific gravity (g/mL)	1.014 (0.008)	1.024 (0.007)	+ 0.009 (0.007) ***	0.9 (0.8) ***

Table 2: Changes of anthropometric and laboratory parameters for the 219 participants. Results are presented as mean (*s*). * = $P < 0.05$, *** = $P < 0.001$.

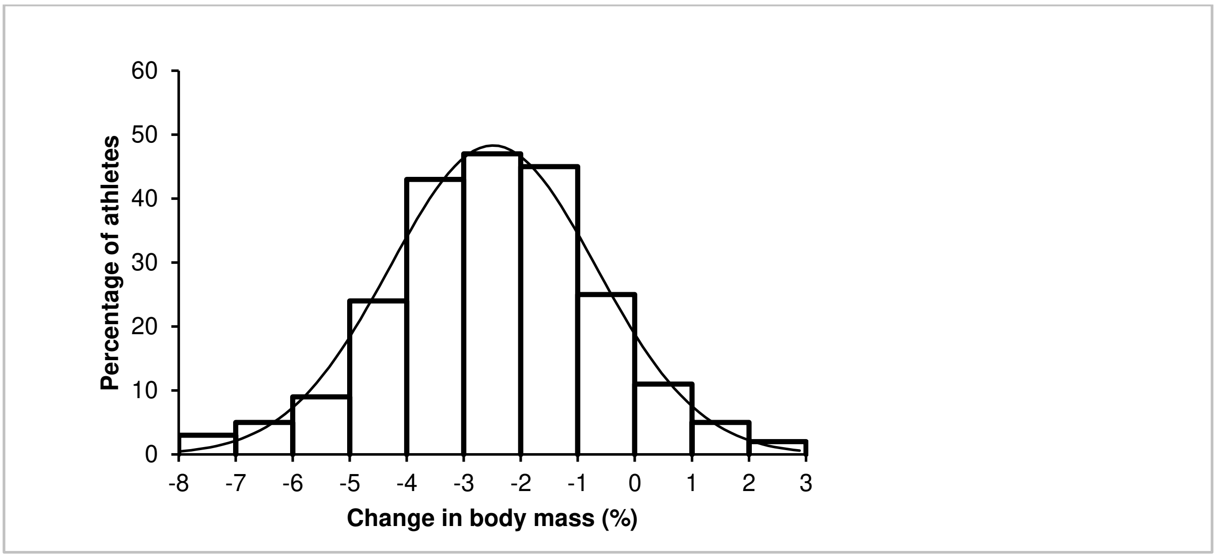

Figure 1: The distribution of percent changes in body mass (*n*=219).

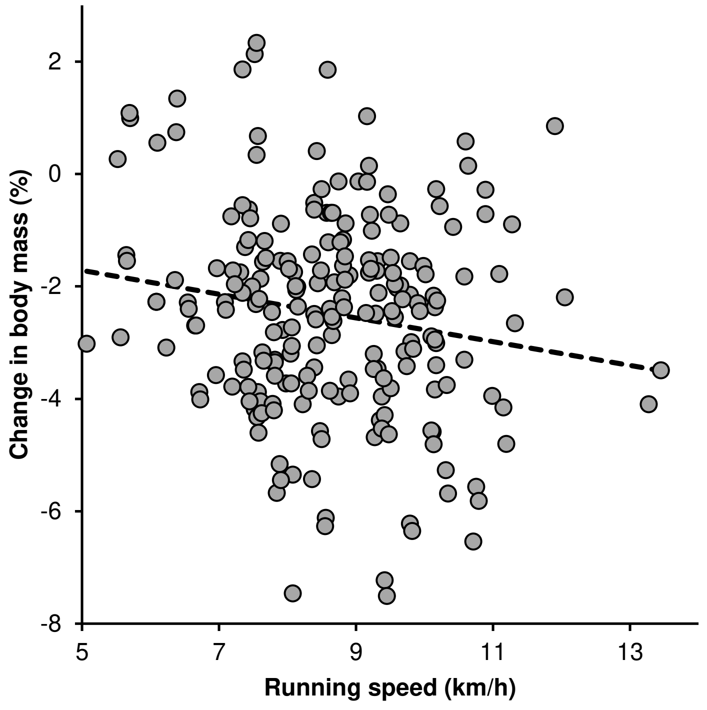

Figure 2: The change in body mass was significantly and negatively related to running speed (*n*=219) ($r = -0.16$, $P < 0.05$).

