# Athletic Performance and Weight Changes during the "Marathon of Sands" in Athletes Well-trained in Endurance

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Key words
- haematocrit
- hydration
- fluid loss
- long duration race

## Abstract

The purpose of this study is to examine the effects of the "Marathon of Sands" (MS), a 7–day, self-sufficient-diet, multi-stage running race across a section of the Moroccan desert, on body weight and plasma volume variation (PVV) and the relationship of these factors to performance in athletes who are well-trained in endurance. Sixteen MS runners agreed to participate in this study. Weight and body composition were measured and venous blood samples were taken before the first stage ($D_0$), after the third stage ($D_3$) and at the end of the MS (after the sixth stage: $D_6$). Haematocrit and haemoglobin were used to calculate PVV at ($D_0$, $D_3$, and D6). No significant plasma volume decrease was observed throughout the race. Significant decreases in total body weight (BW), fat-free mass (FFM) and fat mass (FM) were observed in $D_3$ and $D_6$ (−4.3%, −3.5%, −0.8%; and −6.1%, −5%, −1.1%, respectively, for BW, FFM and FM at $D_3$ and $D_6$). This study clearly shows that, despite extreme conditions, the MS did not lead to a significant PV decrease in athletes well-trained in endurance. This study also supports the hypothesis that significant body weight loss may not systematically affect performances during long duration multiple-stage races.

## Introduction

It is now well known that prolonged aerobic exercise is accompanied by important variations in body fluid and electrolytes [10]. Indeed, a decrease of plasma volume (PV) is frequently observed at the end of prolonged aerobic exercise. This decrease of PV is mainly due to perspiration [12], osmolarity [21] and sweat loss induced by exercise. This fluid loss depends on several factors, such as the intensity and the nature of the exercise [3, 12], the ambient conditions [14], the posture of the subjects before and during the exercise [26], their training level, and their degree of hydration, as well as their level of acclimatization to heat [14].

Several studies state that dehydration during long-term exercise is detrimental to physical performance [2, 28, 29]. However, other authors argue that it is the presence of thirst that produces this effect rather than dehydration per se [25, 29]. It is also stated that adequate fluid replacement during exercise is important to replace sweat loss. In this way, exercise capacity is maintained by avoiding dehydration and a decline in thermoregulation [2]. In fact, numerous studies show that prolonged aerobic exercise performed in warm weather induces a decrease in endurance performance, an increase in osmolarity, and an increase in heart rate as well as an increase in the central temperature of dehydrated subjects compared to normally hydrated subjects [2, 14]. Recently, hydration guidelines suggested that athletes should drink sufficiently before and during exercise to prevent excessive (>2% body weight loss from water deficit) dehydration and excessive changes in electrolyte balance compromising performance and health [2]. However, one can note that the majority of these last conclusions are based on laboratory studies focusing on physiological changes during exercise [25]. These studies are often performed under conditions that are less stressful than the conditions of competition realized in the desert. Hence, in all these studies no substantive health complications as a consequence of dehydration have been documented [27, 32]. For several authors [23, 24, 25, 26, 31, 32], this is a "foundation myth". In fact, several studies conducted in real outdoor conditions, such as the South Africa Ironman Triathlon

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(SAIT) (3.8 km swimming, 180 km cycling and 42.2 km running), show that there is no evidence that more severe levels of weight loss or dehydration are related to either higher body temperature or impaired performance [24, 31, 32]. In that way, one study [31] observes that some of the most successful athletes completed the race with body weight loss percentages greater than those considered to be incapacitating [1]. Hence, during SAIT, the athlete with the greatest individual weight loss (8.2 %) had one of the fastest 42 km marathon times (213 min). Moreover, since the triathletes who were the most dehydrated at the end of the SAIT were also among the fastest to finish the race, some authors [35] suggested that there is no apparent negative effect of high levels of dehydration during long-term endurance events. More recently, Kao et al. [16] observe that weight loss is positively associated with performance in a 24-h race.

All these new findings were drawn from studies conducted during an isolated long-term exercise (224 km Ironman Triathlon) performed without food restriction. Thus, one can assume that responses may be very different during a long duration stage race. In this study, we hypothesize that repetition of long duration stages under extreme conditions (heat, under-hydration, etc.) such as the Marathon of Sands (MS), which takes place in the Moroccan desert (self-sufficient diet and restricted water intake) could induce an important variation firstly in body weight and secondarily in PV, which may significantly reduce performance: the best athletes would be those who lost the least weight, whereas those who lost the most weight performed the worst. To test this hypothesis, we focused our study on the performance related to the body weight changes and to the variation of PV levels measured after the third and the sixth stage of the MS competition in 16 subjects well-trained in endurance.

