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DOI: https://doi.org/10.1016/B978-0-12-396454-0.00016-3

Originally published at:
Knechtle, B (2013). Nutrition and ultra-endurance: an overview. In: Bagchi, D; Nair, S; Sen, C. Nutrition and Enhanced Sports Performance. Printed and bound in United States of America: Elsevier, 161-170.
DOI: https://doi.org/10.1016/B978-0-12-396454-0.00016-3

Nutrition and ultra-endurance: an overview

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Abstract

In ultra-endurance races, athletes face limits in nutrition regarding energy and fluid metabolism. An ultra-endurance performance lasting for 24 hours or longer leads to a mean daily energy deficit of ~7,000 kcal. This energy deficit leads to a decrease in body mass, covered by a decrease in both fat mass and skeletal muscle mass. The energy deficit cannot be prevented by adequate energy intake. To avoid dehydration during an ultra-endurance performance, adequate fluid intake is required. In case of fluid overload, both exercise-associated hyponatremia and swelling of limbs may occur. Adequate *ad libitum* fluid intake of ~300-400 ml per hour may prevent both exercise-associated hyponatremia and swelling of limbs. To summarize, in ultra-endurance races, an energy deficit seems to be unavoidable. Potential strategies might be to increase pre-race body mass by a diet to increase fat mass and/or strength training to augment skeletal muscle mass. Another possibility could be increasing energy intake during racing by consuming a fat-rich diet. However, future studies are required to investigate these aspects.

Keywords: energy deficit; fluid overload; exercise-associated hyponatremia; limb swelling

Introduction

Ultra-endurance performance is defined as an endurance performance lasting for six hours or longer (1). Ultra-endurance athletes compete for hours, days or even weeks, face different problems regarding nutrition which may occur as a single problem or in combination. The continuous physical stress consumes energy and an energy deficit occurs. Furthermore, ultra-endurance performances may lead to dehydration due to sweating.

We may separate these two problems in (*i*) energy deficit with corresponding loss in solid body masses such as fat mass and skeletal muscle mass and (*ii*) dysregulation of fluid metabolism with dehydration or fluid overload with the risk of exercise-associated hyponatremia (EAH).

Before considering potential aspects of nutrition during ultra-endurance races, we need to review the existing literature regarding the above cited problems. The findings may help to give recommendations or prescriptions for nutrition in ultra-endurance performances.

Problems associated with ultra-endurance performance

Energy turnover and energy deficit in ultra-endurance

An ultra-endurance athlete competing for hours or days with or without breaks expends energy (2-22). Meeting the energy demands of ultra-endurance athletes requires careful planning and monitoring of food and fluid intake (10, 23). Numerous controlled case reports (2,10,13-19,24) and field studies (4,9,25-28) in ultra-endurance performances showed, however, that ultra-endurance athletes were unable to self-regulate diet or exercise intensity to prevent a negative energy. Furthermore, the insufficient energy intake is also associated with malnutrition such as a low intake of antioxidant vitamins (29).

Generally, an adequate food and fluid intake is related to a successful finish in an ultra-endurance race (9,30,31). An important key to a successful finish in an ultra-endurance race seems an appropriate nutrition strategy during the race (31). An energy deficit impairs ultra-endurance performance. In ultra-cyclists, a significant negative relationship between energy intake and finish time in a 384-km cycle race has been demonstrated (28). An ultra-endurance performance leads to an energy deficit (2,4-16,19,21-24,32-39). In Table 1, results from literature are summarized and separated by discipline (*i.e.* swimming, cycling, running and the combination as triathlon). Regarding the single disciplines, the energy deficit seems higher in swimming compared to cycling and running. This might be explained by the different environment (water) compared to cycling and running. For events lasting 24 hours or longer, the energy deficit is highest in multi-sports disciplines and cycling. In running the energy deficit is around three times lower compared to both triathlon and cycling.

Change in body mass during an ultra-endurance performance

An ultra-endurance performance leads to a loss in body mass (Table 2) (2,6-8,10,12,13,16,20-22,32,33,36,38,39-52). The loss in body mass occurs preferably in the lower trunk (6,22,44). Depending upon the length of an endurance performance and the discipline, the decrease in body mass corresponds to a decrease in fat mass (2,8,11,18,19,39,40,46-51) and/or skeletal muscle mass (2,8,17,39,40,42,43,45,46,50). It seems that a concentric performance such as cycling rather leads to a decrease in fat mass (19,49) where as an eccentric performance such as running rather leads to a decrease in muscle mass (43). In runners, a decrease in both fat mass and skeletal muscle mass has been observed (42,43). For swimmers, no change in body mass, fat mass or skeletal muscle mass has been reported for 12-hour indoor pool swimmers (53). In male open-water ultra-swimmers, however, a decrease in skeletal muscle mass was observed (54).

In some instances, an increase in body mass has been reported during ultra-endurance performances (13,16,21,41,44) (Table 2) where also an increase in skeletal muscle mass was found (13,16,19,21,38,41,44) (Table 2). The increase in body mass was most probably due to fluid overload, which will be discussed in the next section. An increase in skeletal muscle mass might occur in cases where anthropometric methods were used and an increase in skin-fold thicknesses and limb circumferences might occur. This will also be discussed in the next section. Overall, ultra-endurance athletes seem to lose ~0.5 kg in body mass and ~1.4 kg in fat mass where skeletal muscle mass seems to remain unchanged. However, total body water seems to increase by ~1.5 L (20,21,36,38,39,40,41,42) (Table 2).