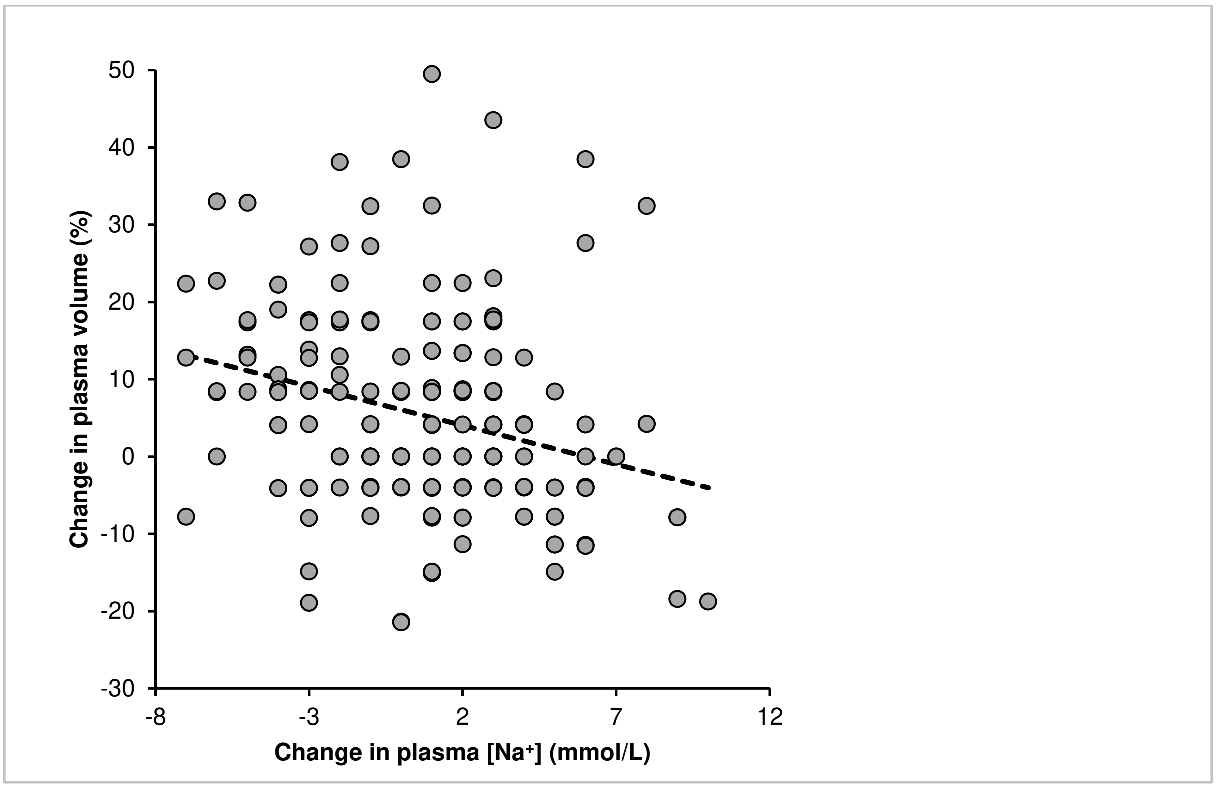

Figure 3: The change in plasma volume was significantly and negatively associated with the change in plasma [Na$^+$] (*n*=219) (*r* = - 0.28, *P* < 0.0001).

