Original Article

Does a 24-hour ultra-swim lead to dehydration?

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ABSTRACT

Knechtle B, Knechtle P, Kohler G, Rosemann T. Does a 24-hour ultra-swim lead to dehydration? *J. Hum. Sport Exerc.* Vol. 6, No. 1, pp. 68-79, 2011. We investigated the change in body composition and hydration status in one male ultra-endurance swimmer during a 24-hour swim. Body mass, percent body fat and skeletal muscle mass using the anthropometric method as well as total body water using bioelectrical impedance analysis were determined pre race, every 6 hours and after the race. Parameters of hydration status (urinary specific gravity, haematocrit, plasma sodium) and skeletal muscle damage (plasma urea) were measured at the same time. The swimmer achieved a total distance of 41.1 km. Body mass decreased by 1.6 kg, skeletal muscle mass by 1.5 kg, body fat by 2.4 kg and total body water by 3.9 l. Urinary specific gravity remained unchanged at 1.015 g/ml. Haematocrit increased from 46 to 47, plasma volume decreased by 4 % and plasma sodium by 4.0 mmol/l. We found in this ultra-swimmer a decrease in body mass of 1.7 % and a consistent urinary specific gravity of 1.015 g/ml. According to the general concept of dehydration, this corresponds to minimal dehydration. **Key words**: ULTRA-ENDURANCE, BODY MASS, FAT MASS, SKELETAL MUSCLE MASS.

INTRODUCTION

Dehydration is a common finding in endurance performance and defined as 'the process of losing water from the body' according to Shireffs (2003). During the past 20 years, many indices have been developed to accurately assess hydration levels in humans. Apart from a change in body weight, haematological and urinary indices, bioelectrical impedance, skin-fold thicknesses, heart rate and blood pressure are among these indices (Kavouras, 2002; Shireffs, 2003). Although there is no 'gold standard' for the correct assessment of hydration status, changes in body weight, along with urinary markers such as urine osmolality, specific gravity of urine, conductivity and colour of urine are among the most widely used indices (Kavouras, 2002). The current evidence and opinions tend to favour urine indices, as the most promising marker available (Shireffs, 2003) since haematological measurements such as plasma osmolality, plasma sodium or haematocrit are not as sensitive in detecting mild hypo-hydration as selected urinary parameters are (Armstrong, Soto, Hacker et al., 1998). Regarding the decrease in body mass, in ultra-endurance performance, the decrease in body mass in marathon (Whiting, Maughan and Miller, 1984) and ultra-marathon (Kao, Shyu, Yang et al., 2008) running is thought to be a result of dehydration due to fluid loss. However, in recent field studies at ultra-endurance races, a decrease in fat mass (Knechtle, Salas, Andonie and Kohler, 2008a) and skeletal muscle mass (Knechtle, Duff, Schulze and Kohler, 2008b) has been demonstrated as part of the decrease in body mass which is not primarily caused by dehydration.

In swimmers, it is presumed that dehydration is less than in 'land-based' athletes since calculated sweat rate in swimmers is lower than in 'land-based' athletes (Cox, Broad, Riley and Burke, 2002). Nevertheless, Soler, Echegaray and Rivera (2003) concluded from a training study that water intake during a typical training session was not enough to prevent dehydration. In case studies of less than 12 hours non-stop-swimming, decrease in body mass was reported, however, markers of hydration status were not investigated (Knechtle, Knechtle and Heusser, 2004; Knechtle, Baumann and Knechtle, 2007a; Knechtle, Knechtle, Kaul and Kohler, 2007b). In a recent field study with female swimmers in a 12-hour swim, body mass, fat mass, skeletal muscle mass and total body water decreased whereas urinary specific gravity remained stable (Knechtle, Knechtle, Kaul and Kohler, 2008c).

No study ever investigated the changes in body composition during 24 hours of ultra-endurance swimming. Since only a few athletes in the World are able to swim for 24 hours, we had to restrict to a case study. The aim of this present field study with one swimmer in a 24-hour ultra-swim was therefore to investigate whether ultra-swimming of longer than 12 hours leads to dehydration.