## Materials and Methods

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Approval for the study was obtained from the consultative committee of the protection of the persons in biomedical researches (CCPPRB) of the University of Rennes 1.

### Subjects

Sixteen healthy male volunteers participating in regular running exercises were involved in this study. All the athletes have been involved in endurance training since the age of 10–22 years, and this was their first participation in the Marathon of Sands. All the subjects gave their written consent prior to participating in this study after the design and risks had been described to them. The subjects had no major medical illnesses.

### The Marathon of Sands (MS)

The MS consists of six exhaustive and long stages divided into seven days. During the MS, all athletes carry their own food (12 000 kcal minimum) and equipment, which weighs between 5 and 15 kg at the beginning of the competition. Those athletes who run for the victory depart with the minimum 12 000 kcal to avoid excessive ballasting. Infractions of rules against shedding unused provisions are carefully monitored during each of the six stages of the race. The organization provides only the water, which is restricted to 9–10.5 L per day according to the distance. These quantities were chosen taking into account the advice of the medical organization (DOC TROTTER) and the experiences of organizers and runners.

The competition took place from the 7$^{th}$ to the 13$^{th}$ of April in 2002. All the athletes completed the 230 km during the week. The MS competition consisted of six stages according to the following protocol. During the first three days, subjects ran 26, 36 and 31 km per day, respectively. The distance of the fourth stage [day 4] was 71 km. Day 5 was a rest day. Stages 5 and 6 on day 6 and day 7 were 42 km and 20 km, respectively. All the races began at 9:00 am.

**Table 1** illustrates the ambient conditions and the distance of each stage. Conditions were mostly dry and windy except during stage 4 when it rained. One can note that conditions were exceptionally mild at that time.

A certain amount of water was given to each athlete every 24 h. This volume of mineral water provided by the organization during each race was restricted to 9 l (stages 1, 2, 3 and 6) and 10.5 l (stage 4) according to the race distance. An additional overnight supply of 3L was provided at the campsite for the evening's recovery including food preparation and toilet. It is of importance to note that the athletes generally drank according to thirst.

### Experimental procedure

The subjects came to the laboratory 3 days before the beginning of the race ($D_0$). The first blood sample was drawn between 9:00 and 10:00 am from the antecubital vein at rest. Height, weight and percentage of body fat were determined according to the method of Durnin and Rahaman [8]. Body-fat percent was estimated from 4 skin folds (biceps, triceps, sub-scapular and supra-iliac). Fat-free mass (FFM) was calculated by subtracting total body fat from body weight. After a 5-min warm-up, subjects performed a continuous, progressive treadmill program to determine their maximal oxygen uptake ($VO_2$max). After the warm-up, speed was increased by 2 km.h$^{-1}$ every 2 min until exhaustion. An open circuit technique was used to determine $VO_2$max (breath-by-breath automated exercise metabolic system: CPX, Medical Graphics, St. Paul, Minnesota).

At $D_3$ and $D_6$, anthropometric measurements (weight, percentage of fat mass and FFM) and blood sample collection were performed in the Moroccan desert.

### Blood samples

All the blood samples were obtained while the subjects were resting in a sitting position. 3 mL of resting venous blood samples were collected into ETDA vacutainers at $D_0$, $D_3$ and $D_6$ (for $D_3$ and $D_6$ 2–3 h after the end of the race) to determine haemat-

**Table 1** Program of the MS and meteorological conditions.

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Stage 6 |
|---|---|---|---|---|---|---|
| date | April 7$^{th}$ | April 8$^{th}$ | April 9$^{th}$ | April 10$^{th}$ .11$^{th}$ | April 12$^{th}$ | April 13$^{th}$ |
| distance km) | 26 | 36 | 31 | 71 | 42 | 24 |
| temperature (°C) | 20° | 22° | 20° | 22° | 25° | 25°–30° |
| weather | strong wind weather: dry | strong wind weather: dry | strong wind weather: dry | strong wind raining | moderate wind | moderate wind |

