

# Higher prevalence of exercise-associated hyponatremia in female than in male open-water ultra-endurance swimmers: the ‘Marathon-Swim’ in Lake Zurich

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**Abstract** We investigated the prevalence of exercise-associated hyponatremia (EAH) in 25 male and 11 female open-water ultra-endurance swimmers participating in the ‘Marathon-Swim’ in Lake Zurich, Switzerland, covering a distance of 26.4 km. Changes in body mass, fat mass, skeletal muscle mass, total body water, urine specific gravity, plasma sodium concentration  $[Na^+]$  and haematocrit were determined. Two males (8%) and four females (36%) developed EAH where one female was symptomatic with plasma sodium  $[Na^+]$  of 127 mmol/L. Body mass and plasma  $[Na^+]$  decreased ( $p < 0.05$ ). The changes in body mass correlated in both male and female swimmers to post-race plasma  $[Na^+]$  ( $r = -0.67$ ,  $p = 0.0002$  and  $r = -0.80$ ,  $p = 0.0034$ , respectively) and changes in plasma  $[Na^+]$  ( $r = -0.68$ ,  $p = 0.0002$  and  $r = -0.79$ ,  $p = 0.0039$ , respectively). Fluid intake was neither associated with changes in body mass, post-race plasma  $[Na^+]$  or the change in plasma  $[Na^+]$ . Sodium intake showed no association with either the changes in plasma  $[Na^+]$  or post-race plasma  $[Na^+]$ . We concluded that the prevalence of EAH was greater in female than in male open-water ultra-endurance swimmers.

**Keywords** Fluid intake · Sodium · Body mass · Electrolyte · Gender

## Introduction

The popularity of participation in ultra-endurance events such as ultra-marathons (Kim et al. 2007; Knechtle et al. 2010b, c; Lebus et al. 2010; Skenderi et al. 2006) and ultra-triathlons (Knechtle et al. 2010a; Lepers 2008) has increased considerably over the past decade. However, athletes in ultra-endurance races can face serious problems, such as exercise-associated hyponatremia (EAH) (Knechtle et al. 2011a; Lebus et al. 2010). In ultra-endurance events, EAH is one of the most common medical complications. In the scientific literature, EAH was first described in ultra-runners in South Africa by Noakes et al. (1985), and is defined as serum or plasma sodium concentration  $[Na^+] < 135$  mmol/L during or within 24 h post-race (Hew-Butler et al. 2005, 2008; Noakes et al. 2005). Athletes with EAH may present with symptoms such as weakness, confusion, headache, nausea or vomiting, leading to complications such as encephalopathy, seizures, and pulmonary oedema (Ayus et al. 2000; Hew-Butler et al. 2005; Speedy et al. 2001a). In some cases, EAH can lead to death due to cerebral oedema (Gardner 2002; Petzold et al. 2007). Alternatively, athletes may be asymptomatic despite serum  $[Na^+] < 135$  mmol/L (Hew et al. 2003; Knechtle et al. 2011a, b, c, d; Rosner and Kirven 2007).

Three main factors are responsible for the occurrence of EAH: (a) overdrinking due to biological or psychological factors; (b) inappropriate ADH secretion, in particular, the failure to suppress ADH-secretion in the face of an increase in total body water; and (c) a failure to mobilise  $Na^+$  from the osmotically inactive sodium stores or, alternatively,

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inappropriate osmotic inactivation of circulating  $\text{Na}^+$  (Noakes et al. 2005). The main reason for developing EAH is a behavioural condition such as overdrinking during an endurance performance (Noakes et al. 2005; Noakes 2011). Some studies showed that when athletes were encouraged to limit their fluid intakes and drinking only in response to thirst, no cases of EAH occurred (Noakes et al. 2004; Speedy et al. 2000). Fluid overload leads to EAH, and a correlation between an increase in body weight due to fluid overload and a decrease in serum  $[\text{Na}^+]$  has been described in several studies (Irving et al. 1991; Noakes et al. 2005; Speedy et al. 1999). In addition, gender is a risk factor for EAH since females are at a higher risk to develop EAH compared to males mainly due to their lower body weight (Rosner and Kirven 2007; Speedy et al. 2001a). In marathoners, the female runners in the study of Almond et al. (2005) were younger, had a lower pre-race weight, a lower body mass index, a slower training pace, less marathon experience and longer racing times compared with the males.

The extent of the prevalence of EAH seems to differ depending upon various other factors, such as the type of exercise, the previous athletic experience, the physical constitution of the athletes, the gender and the environmental conditions (Hew-Butler et al. 2005, 2008). In marathoners, the prevalence of EAH amounted to  $\sim 12$  and  $\sim 13\%$  (Almond et al. 2005; Kipps et al. 2011), respectively. In non-elite marathoners, the prevalence of EAH increased to  $\sim 22\%$  (Chorley et al. 2007). Apart from marathon running, studies of ultra-marathon performances such as Ironman triathlons have reported prevalence rates of EAH amounting up to  $\sim 29\%$  (Speedy et al. 1999).

There is abundant literature about the prevalence of EAH in marathoners (Almond et al. 2005; Chorley et al. 2007; Davis et al. 2001; Hew et al. 2003; Kipps et al. 2011), Ironman triathletes (Sharwood et al. 2004; Speedy et al. 1997a, b, 1999, 2001b), Triple Iron ultra-triathletes (Rüst et al. 2012) and ultra-marathoners (Lebus et al. 2010; Knechtle et al. 2010b, c), however, there are no data about the prevalence of EAH in male and female open-water ultra-endurance swimmers. In these races, the swimmers are followed by a support boat. This offers them the opportunity to consume food and fluid ad libitum, which may increase the risk of fluid overload. Since female endurance athletes hydrated more during a marathon (Hew 2005), developed a positive fluid balance (Chorley et al. 2007), showed a significant lower post-race  $[\text{Na}^+]$  after an Ironman triathlon (Speedy et al. 1999) and EAH was more frequently found in females (Almond et al. 2005; Davis et al. 2001), we investigated both male and female open-water ultra-swimmers. We aimed, therefore, to investigate the prevalence of EAH in both male and female open-water ultra-endurance swimmers in the

longest open-water ultra-swim in Europe, the ‘Marathon Swim’ in Lake Zurich, Switzerland, covering a total distance of 26.4 km. In case of an excessive fluid intake with fluid overload (Hew-Butler et al. 2005, 2008; Noakes et al. 2005) we expected post-race a stable or possibly increased body mass (Speedy et al. 1997a, b) and a decrease in plasma  $[\text{Na}^+]$  (Hew 2005; Noakes et al. 2005). Regarding all the present literature on EAH, we hypothesised that female ultra-endurance swimmers would be younger, have a lower pre-race body mass, a lower body mass index, a slower training pace, compete more slowly, drink more while racing and show a higher prevalence for EAH compared to male ultra-swimmers.