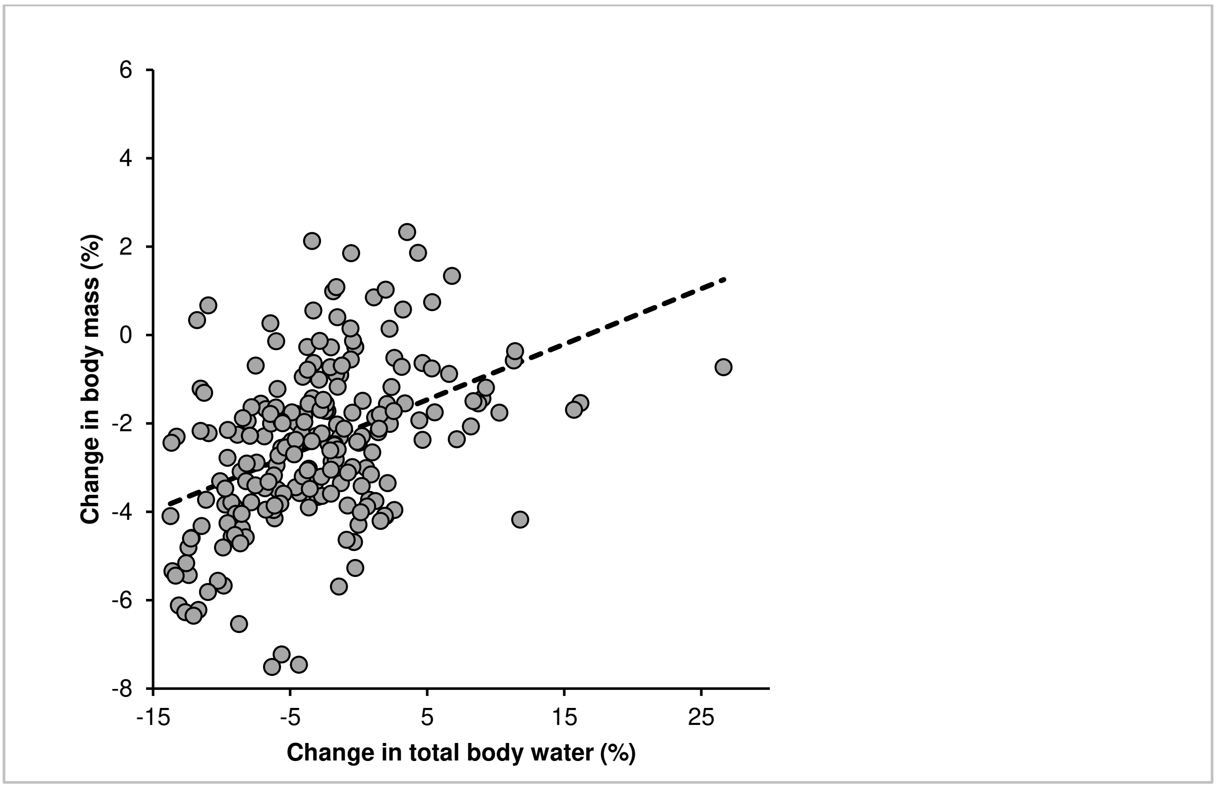

Figure 4: The change in body mass was significantly and positively associated with the change in predicted total body water (*n*=219) ($r = 0.42$, $P < 0.0001$).