MATERIAL AND METHODS

Subject
Our athlete was an experienced male ultra-swimmer (43 years, 93.7 kg body mass, 1.84 m body height, BMI 27.7 kg/m^2). From 2003 to 2008, he had finished several lake crossings in Switzerland (3 to 4 km) in the top 5. In 2006, he finished the 12-hour swim in Zurich, Switzerland, in 2nd place with 30.3 km. In 2007, he won the race with 31.9 km. The 12-hour swim in Zurich, Switzerland, is the longest ultra-distance swimming event in Europe. The average weekly training volume in swimming of this athlete is about 20 km with a yearly volume of around 1,000 km swimming. The athlete gave written informed consent for collecting data during the race according to the guidelines established by the local ethical committee.

The event

On 9th august 2008 at noon, the start of a charity event over 24-hour ultra-swimming in a 50 m out door pool (Schönenwerd, Aargau, Switzerland) was held. Temperature in the pool was at 23° Celsius during the day and dropped during the night to 21° Celsius. Ambient temperature was 23.5° Celsius at the start and the sky was clouded. During the afternoon, the clouds disappeared and the temperature rose to 30.6° Celsius maximally. The lowest temperature was in the morning of 10th August at 04:00 a.m. with 14° Celsius. The competitors were free to swim as many laps of 100 m counted by a personal lap counter. The swimmer had his support crew for food and fluids.

Pre race laboratory exercise testing

We intended to determine energy expenditure during performance with the heart rate method where the determination of maximal oxygen uptake (VO_2max) is required (Hiilloskorpi et al., 2003). Two month before the performance, a maximal exercise test was performed on an arm cranking ergometer (ergoline 800®, ergoline, Bitz, Germany) to assess $VO_2max_{armcranking}$ (Table 1). The cranks of the arm ergometer were mounted antiparallel. The test started a 40 W and was increased by 20 W every 2 min until exhaustion. One week later, a VO_2max-test was performed on a stationary cycle ergometer (ergoline 800®, ergoline, Bitz, Germany) (Table 2) to assess $VO_2max_{cycling}$. The exercise protocol started at 100 W and was increased by 30 W every 2 min until volitional exhaustion. During exercise, oxygen uptake (VO_2) and production of carbon dioxide (VCO_2) were measured continuously (Oxycon Pro, Jaeger, Würzburg, Germany). Heart rate was recorded continuously (Polar Vantage, Polar Oy, Kempele, Finland). Capillary blood samples (20 µl) for the determination of blood lactate concentration were taken at the earlobe at rest, at the end of every step and at exhaustion and analyzed enzymatically (Biosen C_line, EFK Industrie-Elektronik, Barleben, Germany). Lactate threshold was determined according to Coyle, Martin, Ehsani et al. (1983) and identified as the VO_2 at which concentration of lactate increased 0.5 mmol/l above baseline.

Table 1. *Relationship between heart rate and energy expenditure (EE) during the incremental exercise (VO₂max test) on an arm cranking ergometer. Included are lactate concentrations at each stage.*

Power output (W)	VO₂ (ml/min)	VCO₂ (ml/min)	RER	Lactate (mmol/l)	Heart rate (bpm)	EE (kcal/min)
40	1,051	953	0.80	1.40	95	5.1
60	1,234	1,319	0.88	1.61	102	6.3
80	1,518	1,579	0.93	2.31	119	8.0
100	1,765	1,902	0.99	3.23	130	9.6
120	2,096	2,086	1.00	4.33	143	11.5
140	2,569	2,719	1.06	6.34	150	14.6
160	3,036	3,289	1.08	8.31	161	17.5
180*	3,123	3,602	1.15	9.87	165	18.8

* 1 min at this stage

Table 2. *Relationship between heart rate and energy expenditure (EE) during incremental exercise (VO$_2$max test) on the cycle ergometer. Included are lactate concentrations at each stage.*

Power output (W)	VO$_2$ (ml/min)	VCO$_2$ (ml/min)	RER	Lactate (mmol/l)	Heart rate (bpm)	EE (kcal/min)
100	1,732	1,325	0.77	0.96	103	8.2
130	2,037	1,700	0.83	1.25	109	10.1
160	2,391	2,086	0.87	1.42	118	12.1
190	2,669	2,350	0.88	1.78	123	13.6
220	3,080	2,791	0.91	2.06	134	16.0
250	3,416	3,267	0.93	2.98	144	18.3
280	3,852	3,726	0.97	4.13	152	20.8
310	4,199	4,280	1.02	5.90	161	23.4
340	4,574	4,899	1.05	10.07	174	26.3