## Materials and methods

### The subjects

The participation in open-water ultra-endurance swimming such as the ‘Marathon Swim’ in Lake Zurich (<http://ch.srichinmoyraces.org/veranstaltungen/zhlake>) is rather low (Knechtle et al. 2010e). In order to increase the sample size, athletes in both the 2009 and 2010 ‘Marathon Swim’ were recruited. The organiser contacted all race participants 6 months before the start via a separate newsletter and informed them about the planned investigation. A total of 25 male with (mean and standard deviation) 39.7 (8.5) years of age, 84.1 (10.2) kg of body mass, 1.80 (0.07) m of body height and a body mass index of 25.8 (3.1)  $\text{kg}/\text{m}^2$  as well as 11 female swimmers with 40.0 (13.7) years of age, 67.5 (6.3) kg of body mass, 1.66 (0.03) m of body height and a body mass index of 24.3 (2.3)  $\text{kg}/\text{m}^2$  volunteered to participate in the analysis. All subjects were informed of the experimental 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. All participants finished the race successfully within the time limit of 12 h. Table 1 represents the anthropometric data of the athletes, Table 2 their pre-race experience and training.

### The race

The ‘Marathon Swim’ in Lake Zurich usually takes place on the first weekend in August and  $\sim 20$  male and  $\sim 15$  female solo swimmers generally start (Knechtle et al. 2010e). The field of participants is strictly limited because of the number of boats available for support, and athletes from all over the World compete in this race. Generally, the ultra-swimmers use the ‘Marathon Swim’ in Lake Zurich in preparation for crossing the Channel between Dover (England) and Calais (France). The swimmers start in the

**Table 1** Age and anthropometric characteristics of the swimmers

|                                      | Male swimmers<br>(n = 25) | Female swimmers<br>(n = 11) |
|--------------------------------------|---------------------------|-----------------------------|
| Age (years)                          | 39.7 (8.5)                | 40.0 (13.7)                 |
| Body mass (kg)                       | 84.1 (10.2)*              | 67.5 (6.3)                  |
| Skeletal muscle mass (kg)            | 42.0 (3.2)*               | 29.4 (2.2)                  |
| Fat mass (kg)                        | 12.3 (5.5)*               | 20.9 (4.4)                  |
| Percent body fat (%)                 | 18.8 (4.5)**              | 30.7 (3.7)                  |
| Body height (m)                      | 1.80 (0.07)*              | 1.66 (0.03)                 |
| Body mass index (kg/m <sup>2</sup> ) | 25.8 (3.1)                | 24.3 (2.3)                  |

Results are presented as mean (SD)

\*  $p < 0.05$ , \*\*  $p < 0.01$

**Table 2** Pre-race experience and training parameters of the swimmers

|   | Male swimmers<br>(n = 25) | Female swimmers<br>(n = 11) |
|---|---------------------------|-----------------------------|
| Years as active swimmer                       | 15.8 (14.3)               | 13.3 (6.3)                  |
| Number of swim training units per week        | 4.6 (1.1)                 | 5.0 (2.2)                   |
| Duration per unit (min)                       | 80.2 (22.3)               | 89.1 (38.3)                 |
| Number of kilometres of swimming per unit     | 4.5 (1.9)                 | 5.0 (3.5)                   |
| Speed in swimming during training (km/h)      | 3.4 (0.5)                 | 3.3 (0.6)                   |
| Number of swimming hours per week in training | 8.1 (4.5)                 | 7.3 (3.6)                   |
| Minimal distance in swimming per week (km)    | 9.4 (9.8)                 | 8.7 (8.3)                   |
| Maximal distance in swimming per week (km)    | 30.9 (19.4)               | 21.3 (14.2)                 |
| Average distance in swimming per week (km)    | 20.5 (9.9)                | 18.4 (9.7)                  |

Results are presented as mean (SD)

No differences were found between the genders

morning at 07:00 a.m. at Rapperswil and have to swim to Zurich covering a total distance of 26.4 km. However, the distance may vary for each swimmer depending upon currents and can be up to 30 km. The athletes have to be followed by a support boat with a crew providing nutrition and fluid. The details of the weather conditions are reported in Table 3 for both years.

#### Measurements and calculations

On the evening before the start of the race, and immediately after finishing, every participant underwent determination of anthropometric characteristics, such as body mass, body height, circumferences of limbs and thicknesses of skin-folds. At the same time, samples of capillary blood and

**Table 3** General weather conditions during the race. Data was generously provided by Lake Police Zurich, Switzerland

|                        | Start at 07:00 |      | 12:00 |      | Finish at 19:00 |      |
|------------------------|----------------|------|-------|------|-----------------|------|
|                        | 2009           | 2010 | 2009  | 2010 | 2009            | 2010 |
| Air temperature (°C)   | 20.4           | 18.5 | 24.5  | 23.3 | 28.1            | 27.5 |
| Water temperature (°C) | 23.1           | 22.9 | 23.3  | 23.0 | 24.1            | 23.5 |
| Relative Humidity (%)  | 73             | 93   | 55    | 52   | 42              | 44   |

urine were taken. The procedure of the pre- and post-race measurements was identical.

Body mass was measured to the nearest 0.1 kg using a commercial scale (Beurer BF 15, Beurer GmbH, Ulm, Germany) after voiding the bladder. Body height was determined using a stadiometer to the nearest 0.01 m. Body mass index was calculated using body mass and body height. The circumferences of upper arm, thigh and calf were measured on the right side of the body to the nearest 0.01 cm using a non-elastic tape measure (cm) (KaWe CE, Kirchner und Welhelm, Germany). The circumference of the upper arm was measured at mid-upper arm, the circumference of thigh at mid-thigh and the circumference of calf at mid-calf. Skin-fold thicknesses were measured on the right side of the body and recorded to the nearest 0.2 mm using a skin-fold calliper (GPM-Hautfaltenmessgerät, Siber & Hegner, Zurich, Switzerland). One trained investigator took all the measurements. The skin-fold measurements were taken three times and the mean was then used for the analyses. The skin-fold measurements were standardised to ensure reliability and readings were performed 4 s after applying the calliper, according to Becque et al. (1986). Intra- and inter-investigator agreement was assessed using data from 27 male and 11 female runners, based on measurements taken by two experienced primary care physicians (Knechtle et al. 2010f). Intra-class correlation (ICC) within the two investigators was excellent for all anatomical measurement sites and for various summary measurements of skin-fold thicknesses (ICC > 0.9). Agreement tended to be higher within than between investigators, but still reached excellent reliability (ICC > 0.9) for the summary measurements of skin-fold thicknesses.