**Table 2** Morphological and physiological characteristics of the athletes before the MS.

| Subjects | Age (years) | Height (cm) | $\dot{V}O_2max$ (L/min) | $\dot{V}O_2max$ (mL/kg/min) | 42 km Marathon personal best (min) | MAV (km/h) |
|---|---|---|---|---|---|---|
| before MS | 40.3 ± 1.7 | 174.5 ± 1.7 | 4 ± 0.1 | 58.7 ± 0.7 | 187.5 ± 6.4 | 17.4 ± 0.3 |

Values are means ± SEM
$\dot{V}O_2max$: Maximal oxygen uptake
MAV: maximal aerobic velocity

**Table 3** Morphological characteristics and body composition of the subjects determined before the MS ($D_0$), after the third stage ($D_3$) and after the sixth stage ($D_6$).

| | Weight (kg) | % body fat (%) | Fat free mass (kg) | Fat mass (kg) |
|---|---|---|---|---|
| before MS ($D_0$) | 69.2 ± 2.3 | 16.9 ± 0.4 | 57.5 ± 0.1 | 11.7 ± 0.4 |
| after race 3 ($D_3$) | 66.2* ± 2.2 | 16.1* ± 0.4 | 55.5* ± 1.8 | 10.7* ± 0.5 |
| after race 6 ($D_6$) | 65 $ ± 2.3 | 15.8 $ ± 0.5 | 54.6 $ ± 1.8 | 10.3 $ ± 0.6 |

*Significant difference between rest and $D_3$; $p < 0.05$
$ Significant difference between rest and $D_6$; $p < 0.05$

ocrit (Ht), haemoglobin (Hb) and blood lactate concentration. Determinations of both Ht and Hb were realized in order to calculate plasma volume changes (ΔPV) and expressed as %ΔPV [34]:

$$\%\Delta VP = 100\left[\frac{Hb_B}{Hb_A} \times \frac{(1 - Ht_A \times 10^{-2})}{(1 - Ht_B \times 10^{-2})}\right] - 100$$

B: Value measured 3 days before the MS, at rest at $D_0$
A: Value measured after the end of race ($D_3$ or $D_6$)
Ht: haematocrit in %
Hb: haemoglobin in g/100mL/100mL

### Analyses and measurements

For the Ht measurements, whole blood samples were collected into micro Ht tubes, which were then centrifuged for 3 min (Hema-C, Jouan, France). Ht measurements were done in triplicate.
For hemoglobin determination, 20 µL of whole blood was analyzed with an automate (Hemocue B-haemoglobin, Hemocue®, UK).

### Statistical analyses

Data are presented as mean and the standard error of the mean ($\bar{x}$ ± SEM). Statistical differences of time course between the three races were made by one-way analysis of variance for repeated measures (RM-ANOVA). When the distribution of the values was not normal, an ANOVA on the ranks for repeated measure was performed. The limit of significance was set at $p < 0.05$.

## Results

### Morphological and physiological characteristics of the subjects (Table 2)

The morphological and physiological characteristics of the subjects determined before the MS are presented in **Table 2**.
Anthropometric measurements realized at $D_3$ and $D_6$ are presented in **Table 3**. A significant decrease in body weight was observed at $D_3$ (−4.3 %) and $D_6$ (−6.1 %) accompanied by a significant decrease of FFM and FM at $D_3$ (−3.5 % and −0.8 % respectively) and D6 (−5 % and −1.1 % respectively).

**Table 4** Performances of the 16 subjects during the MS competition.

| | | FINAL RANKING | |
|---|---|---|---|
| Subject | Rank | Performance | Average Speed (km/h) |
| 1 | 6 | 22h41′21″ | 9.96 |
| 2 | 7 | 22h44′44″ | 9.94 |
| 3 | 11 | 23h17′59″ | 9.7 |
| 4 | 29 | 25h32′13″ | 8.85 |
| 5 | 48 | 26h47′20″ | 8.44 |
| 6 | 64 | 27h31′33″ | 8.21 |
| 7 | 75 | 28h06′42″ | 8.04 |
| 8 | 88 | 28h32′20″ | 7.92 |
| 9 | 98 | 28h51′33″ | 7.83 |
| 10 | 99 | 28h54′34″ | 7.82 |
| 11 | 180 | 32h01′15″ | 7.06 |
| 12 | 184 | 32h11′02″ | 7.02 |
| 13 | 291 | 30h22′32″ | 6.21 |
| 14 | 291 | 30h22′32″ | 6.21 |
| 15 | 321 | 37h35′49″ | 6.01 |
| 16 | 351 | 38h46′14″ | 5.83 |

### Performances and classification of the subjects during the MS (Table 4)

All subjects finished in the top 54 % of the field, and 10 of 16 finished in the top 100 with a further three subjects among the top 11 finishers out of a total of 650 participants.