Anthropometric and laboratory measurements

Before the start of the race, every 6 hours and immediately after finish, our athlete underwent anthropometric measurements, bioelectrical impedance analysis (BIA) and the collection of blood and urinary samples in order to determine total body mass, skeletal muscle mass, percent body fat, and percent total body water. Total body mass was measured using the BIA balance Tanita BC-545 (Tanita Corporation of America Inc., Arlington, IL, USA) to the nearest 0.1 kg. Skeletal muscle mass (Lee et al., 2000) and percent body fat (Ball, Altena and Swan, 2004) were determined using the anthropometric method. Circumferences of the upper-arm, thigh and calf were measured at the largest circumference of the limb to the nearest 0.1 cm. At the thigh, circumference was determined 20 cm above the upper pole of the patella. Skin-fold thicknesses of chest, midaxillary (vertical), triceps, subscapular, abdominal (vertical), suprailiac (at anterior axillary), thigh and calf were measured using a skin-fold calliper (GPM-Hautfaltenmessgerät, Siber & Hegner, Zurich, Switzerland) to the nearest 0.2 mm at the right side of the body. One trained investigator took all measurements as inter-tester variability is a major source of error in skin-fold measurements. Intra-tester reliability check was conducted on 27 male runners prior to testing. No significant difference between the 2 trials for the sum of 8 skin-folds was observed (p>0.05). The intra-class correlation was high at r=0.95. The same investigator was also compared to another trained investigator to determine objectivity. No significant difference existed between testers (r=0.97; p>0.05). The skin-fold measurements were taken once through entire 8 skin-folds and then repeated 2 times by the same investigator; the mean of the 3 times was then used for the analyses. The timing of the taking of the skin-fold measurements was standardised to ensure reliability. According to Becque, Katch and Moffat (1986), readings were performed 4 s after applying the calliper. Percent body fat was calculated using the following anthropometric formula for men: Percent body fat = $0.465 + 0.180(\Sigma 7SF) - 0.0002406(\Sigma 7SF)^2 + 0.0661(age)$, where $\Sigma 7SF$ = sum of skin-fold thickness of chest, midaxillary, triceps, subscapular, abdomen, suprailiac and thigh mean, according to Ball, Altena and Swan (2004). This formula was evaluated using 160 men aged 18 to 62 years old and cross-validated using DXA (dual energy X-ray absorptiometry). The mean differences between

DXA percent body fat and calculated percent body fat ranged from 3.0 – 3.2%. Significant (p<0.01) and high (r>0.90) correlations existed between the anthropometric prediction equations and DXA. Skeletal muscle mass was calculated using the following formula: Skeletal muscle mass = Ht x (0.00744 x CAG^2 + 0.00088 x CTG^2 + 0.00441 x CCG^2) + 2.4 x sex – 0.048 x age + race + 7.8, where Ht = height, CAG = skin-fold-corrected upper arm girth, CTG = skin-fold-corrected thigh girth, CCG = skin-fold-corrected calf girth, sex = 1 for male, race = 0 for white, according to Lee et al. (2000). This anthropometric method was evaluated using 189 non-obese subjects and cross-validated using MRI (magnetic resonance imagining) evaluation. Percent total body water was measured using Tanita BC-545. The Tanita-method was evaluated by Jebb, Cole, Doman, Murgatroyd and Prentice (2000) and cross-validated using the dilution method for total body water and DXA (dual energy X-ray absorptiometry) for percent body fat in 104 men and 101 women aged 16 to 78 years. Reliability check of Tanita BC-545 was conducted on 28 male runners prior to testing to ensure reliability in determination of percent total body water. No significant difference between the 2 trials was found (p>0.05); the intra-class correlation was high at r=0.99. Impedance measurements were performed with the athlete standing in an upright position, barefoot in swimwear, on foot-electrodes on the platform of the instrument, with the legs and thighs not touching, and the arms not touching the torso. The athlete stood on the 4 foot-electrodes: 2 oval and 2 heel shaped electrodes, and gripped the 2 palm-and-thumb electrodes in order to yield 2 thumb and 2 palm electrodes. The skin and the electrodes were pre cleaned and dried. Since body mass and skeletal muscle mass are expressed in kg, fat mass was calculated in kg from body mass and percent body fat; total body water was calculated from body mass and percent total body water. Samples of urine were collected for determination of urinary specific gravity using Clinitek Atlas® Automated Urine Chemistry Analyzer (Siemens Healthcare Diagnostics, Deerfield, IL, USA). Capillary blood samples (65 µl) were drawn from the finger tip to determine haematocrit, plasma urea, plasma potassium and plasma sodium using i-STAT® 1 System (Abbott Laboratories, Abbott Park, IL, USA). This portable device was evaluated in several studies and cross-validated with laboratory devices. Schneider, Dudziak, Westphal and Vettermann (1997) found correlation coefficients (r) between conventional and i-STAT of 1.0 for potassium, 0.86 for sodium and 0.74 for haematocrit. According to Papadea, Foster, Grant et al. (2002), reproducibility was good for electrolytes and urea (CV < 2 %). Jacobs, Vadasi, Sarkozi and Coleman (1993) reported CVs < 2 % for sodium and potassium, for urea between 2.2 % and 4.0 %. Erickson and Wilding (1993) evaluated accuracy for i-STAT compared to stationary laboratory setting. CV were 0.46 % – 0.89 % for sodium, 1.06 % – 1.45 % for potassium, and 2.54 % – 6.12 % for urea. R varied between 0.974 and 0.994 for sodium, potassium, urea and haematocrit. Changes in plasma volume were determined from the haematocrit values according to Beaumont (1972).