Percent body fat was estimated using an anthropometric method for both males (Ball et al. 2004a) and females (Ball et al. 2004b). Percent body fat was estimated by using the equation for the general population for males following Ball et al. (2004a) where percent body fat =  $0.465 + 0.180 \times (\Sigma 7SF) - 0.0002406 * (\Sigma 7SF)^2 + 0.0661 \times (\text{age})$  with  $\Sigma 7SF$  being the sum of skin-fold thickness of pectoralis, axillar, triceps, subscapular, abdomen, suprailiac and thigh mean in mm, and age being in years. For females, percent body fat

was estimated by using the equation for the general population for females where percent body fat =  $-6.40665 + 0.41946 \times (\Sigma 3SF) - 0.00126 \times (\Sigma 3SF)^2 + 0.1215 \times (\text{hip}) + 0.0673 \times (\text{age})$  with  $\Sigma 3SF$  = sum of triceps, suprailiac and thigh skin-fold thickness, hip = circumference of hip in cm, and age = years, following Ball et al. (2004b). Skeletal muscle mass was estimated in kg using the anthropometric equation of Lee et al. (2000) with skeletal muscle mass =  $\text{Ht} \times (0.00744 \times \text{CAG}^2 + 0.00088 \times \text{CTG}^2 + 0.00441 \times \text{CCG}^2) + 2.4 \times \text{sex} - 0.048 \times \text{age} + \text{race} + 7.8$ , where Ht = height, CAG = skin-fold-corrected upper arm girth, CTG = skin-fold-corrected thigh girth, CCG = skin-fold-corrected calf girth, sex = 0 for female and 1 for male; age in years; race = 0 for white and 1 for non-white men. In addition, we estimated fat-free mass in kg for male athletes using the equation from Stewart and Hannan (2000), where fat-free mass (g) =  $888 \times m - 252 \times (\text{abdominal}) - 382 \times (\text{suprailium}) - 335 \times (\text{thigh}) + 9120$  where  $m$  is mass in kilograms and skin-folds are in millimetres. Fat-free mass was estimated in kg for females according to Warner et al. (2004), with fat-free mass (kg) =  $8.51 + (0.809 \times \text{weight}) - (0.178 \times \text{abdominal skin-fold}) - (0.225 \times \text{thigh skin-fold})$ . Fat mass was estimated using this data. In addition, the change ( $\Delta$ ) in total body water was estimated using the equation  $\Delta \text{ total body water} = \Delta \text{ body mass} - (\Delta \text{ skeletal muscle mass} + \Delta \text{ fat mass})$  following Weschler (2005).

Samples of urine were collected for the determination of urine specific gravity. Urine specific gravity was analysed using Clinitek Atlas<sup>®</sup> Automated Urine Chemistry Analyzer (Siemens Healthcare Diagnostics, Deerfield, IL, USA). Capillary blood samples of 80  $\mu\text{l}$  were taken from the fingertip to determine haematocrit and plasma  $[\text{Na}^+]$ . Plasma  $[\text{Na}^+]$  and haematocrit were immediately analysed using the i-STAT<sup>®</sup> 1 System (Abbott Laboratories, Abbott Park, IL, USA). Standardisation of posture prior to blood collection was respected since postural changes can influence blood volume and therefore haemoglobin concentration and haematocrit (Theodoridis and Lee 1995). Changes in plasma volume were determined from the pre- and post-race haematocrit values according to Beaumont (1972).

During the swim, the support crews recorded the intake of fluid and solid nutrition of their athlete. They also reported the intake of ergogenic supplements and non-steroidal anti-inflammatory drugs. Ingestion of water, sodium and calories were estimated according to the reports of the athletes, using a food table (Kirchhoff 2002). We assumed there was no great unintentional water intake while swimming in the lake. Energy expenditure during the event was estimated using a stepwise calculation of body mass, mean velocity and time spent swimming (Williams 1995).

The athletes kept a training diary upon inscription to the study, recording their training units in swimming, showing the duration in minutes and distance in kilometres, until the

start of the race. Furthermore, they recorded their years as an active swimmer. All swimmers were trained and experienced open-water ultra-endurance swimmers. Three of the swimmers had already crossed the Channel, and two were preparing to do so. Upon arrival for the post-race measurements, the athletes were asked for any symptoms of EAH (Hew-Butler et al. 2008; Rosner and Kirven 2007).

#### Statistical analysis

Results are presented as mean and standard deviation (SD). The Mann–Whitney  $U$  test was used to check for significant differences between males and females. The paired  $t$  test was used to check for significant changes of the parameters before and after the race. Correlation analysis was used to check for associations between parameters with statistically significant changes. Significance was set at a level of 0.01 and 0.05, respectively.

## Results

### Comparison of anthropometry, training and performance

The male swimmers were taller and heavier, had less fat mass and more skeletal muscle mass compared with the females (see Table 1). Considering pre-race experience and training (see Table 2), as well as the intake of energy, fluids and electrolytes during the race (see Table 4), no differences were found between the sexes. The males finished the 26.4 km swim within 8:48.8 (1:57.7) h:min, swimming at a speed of 3.0 (0.5) km/h. The females performed within 9:59.9 (2:33.4) h:min, swimming at a speed of 2.8 (0.7) km/h. Males were not faster than females.