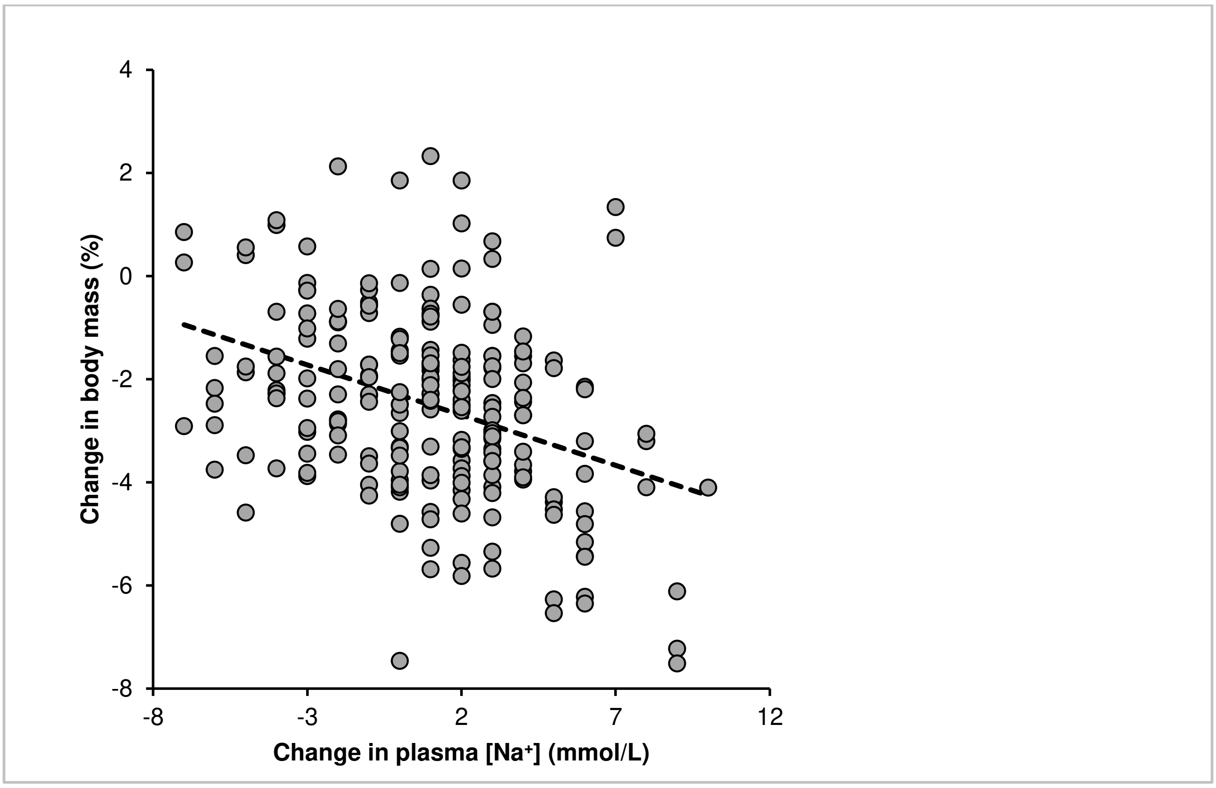

Figure 5: The change in body mass was significantly and negatively associated with the change in plasma [Na$^+$] (*n*=219) (r = - 0.36, P < 0.0001).

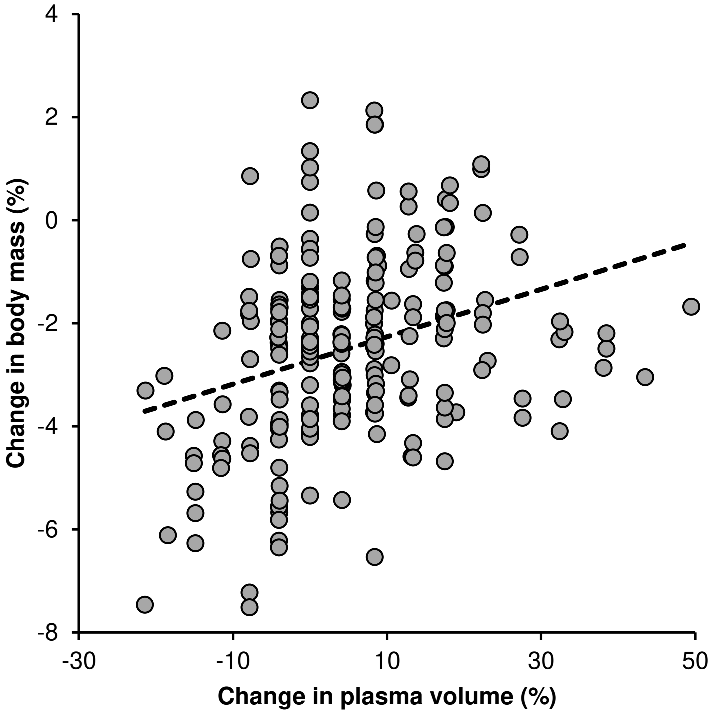

Figure 6: The change in plasma volume was significantly and positively associated with the change in body mass ($r = 0.31$, $P < 0.0001$).