Determination of energy expenditure and energy intake during swimming
A portable heart rate monitor POLAR® S710 (POLAR Electro Oy, Kempele, Finland) was programmed with gender, age, body mass and the subject's VO$_2$max in order to determine energy expenditure during performance (Hiilloskorpi, Pasanen, Fogelholm, Laukkanen and Mantari, 2003). The oxidation rate of fat and carbohydrate was calculated using the stochiometric equations of Frayn (1983). Energy expenditure from fat and carbohydrate were converted into kcal·min^{-1} by multiplying the oxidation rate of fat by 9.1 and the oxidation rate of carbohydrate by 4.2 following Atwater (1909). In addition to the method of heart-rate based measurement of energy expenditure using the POLAR® S710, we established the individual relationship between heart rate and oxygen uptake (VO$_2$) during laboratory testing for the cycling test (Table 1) and the arm cranking test (Table 2). During the swim, the support crew provided pre packed nutrition to the athlete and recorded intake of calories and fluids. Ingestion of water and calories were calculated according to the reports of the athletes with a food table (Kirchhoff, 2002).

RESULTS

Pre race, our athlete reached a VO2max of 31.2 ml·min^{-1}·kg^{-1} in the arm cranking test (VO2max$_{armcranking}$) (Table 1), and of 45.7 ml·min^{-1}·kg^{-1} in the cycling test (VO2max$_{cycling}$) (Table 2). Lactate threshold was at 44 % VO2max$_{armcranking}$ and at 40 % VO2max$_{cycling}$, respectively. During performance, the swimmer achieved a total distance of 41.1 km. Due to the cold in the night he had to make a break of 6 hours in order to warm up. During swimming, his heart rate was on average at 107 beats per minute (bpm). This corresponds to an intensity of about 41 % VO2max$_{armcranking}$ and 44 % VO2max$_{cycling}$, respectively. Energy expenditure determined with the method of VO2max$_{cycling}$ was 11,460 kcal during the 24 hours and 6,590 kcal with the method of VO2max$_{armcranking}$. By using the individual relation of heart rate – VO$_2$, he expended by using the results of the VO2max$_{cycling}$ a total of 10,900 kcal and by using the results of the VO2max$_{armcranking}$ a total of 7,560 kcal. The swimmer ingested 3,900 kcal and drank 9.2 l of fluids. An energy deficit of 7,480 kcal by using the results of the VO2max$_{cycling}$ occurred, respectively 2,690 kcal by using the VO2max$_{armcranking}$. During the swim, body mass decreased by 1.6 kg, skeletal muscle mass decreased by 1.5 kg, body fat decreased by 2.4 kg and total body water decreased by 3.9 l. Urinary specific gravity remained unchanged at 1.015 g/ml (Figure 1). Haematocrit increased from 46 to 47, plasma volume decreased by 4%, plasma sodium decreased by 4.0 mmol/l, plasma potassium increased by 0.2 mmol/l and plasma urea increased by 0.8 mmol/l (Table 3).