### Haematocrit and haemoglobin variation during the MS

Haematocrit variations during the MS appear in **Table 5**. This competition induced a significant decrease of haematocrit at $D_6$ compared to $D_3$ or $D_0$.
No significant variation of haemoglobin concentration was noted throughout the race (**Table 5**).

### Plasma volume variations (PVV) during the MS

As shown in **Fig. 1**, PV did not significantly vary throughout the race. Only a slight and insignificant decrease of PVV was observed at $D_3$ (−4.7 ± 3.9 %). The end of the MS ($D_6$) was associated with a restoration of the plasma volume (0.5 ± 2.9 %).

**Table 5** Lactatemia, haematocrit and haemogmobin values determined at rest before the Marathon of Sands ($D_0$), 2–3 h after the third stage ($D_3$) and 2 to 3 h after the sixth stage ($D_6$).

| | Lactatemia (mmol.L$^{-1}$) | Haemat-ocrit (%) | Haemoglobin (g/100ml of blood) |
|---|---|---|---|
| before MS ($D_0$) | 1.7 ± 0.6 | 43.2 ± 0.4 | 14.1 ± 0.1 |
| after race 3 ($D_3$) | 1.4 ± 0.9 | 45.2 ± 1.9 | 14.6 ± 0.2 |
| after race 6 ($D_6$) | 1.8 ± 0.2 | 40.7 ± 0.4 * $ | 14.9 ± 0.3 |

*Significant difference between $D_0$ and $D_6$; $p < 0.05$
$Significant difference between $D_3$ and $D_6$; $p < 0.05$

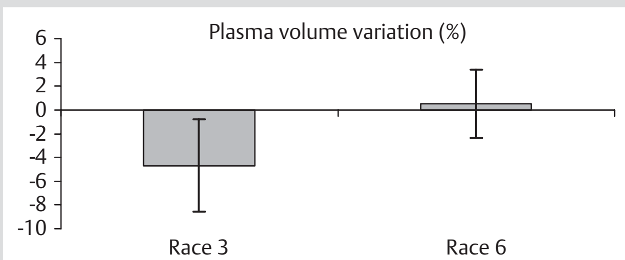


**Fig. 1** Plasma Volume Variation.

Significant relationships between starting body mass and $VO_2max$ (ml/min) ($r = 0.85$; $p < 0.0001$) and between the mean speed during the Marathon of Sands of our athletes and their body weight determined at $D_0$ ($r = -0.52$; $p < 0.05$) at $D_3$ ($r = -0.57$; $p < 0.05$) and at $D_6$ ($r = -0.51$; $p < 0.05$).

## Discussion

This study demonstrated that during the "Marathon of Sands", athletes well-trained in endurance exhibited significant loss of body weight but no significant variation in plasma volume. No medical complications or decreases in performance were observed. These results are in accordance with recent studies [16, 31, 32] that also reported no effect of weight changes on performance during the South Africa Ironman Triathlon.

In this study all the athletes completed the competition. Ten were among the first 100 competitors and 5 among the first 50 in a field of 650 participants. This reflects the high level of performance of the group as well as the adequate level of the preparation for this competition.