### Change in body mass and laboratory parameters

Table 5 summarises the changes in solid masses, total body water and laboratory parameters for all subjects. In the males, body mass and skeletal muscle mass decreased, total body water and haematocrit increased, plasma  $[\text{Na}^+]$  and urine specific gravity decreased. Plasma volume decreased by 6.3 (9.2)%, the change in plasma volume was not associated with race time. Pre-race body mass was not related to post-race plasma  $[\text{Na}^+]$ . The change in body mass correlated to both post-race plasma  $[\text{Na}^+]$  and the change in plasma  $[\text{Na}^+]$  (see Fig. 1). The change in body mass was not related to finishing times. Post-race plasma  $[\text{Na}^+]$  correlated to the change in plasma  $[\text{Na}^+]$  ( $r = 0.78$ ,  $p < 0.0001$ ). The change in body mass was not associated with the change in urine specific gravity. Race time was not associated with either post-race plasma  $[\text{Na}^+]$  or the change in plasma  $[\text{Na}^+]$ . For the females, body mass, skeletal muscle mass, fat mass, total body water

**Table 4** Intake of energy, fluid and electrolyte for male and female swimmers

|                                  | Absolute           | Relative per kg body mass | Relative per h of race time |
|----------------------------------|--------------------|---------------------------|-----------------------------|
| Male swimmers ( <i>n</i> = 25)   |                    |                           |                             |
| Energy intake                    | 2,839 (1,415) kcal | 33.9 (16.2) kcal/kg       | 325.2 (174.6) kcal/h        |
| Fluid intake                     | 5.1 (2.6) L        | 0.06 (0.03) L/kg          | 0.56 (0.22) L/h             |
| Sodium intake                    | 1,829 (1,172) mg   | 21.7 (13.3) mg/kg         | 201.3 (108.4) mg/h          |
| Female swimmers ( <i>n</i> = 11) |                    |                           |                             |
| Energy intake                    | 1,901 (943) kcal   | 29.1 (15.9) kcal/kg       | 199.3 (104.1) kcal/h        |
| Fluid intake                     | 4.3 (1.8) L        | 0.06 (0.03) L/kg          | 0.44 (0.17) L/h             |
| Sodium intake                    | 1,324 (711) mg     | 20.3 (12.1) mg/kg         | 142.7 (83.7) mg/h           |

No differences were found between the genders

**Table 5** Changes in body mass, muscle mass, fat mass, body water and laboratory parameters in male and female swimmers

|                                  | Pre-race      | Post-race     | Change absolute | Change in %  |
|----------------------------------|---------------|---------------|-----------------|--------------|
| Male swimmers ( <i>n</i> = 25)   |               |               |                 |              |
| Body mass (kg)                   | 84.1 (10.2)   | 83.6 (10.4)   | −0.5 (0.9)*     | −0.5 (1.1)   |
| Skeletal muscle mass (kg)        | 42.0 (3.2)    | 41.3 (3.1)    | −0.7 (0.7)**    | −1.5 (1.7)   |
| Fat mass (kg)                    | 12.3 (5.5)    | 12.3 (6.3)    | −0.0 (1.3)      | −1.6 (10.1)  |
| Body water (kg)                  | 29.7 (5.1)    | 30.4 (5.0)    | +0.6 (1.2)*     | +2.3 (4.5)   |
| Haematocrit (%)                  | 43.5 (2.9)    | 45.2 (2.7)    | +1.7 (2.5)**    | +4.2 (5.8)   |
| Plasma sodium (mmol/L)           | 140.0 (1.6)   | 137.8 (2.5)   | −2.2 (2.4)**    | −1.6 (1.7)   |
| Urine specific gravity (g/mL)    | 1.014 (0.008) | 1.011 (0.008) | −0.003 (0.007)* | −0.3 (0.7)   |
| Plasma volume                    |               |               |                 | −6.3 (9.2)   |
| Female swimmers ( <i>n</i> = 11) |               |               |                 |              |
| Body mass (kg)                   | 67.5 (6.3)    | 67.4 (5.8)    | −0.1 (1.0)      | −0.1 (1.6)   |
| Skeletal muscle mass (kg)        | 29.4 (2.2)    | 29.6 (2.9)    | +0.2 (2.5)      | +0.7 (8.6)   |
| Fat mass (kg)                    | 20.9 (4.4)    | 20.3 (5.7)    | −0.6 (2.5)      | −3.5 (13.4)  |
| Body water (kg)                  | 17.1 (1.9)    | 17.4 (1.0)    | +0.3 (1.5)      | +2.6 (9.8)   |
| Haematocrit (%)                  | 40.0 (2.8)    | 43.0 (4.3)    | +3.0 (3.0)**    | +7.5 (7.2)   |
| Plasma sodium (mmol/L)           | 139.3 (1.7)   | 135.2 (3.2)   | −4.1 (3.7)**    | −2.9 (2.7)   |
| Urine specific gravity (g/mL)    | 1.014 (0.006) | 1.012 (0.008) | −0.002 (0.006)  | −0.2 (0.6)   |
| Plasma volume                    |               |               |                 | −11.0 (10.6) |

Results are presented as mean (SD)

\*  $p < 0.05$ ; \*\*  $p < 0.01$

and urine specific gravity remained unchanged, haematocrit increased, and plasma  $[Na^+]$  decreased. Plasma volume decreased by 11.0 (10.6)%. The change in plasma volume was not associated with race time. Pre-race body mass was not related to post-race plasma  $[Na^+]$ . The change in body mass correlated to both post-race plasma  $[Na^+]$  and the change in plasma  $[Na^+]$  (see Fig. 2). Post-race plasma  $[Na^+]$  correlated to the change in plasma  $[Na^+]$  ( $r = 0.90$ ,  $p = 0.0002$ ). Race time was not associated with either post-race plasma  $[Na^+]$  or the change in plasma  $[Na^+]$ . Post-race plasma  $[Na^+]$  showed no difference between the sexes. Body mass was not related to race time for both males and females.