Figure 1. Changes in body composition (body mass, skeletal muscle mass, fat mass, total body water) and urinary specific gravity during the performance.
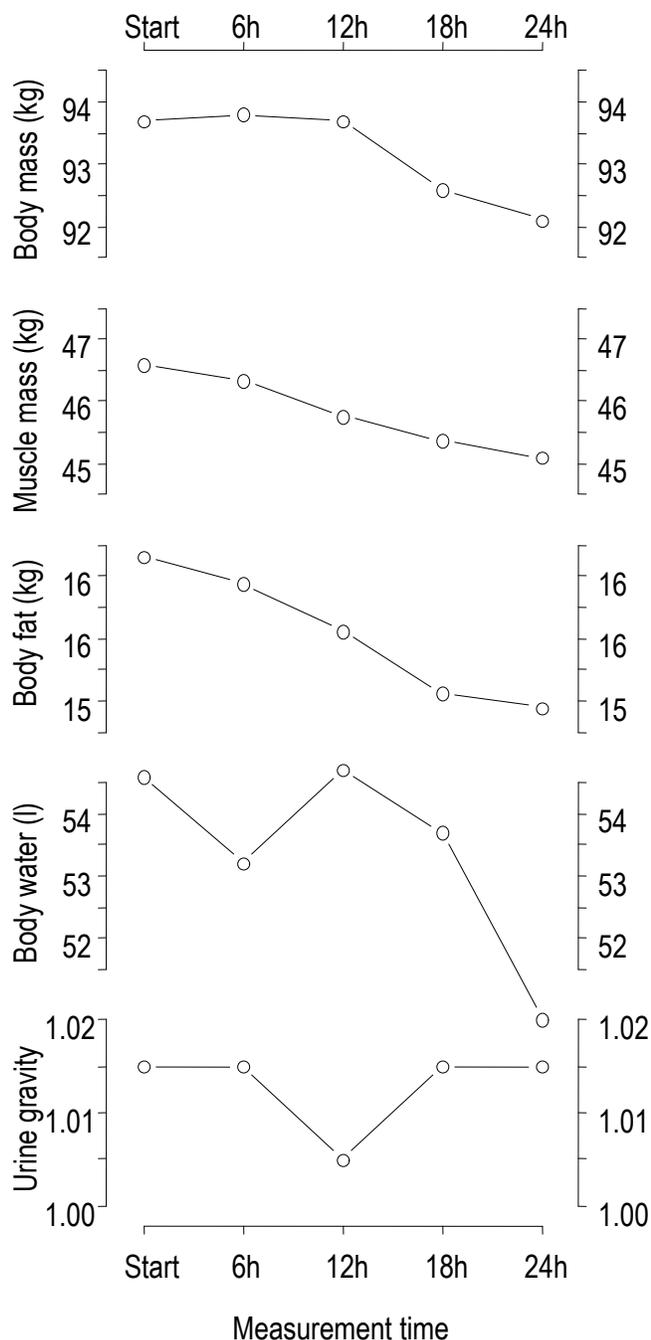
Table 3. *Changes in haematological parameters during the performance.*

Parameter	Unit	Pre race	After 6 h	After 12 h	After 18 h	After 24 h
Haematocrit		46	47	45	47	47
Plasma volume	%	100	96	104	96	96
Plasma sodium	mmol/l	139	136	137	135	135
Plasma potassium	mmol/l	4.3	4.7	4.0	3.8	4.5
Plasma urea	mmol/l	4.2	4.0	4.8	4.8	5.0

DISCUSSION

We found in this ultra-swimmer a decrease in 1.6 kg total body mass (– 1.7 % total body mass) and a constant urinary specific gravity of 1.015 g/ml pre race compared to post race. According to Kavouras (2002), a body weight change of – 1 % to – 3 % and a specific gravity of 1.015 g/ml correspond to minimal dehydration.