The MS induced a significant decrease in the athletes' body mass, which was more pronounced at the end of the competition ($D_6$: −6.1 %) compared to the middle of the MS ($D_3$: −4.3 %). This decrease was observed in all athletes and was associated with a significant decrease of FFM and FM, which was again more pronounced at $D_6$ (−5 % and −1.1 %, respectively for FM and FFM) compared to $D_3$ (−3.5 % and −0.8 %, respectively FM and FFM). Hence, significant relationships were observed between starting body mass and VO2max and between the mean speed during the Marathon of Sands of our athletes and their body weight determined at $D_0$, $D_3$ and $D_6$. In addition, it is important to note that the athlete with the greatest weight changes (5 and 9 % of body weight lost at $D_3$ and $D_6$ respectively) was the fastest one. He terminated the MS in the 6$^{th}$ place from a total of 650 participants. These changes in body weight are among the highest reported, greatly exceeding peak values measured in laboratory trials. However, these results are similar to those reported by Speedy et al. [32] who observed ranges of weight changes (−12 to + 6 %) in the New Zealand Ironman Triathlon. These body mass losses observed in response to endurance exercise are often explained partially by a loss of water stored [26]. Our results do not support the hypothesis that is also proposed by classical studies, which suggests that a weight loss of 7 % or more produces the symptoms and signs of dehydration, which causes exhaustion thus preventing further exercises. Indeed, some of our athletes were able to continue the MS (three more long-lasting stages) without apparent deficiency, even though their percentage of weight loss exceeded that value. Similar results have been previously reported [32]. As suggested by these last authors, new data supports the idea that the percentage of body loss at which exercise must terminate is probably influenced by both environmental and individual factors. Furthermore, a popular statement is that levels of dehydration greater than 2.5 % are associated with linear impairments of exercise performance from 20 to 55 % [2, 6]. This prediction is incompatible with our findings and those of a previous study [16, 32]. In fact, based on the data of Craig and Cummings [6] the 6 % weight loss that we measured would have led to a reduction of performance by 48–132 %.

Haematocrit values measured at rest are comparable to those observed in literature for marathon runners [7, 26]. Indeed, haematocrit values increased slightly at the end of the 3rd stage after 93 km and decreased significantly at the end of the MS. These results are similar to those observed in the literature. Indeed, several studies show that the exercise repetitions which develop endurance induced a decrease of haematocrit [3, 30]. Others observe that the haematocrit values of trained subjects are always lower than those of untrained ones [7]. This decrease of haematocrit in response to endurance training due to a disproportional increase of plasma volume compared to the increase of the red blood cells is well known as sportsman's anaemia [11]. For Selby and Eichner [35], this "pseudo anaemia" must be considered as a physiological adaptation rather than a pathological adaptation.

Haemoglobin rest values are in the range of literature data noted for endurance trained males [9, 26]. As in response to an acute running session, we did not observe any variation of haemoglobinemia in response to the MS [9, 26].

Surprisingly, we did not observe any significant variations in PV despite extreme conditions. Indeed, the MS is an unusual running competition. Taking into account the extremely long duration of each stage, the number of stages, the climatic conditions and the restriction of water intake, we hypothesized that such competition would lead to significant PV decrease. However, we did not observe any significant variation of PVV throughout the competition. Our results are different from those of several studies [5, 19, 26] that reported a decrease of PV after different types of prolonged exercise. These differences can be explained by the different intensity and duration of exercises (walking vs. running and isolated exercise vs. repetition), by the environmental conditions (Europe vs. Africa) or by the hydration conditions (restricted vs. unrestricted).

Classically, when a PV decrease is observed in response to exercise, this change is explained by different mechanisms. The first one is represented by the increase of the blood pressure and by the increase of the hydrostatic pressure, which induce plasma filtration towards extra-vascular compartments [14]. The second one which could explain haemoconcentration is the accumulation of some metabolites such as lactate, ammonium or potassium in the working muscles, which increase the intracellular osmotic pressure and induce water movement from the blood towards the muscular cells [13]. The third mechanism is sweat production, which decreases plasma volume. This sweat production depends on exercise intensity, the training level of the subjects [4] and the environmental conditions.