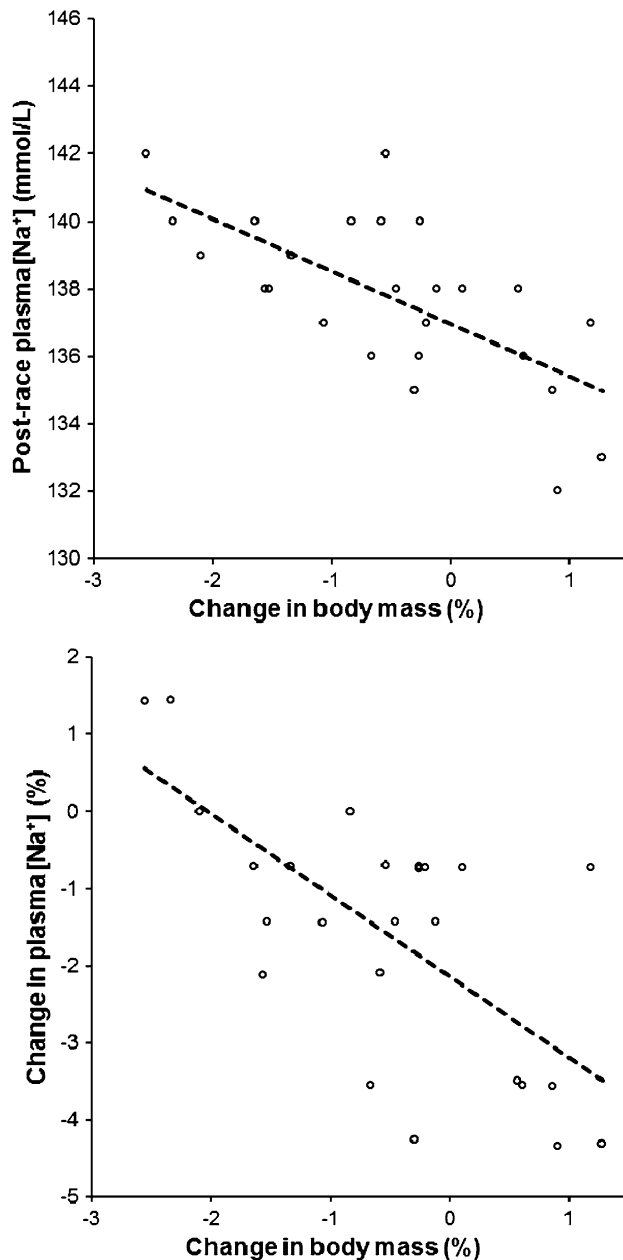
#### Prevalence of exercise-associated hyponatremia

In the males, two out of 25 swimmers (8%) developed asymptomatic EAH. In the females, four out of 11 partici-

pants (36%) developed EAH, though one female with post-race plasma  $[Na^+]$  of 127 mmol/L was symptomatic showing weakness, confusion and headache after finishing the race. Regarding both years of the race, one male swimmer with EAH competed in 2009 and another in 2010. Also for the females, two cases of EAH occurred in 2009 and two cases in 2010. Plasma  $[Na^+]$  was at 132 and 133 mmol/L (corresponding to a mild hyponatremia) for the two hyponatremic males. Plasma  $[Na^+]$  varied between 127 and 134 mmol/L (corresponding to a mild to medium hyponatremia) for the four hyponatremic females. No athlete showed hypernatremia defined as serum  $[Na^+] > 145$  mmol/L.

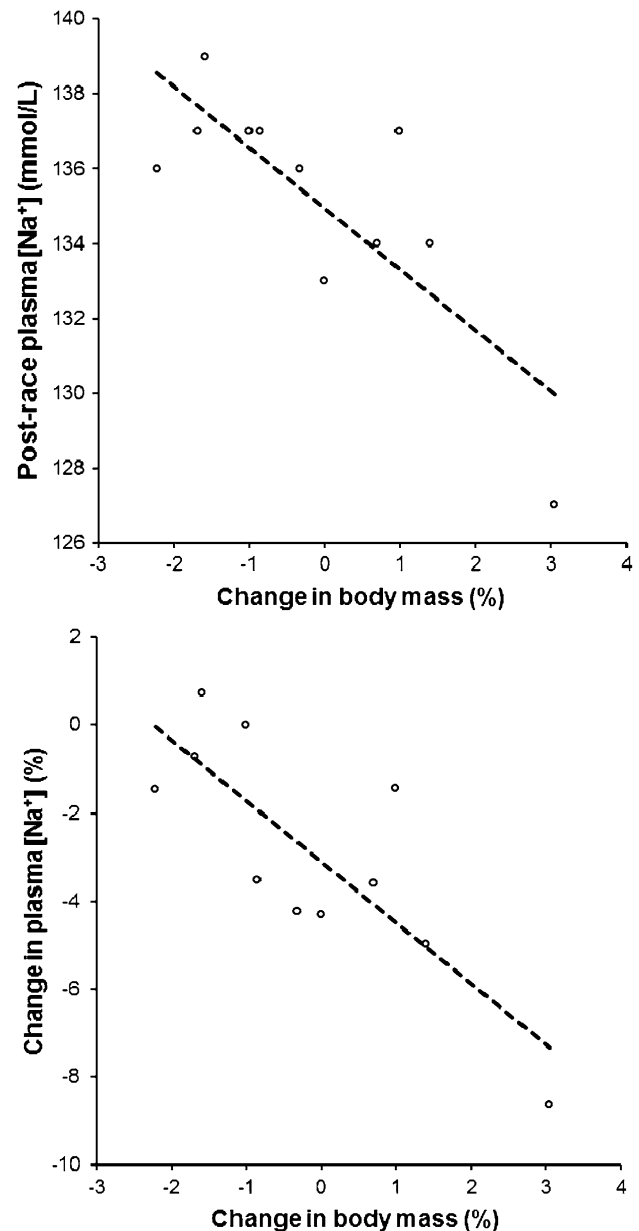
#### Intake of fluids, electrolytes and drugs

There was no difference in fluid intake between the sexes (see Table 4). Males consumed 0.56 (0.22) L/h, females



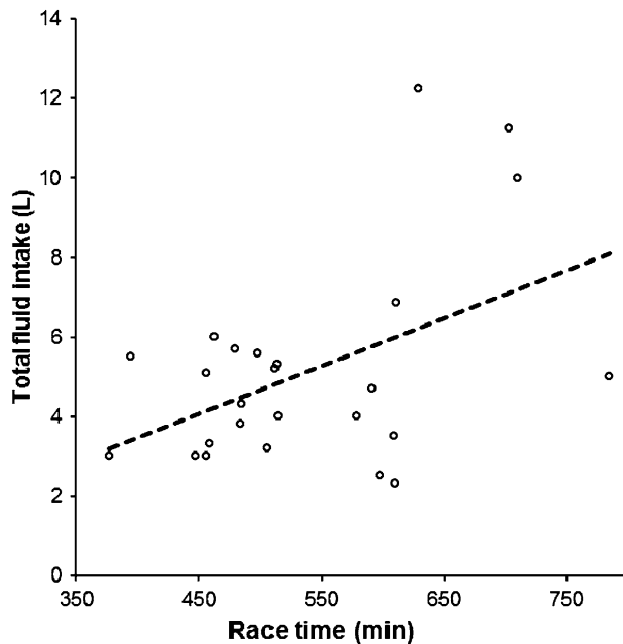
**Fig. 1** The change in body mass correlated significantly and negatively to post-race plasma  $[Na^+]$  ( $r = -0.67$ ,  $p = 0.0002$ ) and to the change in plasma  $[Na^+]$  ( $r = -0.68$ ,  $p = 0.0002$ ) in the males ( $n = 25$ )