Decrease in skeletal muscle mass in male ultra-swimmer
We found a decline of skeletal muscle mass of 1.5 kg. During ultra-endurance performances beyond the marathon-distance, the decrease in body mass is due to a reduced fat mass (Höchli, Schneiter, Ferreti et al., 1995) and not generally a result of dehydration. The question remains as to whether our swimmer suffered a decrease in skeletal muscle mass in the form of contractile proteins or rather a decrease and depletion of the energy rich substrates stored in the muscle fibres. We presume that our athlete suffered apart from a depletion of the intramyocellular stored substrates also a substantial loss of myofibrillar protein since plasma urea was increased after the swim (Table 3). We must guess a substantial damage of myofibrillar proteins with a reduction in skeletal muscle mass, since an increase in urea is associated with skeletal muscle damage in ultra-endurance performance (Gastmann, Dimeo, Huonker et al., 1998). Urea could also be increased due to an impaired renal function due to dehydration. However, in our swimmer, urinary specific gravity showed no alteration. We rather think that the decrease in skeletal muscle mass was as result of the degradation of the intramyocellular stored energy-rich substrates and myofibrillar proteins. Although endurance athletes rely more on intramyocellular lipids during endurance performances (Stellingwerff, Boon, Jonkers et al., 2007), muscular glycogen also gets depleted during endurance exercise (Zehnder, Ith, Kreis et al., 2005). In swimmers, Soler, Echegaray and Rivera (2003) found after a typical interval training session of 9 km within 3 hours in an outdoor pool at 27 °Celsius a decrease in body mass. Although their athletes consumed regularly fluids, total body mass decreased by 1.8 (0.5) kg and plasma volume decreased by 10.7 (5.4) %. The loss in total body mass was 2.5 % corresponding to dehydration by definition (Kavouras, 2002).

Change in total body water, haematocrit and plasma volume
The BIA balance Tanita BC-545 has a dual frequency (50 kHz/6.25 kHz) method. At low frequencies (<50 kHz), the injected current flows only through the extracellular water because of the capacitance of cell membranes, whereas at higher frequencies the current would be conducted through both the intracellular and extracellular water (Segal, Burastero, Chun et al., 1991). We found a decrease in total body water (Figure 1).

The determination of haematocrit has the potential to be used as a marker of hydration status or change in hydration status, provided a reliable baseline can be established (Shireffs, 2003). In addition, the change in plasma volume can be calculated with the haematocrit (Beaumont, 1972). We found a small increase in haematocrit (Table 4). Also Goodman, Rogers, Vermaak and Goodman (1985) could demonstrate after a 100 m and an 800 m swim a significant increase in haematocrit. In contrast, Bonifazi, Bela, Carli et al. (1994) found in 12 top level male ultra-endurance swimmers in an 18 km open-water swim a decrease in haematocrit. Although haematocrit is not considered as a reliable parameter to indicate dehydration (Kavouras, 2002), dehydration may cause a rise in haematocrit i.e. in ultra-endurance cyclists (Neumayr, Pfister, Mitterbauer et al., 2002). Calculated plasma volume was slightly decreased. A decrease in plasma volume is probably a common finding in swimmers. According to Soler, Echegaray and Rivera (2003), plasma volume decreased to about 10 % during a typical training session. Presumably the decrease in plasma volume in swimmers is associated with performance intensity. Goodman, Rogers, Vermaak and Goodman (1985) found after 100 m a decrease in plasma volume by 16 % and after 800 m by 8 %.

Change in sodium
Plasma or serum sodium concentration and osmolality will increase when the water loss inducing dehydration is hypotonic with respect to plasma (Shireffs, 2003). The significant increases in plasma atrial natriuretic peptide and antiddiuretic hormone in the study of Bonifazi, Bela, Carli et al. (1994) led to an increase in plasma [Na$^+$] in swimmers. Also Goodman, Rogers, Vermaak and Goodman (1985) showed after a 100 m and 800 m swim a significant increase in sodium. In contrast, we found a decrease in plasma sodium (Table 3). The change in sodium from pre to post race may be dependent upon the length and duration of a race in 'land-bases athletes' such as runners. After a 90 km ultra-run, serum sodium was significantly elevated after the race (McKechnie, Leary and Noakes, 1982). Rama, Ibáñez, Riera et al. (1994) found an increased concentration of sodium after a 100-km run and concluded with the increased creatine kinase that an acute renal dysfunction contributed to the change in electrolytes. The increase in plasma sodium seems to have an effect on plasma volume. Five consecutive days of hill walking lead to a retention of sodium leading to an expansion of the extracellular space (Milledge, Bryson, Catley et al., 1982). The retention of sodium leads to a positive water balance (Milledge, Bryson, Catley et al., 1982) with a shift of fluid from the intracellular to the extracellular space. Fellmann et al. (1999) concluded that the sodium retention in an ultra-endurance race is the major factor in the increase of plasma volume.