In our study, the lack of significant PVV may be explained as follows. First, the delay between the end of the race and the blood samplings (2–3 h) may explain in part our results. Indeed, after an acute bout of exercise (marathon or longer-duration exercise) the PV returns to its initial value after one hour of recovery [5, 9, 19]. This result suggests that the PV of our marathon runners was even lower than values measured 2–3 h after the race. However, since we did not measure other factors such as ammonium and potassium, we cannot incriminate this factor to explain our results. The second explanation could be the environmental conditions. Indeed, we hypothesised that the PV of the athlete would decrease throughout the week since water was restricted and environmental conditions are tough in the Moroccan desert. However, it is important to note that this 13$^{th}$ edition of the MS took place in 2002 under relatively inclement temperatures (range 20–30 °C). Thirdly, we can explain the non-variation of PV by the adaptation of some mechanisms that may occur after repetition of exercises. Indeed, a restoration or even an increase of PV is often observed after a succession of long-term exercises of moderate intensity [5, 9]. The same observation was noted by a previous study [15] which observed in male subjects a 19.8 % increase of the PV after 3 times 3.33 miles running in 5 days. The more important increase observed in this last study compared to the increase observed between the third stage and the sixth stage [+8.4 ± 7.9 %] is probably due to the intensity of the exercise. Indeed, in this study [15] the subjects ran at higher relative intensity than our subjects during the MS. In the same way, another work [18] noted in physically active men a 10 % increase in PV after the third day of walking in a period of seven days. Fellmann [9] also observed a progressive increase in the PV during a seven-day period of cross-country skiing. The corresponding increase reached a value of 4 % after day 1 and levelling to 33 % on day 5, and then the value stabilized. A movement of water from the intracellular environment towards the extracellular environment could explain the slight increase in the PV observed in our study between $D_3$ and $D_6$ in the desert, despite the limited water intake [18]. Indeed, it has been demonstrated that during long-duration exercises or during heat exposition when the losses of water are important, the PVV tends to remain constant or increases slightly while the intracellular volume decreases [4]. This relatively small change in extracellular volume is probably due to the lack of the $Na^+$ ions exchanged and to the activation of the hormonal system especially the renin-aldosterone system [20]. Another possible mechanism able to explain this PV restoration is represented by the increase in the protein mass in the vascular space in response to long-term exercises [17]. Indeed, the proteins' entrance into the vascular space facilitates the liberation of water, which accumulates in the active muscles, then goes into the plasma. Another parameter to consider which may explain the return of PV to normal levels is the production of metabolic water, which is linked to the oxidation of the fatty acids and carbohydrates and to the liberation of water during the glycogen degradation in the muscle and in the liver [26].

Concerning PVV, body weight loss and performance, we did not observe in this study any relationship between these parameters. The limited number of blood sampling (at rest, at the middle and at the end of the MS) could mask some possible relationships.

In conclusion, this study demonstrates that despite a succession of long-duration exercises performed in tough conditions of recovery, our athletes exhibited a significant weight loss which can be explained by loss of fat and/or fat-free mass. The findings from this study show that high levels of weight loss may not significantly affect performance. Hence, as previously suggested [16, 25, 32] these results provide compelling evidence that the doctrine that "weight loss during exercise must be less than 2 %" needs to be properly evaluated in prospective trials of competitive events lasting longer than a few minutes.

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### References

1 *Adolph EF, Brown AH, Goddard DR.* Physiology of man in the desert. New York: Interscience 1947; 16–33, 226–241, 326–342
2 *Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS.* American College of Sports Medicine. Position stand: Exercise and fluid replacement. Med Sci Sports Exerc. 2007; 39: 377–390
3 *Convertino VA, Keil LC, Greenleaf JE.* Plasma volume, renin and vasopressin responses to graded exercise after training. J Appl Physiol 1983; 54: 508–514.4
4 *Costill DL, Cote R, Miller E, Wynder S.* Water and electrolyte replacement during repeated days of work in the heat. Aviat Space Environ Med 1975; 46: 795–800
5 *Costill DL, Fink WJ.* Plasma volume changes following exercise and thermal dehydration. J Appl Physiol 1974; 37: 521–525
6 *Craig EN, Cummings EG.* Dehydration and muscular work. J Appl Physiol 1966; 21: 670–674
7 *Dufaux B, Hoederath A, Streitberger I, Hollmann W, Assmann G.* Serum ferritin, transferrin, haptoglobin, and iron in middle and long distance runners, elite rowers, and professional racing cyclists. Int J Sports Med 1981; 2: 43–46
8 *Durnin J, Rahaman M.* The assessment of the amount of fat in the human body from measurements of skinfold thickness. Br J Nutr 1967; 21: 681–689
9 *Fellmann N, Bedu M, Giry J, Amadieu M, Bezou MJ, Barlet JP, Coudert J.* Hormonal fluid and electrolyte changes during a 72 h recovery from a 24 h endurance run. Int J Sport Med 1989; 10: 406–412
10 *Grant SM, Green HJ, Phillips SM, Enns DL, Sutton JR.* Fluid and electrolyte. J Appl Physiol 1996; 81: 2386–2392
11 *Green HJ, Sutton JR, Coates G, Ali M, Jones S.* Reponses of red cell volume and plasma volume to prolonged training in humans. J Appl Physiol 1991; 70: 1810–1815
12 *Greenleaf JE, Convertino VA, Mangseth GR.* Plasma volume during stress in man: osmolality and red cell volume. J Appl Physiol 1979; 47: 1031–1038
13 *Häkkinen K, Pakarinen A, Alen M, Kauhanen H, Komi PV.* Neuromuscular and hormonal adaptations in athletes to strength training in two years. J Appl Physiol 1988; 65: 2406–2412
14 *Harrison MH.* Effects of thermal stress and exercise on blood volume in humans. Physiol Review 1985; 65: 149–209
15 *Hill DW, Hill JS, Grisham SC, Zauner CW.* Plasma volume response to exercise on five consecutive days. J Sports Med. 1987; 27: 6–10
16 *Kao WF, Shy CL, Yang XW, Hsu TF, Chen JJ, Kao WC, Polun-Chan, Huang YJ, Kuo FC, Huang CI, Lee CH.* Athletic performance and serial weight changes during 12- and 24- hour Ultra-Marathons. Clin J Sport Med 2008; 18: 155–158
17 *Koch G, Rocker L.* Plasma volume and intravascular protein masses in trained boys and fit young men. J Appl Physiol 1977; 43: 1085–1088
18 *Leiper JB, Mc Cormick JD, Robertson JD, Withing PH, Maughan RJ.* Fluid homeostasis during prolonged low-intensity walking on consecutive days. Clin Sci 1988; 75: 63–70
19 *Margaret A, Stephenson A, Wilkerson JE.* Erythrocyte indices during a competitive marathon. J Appl Physiol 1982; 52: 168–172