0.44 (0.17) L/h. Also expressed as a rate, females consumed no more fluids than males [6.8 (2.9) vs. 6.8 (2.6) ml/min/kg, respectively]. In the males, total fluid intake was significantly and positively related to race time (see Fig. 3). Fluid intake was neither associated with pre-race body mass, the change in body mass, post-race plasma  $[Na^+]$ , the change in plasma  $[Na^+]$ , the change in plasma volume or with the change in haematocrit. In females, fluid intake was not related to race time. Fluid intake was neither associated with pre-race body mass, the change of body mass, post-



**Fig. 2** The change in body mass correlated significantly and negatively to post-race plasma  $[Na^+]$  ( $r = -0.80$ ,  $p = 0.0034$ ) and to the change in plasma  $[Na^+]$  ( $r = -0.79$ ,  $p = 0.0039$ ) in the females ( $n = 11$ )

race plasma  $[Na^+]$ , the change in plasma  $[Na^+]$ , the change in plasma volume or with the change in haematocrit. The change in plasma volume showed no association with either the change in urine specific gravity or with the change in body mass in either sex. No differences were found for sodium intake between the sexes (see Table 4). In the males, sodium intake during the competition was significantly and positively related to fluid intake ( $r = 0.67$ ,  $p = 0.0064$ ). Total sodium intake showed no association with either the change in plasma  $[Na^+]$  or post-race plasma



**Fig. 3** In the males, total fluid intake was significantly and positively related to finishing times ( $r = 0.47$ ,  $p = 0.0179$ ) ( $n = 25$ )

[ $\text{Na}^+$ ] in either sex. Three male and two female swimmers had to ingest non-steroidal anti-inflammatory drugs while swimming due to pain in their shoulders during the race.

#### Energy turnover

Energy turnover showed no difference between the sexes. Male swimmers ingested 2,839 (1,415) kcal and expended 6,554 (1,077) kcal resulting in an energy deficit of 3,715 (1,440) kcal. Female swimmers ingested 1,901 (943) kcal and expended 5,076 (374) kcal resulting in an energy deficit of 3,174 (1,247) kcal. The energy deficit was not related to the change in body mass in either sex.

#### Discussion

Regarding the present literature on EAH, it was hypothesised that female ultra-endurance swimmers would be younger, have a lower pre-race body mass, a lower body mass index, a slower training pace, compete slower, drink more while racing and show a higher prevalence of EAH compared with male ultra-endurance swimmers (Almond et al. 2005; Speedy et al. 2001a). Considering the risk factors for EAH, these female open-water ultra-endurance swimmers were not younger, did not train more slowly, or did they drink more compared with their male counterparts. However, the females had a lower body mass and a higher prevalence for EAH than the males. The prevalence of EAH was not higher in our male ultra-swimmers (8%)

compared with the prevalence rates of between 0.31% (Hew et al. 2003) and 13% (Almond et al. 2005) reported for marathoners. The total prevalence for EAH (17 %) for both males and females was about the same, as has been found in Ironman triathletes with rates of between 18 and 27.8% (Speedy et al. 1999, 2001a, b).

In general, EAH occurs in athletes who (a) drink to excess during exercise, (b) retain excess fluid because of inadequate suppression of antidiuretic hormone secretion, and (c) osmotically inactive circulation  $\text{Na}^+$  or fail to mobilize osmotically inactive sodium from internal stores (Noakes et al. 2005). Regarding the comparison of male and female athletes in the present study, the major finding was that the prevalence for EAH was considerably higher in female ultra-swimmers than in males. The females were drinking as much as the males but their requirements were probably less due to their lower body mass. When fluid intake was expressed as a rate in  $\text{ml}/\text{min}/\text{kg}$ , however, no differences were found between the sexes. Therefore, we assume that no fluid overload occurred either regarding to exercise duration or body mass.

Since the females were not drinking more compared to the males, retention of excess fluid intake due to inadequate suppression of the antidiuretic hormone secretion (SIADH) might be more common in females compared to males. It has recently been shown that females susceptible to hyponatremia retained more fluid and lost more sodium when both oestradiol and progesterone were elevated (Stachenfeld and Taylor 2009). Hew-Butler (2010) summarised recent studies regarding the relationship between antidiuretic hormone and sex showing that (a) neither sex nor menstrual phase affect basal levels the antidiuretic hormone in plasma; (b) males display a greater sensitivity of the antidiuretic hormone in response to osmolality in plasma; (c) the osmotic threshold for the release of the antidiuretic hormone was lowest during the luteal phase of the menstrual cycle when the concentration of oestrogens was highest; (d) the oestrogen-associated increase in the antidiuretic hormone did not contribute to fluid retention; and (e) oestrogens and progesterone alone or in combination likely alter the operating osmotic set-point but not overall water and sodium balance. Presumably, the menstrual cycle in the present females had an effect on the secretion of the antidiuretic hormone and thus led to the increased prevalence of EAH.

The prevalence of EAH might increase with increased race duration (Stuempfle 2010). With increasing length of a race, the risk to overconsume fluids might increase (Lebus et al. 2010; Rüst et al. 2012). A marathon can be completed within five to six hours and the prevalence of EAH is between 0.31% (Hew et al. 2003) and 13% (Almond et al. 2005). An Ironman triathlon takes about 11–12 h to complete and the prevalence of EAH varies from 0.6%

(Sharwood et al. 2002) to 30% (O'Toole et al. 1995). This might explain why our swimmers, competing between 8 and 10 h, had a prevalence of EAH of 8 and 36%, respectively, which was higher compared to reports on marathoners. In a very recent study including male and female 161-km ultra-marathoners, however, the prevalence of EAH amounted to ~50% (Lebus et al. 2010). The 45 male and female athletes in that study competed for ~26 h, considerably longer compared with our ultra-swimmers. Lebus et al. (2010) discussed the significantly longer nature of a 161-km ultra-marathon, compared with a marathon, as a main risk factor for the high prevalence of EAH. The finding that the prevalence of EAH increases with increasing length of an ultra-endurance performance could be confirmed in Triple Iron ultra-triathletes competing for ~48 h where prevalence of EAH was at 26% (Rüst et al. 2012).