Limitations and reliability of applied methods
We found large differences in energy expenditure by using the different VO$_2$max values from VO$_2$max$_{armcranking}$ and VO$_2$max$_{cycling}$, respectively. Trained athletes with a lesion of the spinal cord achieve a VO$_2$max$_{armcranking}$ of 35.9 ml·min^{-1}·kg^{-1} (Knechtle, Müller, Willmann, Eser, and Knecht, 2003) which is not different from the value of our swimmer (Table 1). However, trained cyclists can achieve a VO$_2$max$_{cycling}$ of more than 70 ml·min^{-1}·kg^{-1} (Louana, Campion, Noakes and Medelli, 2007). It has been suggested that heart rate recording in the field is feasible, reasonably priced and accurate due to the new technology of portable heart rate monitors (Hiilloskorpi et al., 2003). Compared with indirect calorimetry or the doubly-labelled water technique, the heart rate method shows no difference, even when differences between subjects and within subjects are reported (Li, Deurenberg and Hautvast, 1993). Nevertheless, measuring energy expenditure using continuous heart rate monitoring has limitations. During field conditions, heart rate is influenced by emotion, high temperature, high humidity, dehydration and illness (Achten and Jeukendrup, 2003). The determination of energy expenditure with the heart rate method is useful as a group mean, but interpretation of the individual energy expenditure requires caution because of great deviations from the reference values (Livingstone, Prentice, Coward et al., 1993). Thus the methodology employing continuous heart rate monitoring may over estimate energy expenditure (Achten and Jeukendrup, 2003). Indeed

energy expenditure measured using heart rate has been reported to be 6 % higher compared with energy expenditure derived using the technique of doubly-labelled water (Davidson, McNeill, Haggarty, Smith and Franklin, 1997). Similarly during measurements in the field, continuous heart rate monitoring to estimate energy expenditure shows a difference compared with the technique of using doubly-labelled water (Kahiwazaki, 1999). In addition to the use of portable heart rate monitors, the relationship between heart rate and VO$_2$, which reflects energy expenditure as oxygen uptake, provides another method for predicting energy expenditure. It is possible to estimate energy expenditure from heart rate during submaximal exercise with a great deal of accuracy, after adjusting for age, gender, body mass and fitness (Keytel, Goedecke, Noakes et al., 2005). The relationship between heart rate and oxygen uptake seems to be linear during dynamic exercise up to about 85 % of the individual maximum heart rate (Li, Deurenberg and Hautvast, 1993). The individual relationship between heart rate and VO$_2$ may provide a closer estimation of energy expenditure during extreme endurance exercise (Bircher, Enggist, Jehle and Knechtle, 2006).

The method of measuring total body water with bioelectrical impedance analysis must be discussed in this context. In ultra-endurance races, an increase in total body water has been demonstrated using bioelectrical impedance analysis (Fellmann et al., 1999; Knechtle, Salas, Andonie and Kohler, 2008a; Knechtle, Duff, Schulze and Kohler, 2008b; Knechtle, Wirth, Knechtle and Kohler, 2009) where we in contrast found a decrease (Figure 1). The methodology of bioelectrical impedance analysis may not provide valid estimates of total body water when hydration status is altered (O'Brien, Young and Sawka, 2002). Plasma osmolality and sodium concentration should be unchanged (Berneis and Keller, 2000; Pialoux, Mischler, Mounier et al. 2004). Regarding our results, plasma sodium as most important electrolyte of extracellular volume continuously decreased (Table 3). This decrease may explain the ongoing decrease in total body water. Unfortunately, osmolality was not determined in this investigation which is a limitation. To determine extra cellular water, single frequency models do not accurately predict change in total body water (Gudivaka, Schoeller, Kushner and Bolt, 1999) and models with at least two frequencies (Segal et al., 1991) are needed. Tanita BC 545 has two different frequencies and is able to detect changes in extra cellular body water. Due to the fact that plasma sodium was reduced by 4 mmol/l, this might explain the decrease in total body water since sodium is the most important electrolyte in extra-cellular volume.

CONCLUSIONS

A male ultra-endurance swimmer achieved 41.1 km in a 24-hour swim where body mass decreased by 1.6 kg, skeletal muscle mass decreased by 1.5 kg, body fat decreased by 2.4 kg and total body water decreased by 3.9 l. Urinary specific gravity remained unchanged at 1.015 g/ml. According to the general concept of dehydration, a body weight change of – 1 to – 3 % corresponds to minimal dehydration as well as a specific gravity of 1.015 g/ml. The minimal fluid intake of 9.2 l during 24 hours swimming obviously prevented from dehydration. These findings should be better investigated in field studies with larger samples of ultra-endurance swimmers.

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