20 *Milledge JS*, *Catley DM*. Renin aldosterone and converting enzyme during exercise and acute hypoxia in humans. J Appl Physiol 1982; 52: 320–323

21 *Nadel JA*, *Mack N*. Influence of fluid replacement beverages on body fluid homeostasis during exercise and recovery. Ex Sci Sport Med 1990; 3: 181–205

22 *Noakes TD*. Fluid replacement during marathon running. Clin Sport Med 2003; 13: 309–318

23 *Noakes TD*. Overconsumption of fluids by athletes. Br Med J 2003; 327: 113–114

24 *Noakes TD*, *Sharwood KA*, *Collins M*, *Perkins DR*. The dipsomania of great distance: water intoxication in an Ironman triathlete. Br J Sports Med 2004; 38: E16

25 *Noakes TD*. Drinking guidelines for exercise: What evidence is there that athletes should either drink "as much us tolerable," "to replace all the weight lost during exercise," or "ad libitum? J Sports Sci 2007; 25: 781–796

26 *Pastene J*, *German M*, *Allevard AM*, *Gharib C*, *Lacour JR*. Water balance during and after marathon running. Eur J Appl Physiol 1996; 73: 49–55

27 *Saunders AG*, *Dugas JP*, *Tucker R*, *Lambert MI*, *Noakes TD*. The effects of different air velocities on heat storage and body temperature in humans cycling in a hot, humid environment. Acta Physiol Scand 2005; 183: 241–255

28 *Sawka MN*, *Monain SJ*. Fluid and electrolyte supplementation for exercise heat stress. Am J Clin Nutr 2000; 72: 564–572

29 *Sawka MN*, *Noakes TD*. Does dehydration impair exercise performance? Med Sci Sports Exerc 2007; 39: 1209–1217

30 *Sharwood KA*, *Collins M*, *Goedecke JH Wilson G*, *Noakes TD*. Weight changes, sodium levels and performance in the South Africa Ironman triathlon. Clin J Sport Med 2002; 12: 391–399

31 *Sharwood KA*, *Collins M*, *Goedecke JH*, *Wilson G*, *Noakes TD*. Weight changes, medical complications, and performance during an Ironman triathlon. Br J Sports Med 2004; 38: 718–724

32 *Speedy DB*, *Faris JG*, *Hamlin M*, *Gallagher PG*, *Campbell RG*. Hyponatremia and weight changes in an ultradistance triathlon. Clin Sport Med 1997; 7: 180–184

33 *Speedy DB*, *Thompson JM*, *Rodgers I*, *Collins M*, *SharwoodK*, *Noakes TD*. Oral salt supplementation during ultradistance exercises. Clin Sport Med 2002; 12: 279–284

34 *Strauss MB*, *Davis RK*, *Rosembaum JD*, *Rossmeil GC*. Water diuresis produced during recumbency by the intravenous infusion of isotonic saline solution. J Clin Invest 1951; 30: 862–868

35 *Selby GB*, *Eichner ER*. Hematocrit and performance: The effect of endurance training on blood volume. Sem Haematol 1994; 31: 122–127