Fluid overload leads to EAH (Hew-Butler et al. 2008; Noakes et al. 2005; Rosner and Kirven 2007; Verbalis 2007). In marathoners, a high availability of fluids together with a higher consumption of fluids is a risk factor for EAH (Chorley et al. 2007; Hew-Butler et al. 2008). The total cups of water and the total amount of ingested fluid were significantly higher in hyponatremic marathoners compared with non-hyponatremic marathoners (Hew 2005). Fluid intake was neither associated with post-race plasma  $[Na^+]$  nor with the change in plasma  $[Na^+]$  in these male and female ultra-endurance swimmers. Fluid intake in males was 0.56 (0.22) L/h, in females 0.44 (0.17) L/h, showing no difference between the sexes. This fluid intake was lower when compared to the median hourly fluid intake of 0.71 L/h in the study of Speedy et al. (2001b) where 5 out of 18 investigated Ironman triathletes developed EAH.

Slower finish times correlated to increased fluid consumption in marathoners (Chorley et al. 2007). We can confirm this finding in the present male ultra-endurance swimmers where slower competitors drank more fluids during the race. We found a significant and positive association between total fluid intake and overall race time. In our females with a higher prevalence for EAH, however, no association between fluid intake and finishing times was found. In a recent study on ultra-runners, however, the opposite was found (Knechtle et al. 2010b). In male 100-km ultra-marathoners, the faster athletes drank more compared to the slower ultra-marathoners. While running, it is easier for an athlete to get fluids from the support crew. While swimming in open water, the swimmer will lose time when he/she has to stop and get fluids provided by the support boat. Therefore, the slower swimmers probably took more breaks for drinking than the faster swimmers. That means that in swimming sports the participants seem not as tempted as in other disciplines to overdrink and so comply with the advice of Dugas and Noakes (2005). These authors reported that athletes should ignore a set hourly drinking

rate, but only drink when thirsty to avoid EAH. However, in general, this important fact has still not been adequately assimilated into the behaviours and beliefs of most athletes (Winger et al. 2011). Noakes (2011) recently asked if it was probably the contrary interests of the sport drinks industry that had caused the ignorance of this knowledge for so many years, since fluid intake being the most important risk factor for EAH is known since 1985 (Noakes et al. 2005; Noakes and Speedy 2006).

The change in body mass is a useful objective measure of both fluid intake (Almond et al. 2005) and fluid retention (Siegel et al. 2007). Weight gain during an endurance performance is a further risk factor for EAH (Hew-Butler et al. 2008; Irving et al. 1991; Rosner and Kirven 2007). The correlation between an increase in body weight due to fluid overload and a decrease of serum  $[Na^+]$  is well known (Irving et al. 1991; Noakes et al. 2005; Speedy et al. 1999). We know that this form of behaviour is the only risk factor because when athletes are told to drink when thirsty during exercise the incidence of EAH becomes negligible, as described in Ironman races held in South Africa and New Zealand (Sharwood et al. 2004; Speedy et al. 1997a, b). In Ironman triathletes, large changes in body weight during a triathlon were not associated with a greater prevalence of medical complications or higher rectal temperatures, but were associated with higher post-race serum  $[Na^+]$  (Sharwood et al. 2004). In another study of Ironman triathletes, there was a significant and positive correlation between serum  $[Na^+]$  and body weight changes during the race; the greater the body weight loss, the higher the serum  $[Na^+]$  (Speedy et al. 1997b). An inverse relationship between post-race serum  $[Na^+]$  and percentage change in body weight was observed in a further study of Ironman triathletes (Speedy et al. 1997a). In the present male and female ultra-endurance swimmers, the change in body mass correlated significantly and negatively to both post-race plasma  $[Na^+]$  and the change in plasma  $[Na^+]$ . This is in line with recent findings for marathoners (Mettler et al. 2008) and ultra-marathoners (Knechtle et al. 2010b, 2011b) where the change in body mass correlated to both post-race  $[Na^+]$  and the change in plasma  $[Na^+]$ . In addition, the significant correlation of post-race  $[Na^+]$  with the change in plasma  $[Na^+]$  in marathoners (Mettler et al. 2008) and ultra-marathoners (Knechtle et al. 2010b, 2011b) has also been found in our male and female swimmers.

Female gender is considered to be a risk factor for EAH (Hew-Butler et al. 2008; Rosner and Kirven 2007; Stumpfle 2010). Almond et al. (2005) investigated 488 marathoners. 13% (62 of 488) of their runners developed EAH, including 22% females (37 out of 166) and 8% males (25 out of 322). The female runners were younger, had a lower pre-race weight, a lower body mass index, a slower training pace, less marathon experience and a longer racing time



compared to the males. Regarding the prevalence of EAH in female ultra-endurance athletes in a recent study of Knechtle et al. (2010d), investigating 11 female ultra-runners consuming fluids ad libitum, no case of EAH occurred. Dugas and Noakes (2005) described one female participant developing hyponatraemic encephalopathy in a cycle race despite a modest fluid intake. They concluded that this athlete developed EAH despite the moderate rate of fluid intake of 735 ml/h and minimal predicted sweat  $[\text{Na}^+]$  losses. On average, female marathoners drink more than males in relation to their body size (Hew 2005) and Knechtle et al. (2010d) concluded that EAH in female ultra-marathoners would not be influenced by gender but was only an effect of their drinking behaviour. Consistent with these results is the study of Baker et al. (2005) reporting that older females drank more than males during cycling and therefore had an increased risk of EAH because of their smaller body size. Also Rogers and Hew-Butler (2009) quoted that especially those females with low body weight and those taking non-steroidal anti-inflammatory drugs were exposed to a higher risk of EAH. In the present study, 18% of our female ultra-endurance swimmers consumed these drugs.