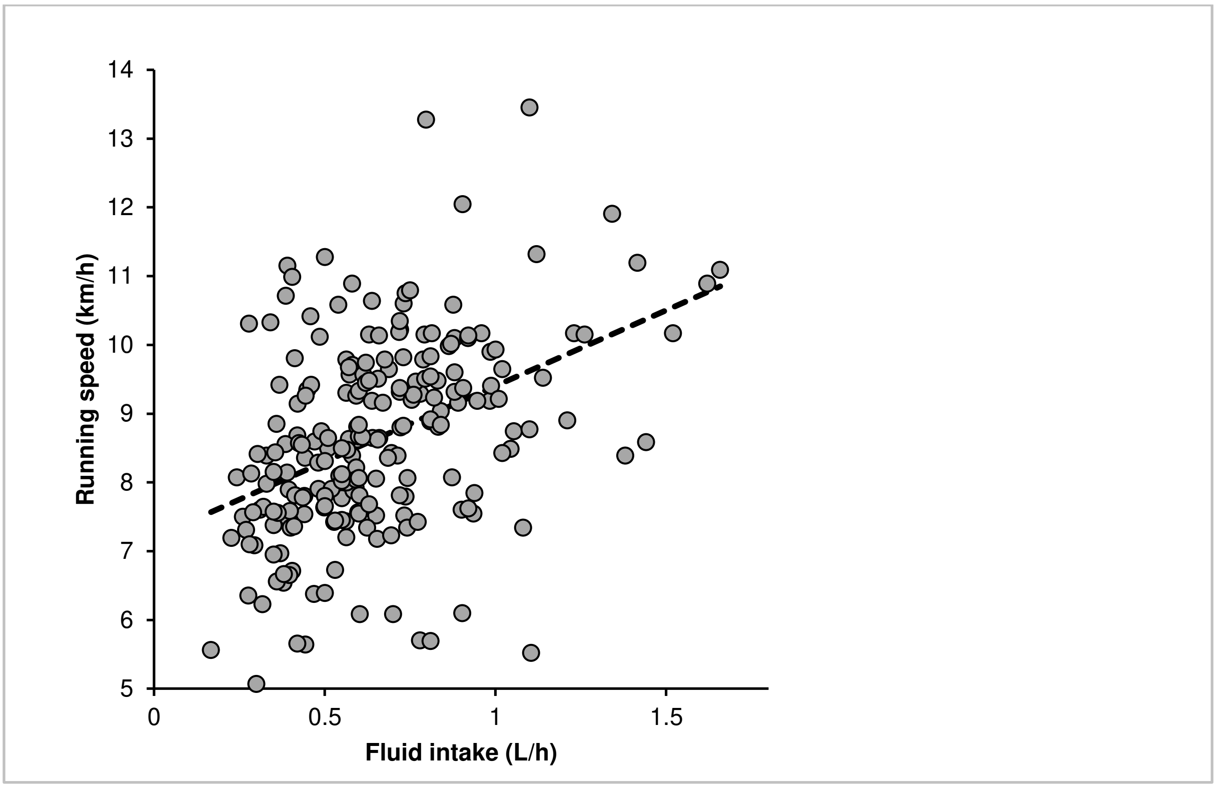

Figure 7: Fluid intake was significantly and positively related to running speed (*n*=219) (*r* = 0.42, *P* < 0.0001).

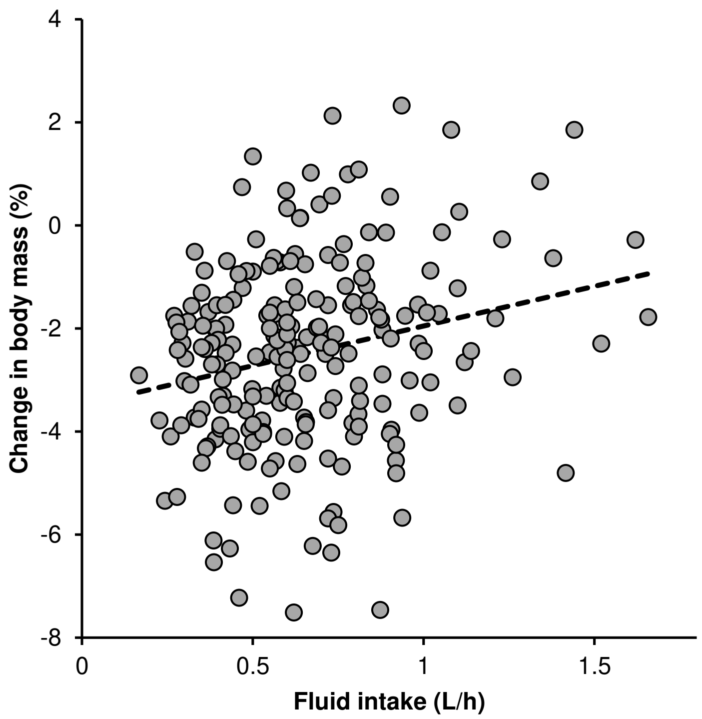

Figure 8: Fluid intake was significantly and positively related to the change in body mass (*n*=219) (*r* = 0.23, *P* = 0.0006).