There was no difference in age between genders in our present subjects; however, body mass and body mass index were lower in females compared to males. Regarding training and performance, neither we found differences in the pre-race preparation between the sexes, nor was there any difference in the race times of our ultra-swimmers. The explanation for this increased risk for EAH in the females may be due to biological and psychosocial factors (Sawka et al. 2007). Regarding only female athletes, the type of physical load might be conclusive. Female swimmers developed EAH in four cases (36%) in our study, Dugas and Noakes (2005) reported one case (1%) of EAH in a cycle race but Knechtle et al. (2010d) found no case of EAH in female ultra-marathoners. We may assume that this descending order shows a negative correlation to the average sweat rates for these sports disciplines (Sawka et al. 2007). Henkin et al. (2010) confirmed this presumption when measuring the sweat volume and sweat  $[\text{Na}^+]$  and  $[\text{Cl}^-]$  of swimmers compared to runners. The swimmers had a significantly lower sweat volume than the runners (0.9 L/30 min compared to 1.5 L/30 min, respectively), whereas the sweat samples of swimmers contained a higher  $[\text{Na}^+]$  than the runners (65.4 mmol/L compared to 45.2 mmol/L, respectively). Maughan et al. (2009) compared the mean sweat  $[\text{Na}^+]$ ,  $[\text{K}^+]$  and  $[\text{Cl}^-]$  as well as the sweat volumes of female and male swimmers and diagnosed only marginal differences between the sexes. Regarding these findings, we assume that sweat loss is generally reduced in swimmers of both sexes. In general, females show lower sweat rates because of their smaller body size

and lower metabolic rates (Sawka et al. 2007). This factor, together with a permanent fluid intake during exercise, may lead to a highly positive waterbalance. This effect is affected by the release of the antidiuretic hormone (Hew-Butler 2010). In females, the diuretic response to a water load can be more expressive, since it has been shown that oestrogen and progesterone interfere with the renal actions of the antidiuretic hormone leading to a higher water turnover, which in turn is dependent on the phase of the menstrual cycle (Claybaugh et al. 2000). Recently, Stachenfeld and Taylor (2009) underlined the significant effect of sex hormones on body fluid and sodium regulation in females.

An exercise performance of more than four hours is considered a risk factor for overdrinking and EAH (Hew-Butler et al. 2008; Rosner and Kirven 2007) especially in marathoners (Chorley et al. 2007). In the present race, the males and females showed no difference in race time. This finding confirms the results of Baker and Tang (2010). The relative performance of females, when compared with male performances in master events, was ~80 to ~85%. Regarding pre-race experience, we did not ask for the number of previous participations in this specific race since event inexperience is also considered a risk factor for EAH (Hew-Butler et al. 2008). However, the years as an active swimmer showed no difference between the sexes.

Regarding environmental factors, Vihma (2010) showed that the effects of weather could also influence the performance of athletes. An extremely hot or extremely cold ambient temperature is also considered as a risk factor for EAH (Hew-Butler et al. 2008). Stuempfle et al. (2002) reported prevalence for EAH of 44% in a cold weather ultra-endurance race. Mettler et al. (2008) reported 3% prevalence for EAH in 167 marathoners competing at 10°C. In the study of Kipps et al. (2011), however, 11 out of 88 volunteers (12.5%) developed EAH while running a marathon at an average air temperature between 9 and 12°C. This prevalence was higher compared with Mettler et al. (2008), although the ambient temperature was about the same. Nonetheless, these prevalence rates were higher compared with marathoners in moderate to hot environments. Chorley et al. (2007) reported a prevalence of 22% for EAH in marathoners in the Houston Marathon during the years 2000–2004. When the temperature is very low, the prevalence of EAH seems to decrease in ultra-marathoners. Stuempfle et al. (2003) reported no hyponatremic athlete in a cold weather ultra-distance race (161 km) where the temperature was between -14 and -2°C, whereas in the previous year, Stuempfle (2002) reported a prevalence of 44% for EAH in an ultra-marathon over the same distance. The ultra-endurance swimmers in the present study were racing in a constant, quite cold, water temperature of ~23°C and the prevalence of EAH was ~4.5 times higher in females than in males, although the females had ~1.6

times more body fat than the males. With these findings, the hypothesis that a mainly cold ambient temperature would be responsible for an increased prevalence of EAH seems difficult to follow. Also Stuemppfle et al. (2003) speculated that the decrease in serum  $[Na^+]$  was not caused by the low temperature but mainly by fluid overload, since for athletes in extremely cold conditions the usual amount of fluid intake may be too high.

The overall prevalence of EAH was higher in these male and female ultra-endurance swimmers when compared to marathoners. The prevalence was about the same when compared to Ironman triathletes. Regarding gender, female ultra-endurance swimmers were at a considerably higher risk of EAH compared to males, as already shown in marathoners and Ironman triathletes. Although differences in anthropometry were found, training and race performances were no different between the sexes. Body mass, body mass index, fluid and sodium intake were not related to post-race plasma sodium concentrations. For both males and females, body mass changes during the race correlated significantly and negatively to both post-race plasma  $[Na^+]$  and changes in plasma  $[Na^+]$  during the race. This study suggests, according to the findings of Irving et al. (1991) that predisposed athletes for EAH such as females should pay particular attention to a reasonable intake of fluids during competitions for the prevention of EAH. Nevertheless, further investigations are needed as to why these ultra-endurance swimmers, especially female swimmers, showed such a high prevalence for EAH. Although the known risk factors for EAH were identical for both sexes, females had a higher prevalence compared with males.

This study is limited that the overall number of subjects was relatively low and the number of male subjects was not equal to the number of female subjects. This might influence our findings. However, since the cases with EAH were occurring for both males and females in the same distribution within the 2 years, we assume that the collected data are reliable to determine the prevalence of EAH in both male and female open-water ultra-endurance swimmers. We further need to consider that the female swimmers took over 1 h longer to complete the race and therefore this may be the factor which dictates the significant difference between males and females in terms of hyponatremia, also, could they therefore swallow (ingest) a greater amount of water during this time which might complicate the fact that over-drinking of water has led to the hyponatremia.

## Conclusions

To summarise, open-water ultra-endurance swimmers are an interesting population to study EAH as a multifactorial phenomenon, as well as the differences that should be con-

sidered in ultra-endurance competitions between the sexes. Therefore, it would be desirable to perform further investigations by using a larger number of participants, standardised conditions and specific screenings that would provide more evidence for the present results. Since both fluid and sodium intake were not related to post-race plasma  $[Na^+]$ , other factors such as endocrine regulation may have been responsible for the post-race decrease in plasma  $[Na^+]$ . In future studies, the concentration of copeptin (Hew-Butler et al. 2011) should be measured in female open-water ultra-endurance swimmers in order to investigate whether SIADH is more common in females compared to males.

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