Dehydration, fluid intake and fluid overload

Most endurance athletes are concerned with dehydration during an ultra-endurance performance. It has been shown that body mass became reduced in a 24-hour ultra-marathon (55). However, body mass reduction in ultra-endurance athletes seems rather to be due to a decrease in sold mass and not due to dehydration (46,48,56).

Dehydration refers both to hypohydration (*i.e.* dehydration induced prior to exercise) and to exercise-induced dehydration (*i.e.* dehydration that develops during exercise). The latter reduces aerobic endurance performance and results in increased body temperature, heart rate, perceived exertion, and possibly increased reliance on carbohydrate as a fuel source (57). Fluid replacement is considered to prevent from dehydration and hypohydration has been shown to impair endurance performance (58). Adequate fluid intake helps to prevent loss in body mass (26,59). However, fluid overload may lead to an increase in body mass (60) and a decrease in plasma sodium (60) with the risk to develop exercise-associated hyponatremia (60-62).

Fluid overload may lead to a considerable increase in body mass (60). For example, one athlete competing in a Deca Iron ultra-triathlon covering 38 km swimming, 1,800 km cycling and 422 km running within 12 d 20 h showed an increase in body mass of 8 kg within the first three days (44). In athletes with a post-race increase in body mass, an increase in skin-fold thicknesses and limb circumferences of the lower limb has been recorded (21,44). In another athlete with an increase in body mass, an increase in skin-fold thicknesses at four skin-fold sites has been shown (13). Both these races were held in rather hot environments where most probably fluid intake was rather high. However, also in athletes with a decrease in body mass, an increase in skin-fold thicknesses at the lower limb has been reported (2,39,51). In one athlete with a decrease in body mass after a Triple Iron ultra-triathlon, a considerable swelling of the feet was described (38).

Most probably, the increase in body mass, skin-fold thicknesses and limb circumferences was due to an increase in body water (21,39,63) (Table 2). In several studies, an increase in total body water in ultra-endurance athletes has been reported (20,21,36,38,39,40,41,42,47,64,65). One might now argue about the potential reasons for the increase in both the skin-fold thicknesses and total body water. The increase in total body water might be due to an increase in plasma volume (20,64-67), which might be due to sodium retention (64,66) due to an increase activity of aldosterone (20,68). An association between an increase in plasma volume and an increase in the potassium-to-sodium ratio in urine might suggest that an increased activity of aldosterone (69) may lead to retention in both sodium and fluid during an ultra-endurance performance (37). In a multi-stage race over seven days, total mean plasma sodium content increased and was the major factor in the increase in plasma volume (64).

Apart from these pathophysiological aspects, fluid overload might also lead to an increase in limb volume. A recent study showed an association between changes in limb volumes and fluid intake (70). Since neither renal function nor fluid regulating hormones were associated with the changes in limb volumes, fluid overload is the most likely reason for increase in both body mass and limb volumes. An actual study showed an association between an increased fluid intake and swelling of the feet in ultra-marathoners (71).

Fluid overload and exercise-associated hyponatremia (EAH)

Fluid overload might lead to exercise-associated hyponatremia (EAH), defined as a serum sodium concentration ([Na^+]) <135 mmol/L during or within 24 hours of exercise (72). EAH was first described in the scientific literature in 1985 by Noakes *et al.* (73) in ultra-marathoners in South Africa as being due to 'water intoxication'.

Three main factors are responsible for the occurrence of EAH in endurance athletes: (*i*) overdrinking due to biological or psychological factors; (*ii*) inappropriate secretion of the antidiuretic hormone (ADH), in particular, the failure to suppress ADH-secretion in the face of an increase in total body water; and (*iii*) a failure to mobilize Na^+ from the osmotically inactive sodium stores or alternatively inappropriate osmotic inactivation of circulating Na^+ (72). Because the mechanisms causing factors (*i*) and (*iii*) are unknown, it follows that the prevention of EAH requires that athletes be encouraged to avoid overdrinking during exercise.

EAH is the most common medical complication of ultra-distance exercise and is usually caused by excessive intake of hypotonic fluids (74,75). The main reason for developing EAH is the behaviour of overdrinking during an endurance performance by excessive fluid consumption (61) and/or inadequate sodium intake (76). Subjects suffering EAH during an ultra-endurance performance consumed the double of fluids compared to subjects without EAH (61). Generally, fluid overload is reported for slower athletes (77). However, in ultra-endurance athletes, faster athletes drink more than slower athletes but seem not to develop EAH (78,79).

The environmental conditions seem to influence the prevalence of EAH. Often, EAH is a common finding in ultra-endurance races held in extreme cold (76,80) or extreme heat (60,81). In temperate climates, EAH is relatively uncommon (68,82-95). There seems to be a gender difference where females seem to be at higher risk to develop EAH (80). Compared to marathoners (77,96-98), the prevalence of EAH in ultra-marathoners is, however, not higher (86,95,99).

The prevalence of EAH seems also to be dependent upon the discipline (Table 3). While EAH was highly prevalent in ultra-swimming (80) and ultra-running (81), the prevalence of EAH was low (84,100) or even absent (83,85) in ultra-cycling. An explanation could be that cyclists can individually drink by using their drink bottles on the bicycle. In addition, the length of an ultra-endurance race seems to increase the risk for EAH. The highest prevalence of EAH has been found in Ironman triathlons (91,93), Triple Iron ultra-triathlons (94) and ultra-marathons covering 161 km (60,81).

Nutritional aspects in ultra-endurance athletes

Adequate energy and fluid intake is needed to successfully compete in an ultra-endurance race (101-109). Most studies are descriptive in nature and reporting the distribution of carbohydrates, fat and protein the athletes ingested (2,6,7,13,14,16,101,104,105) (Table 4). Some studies report the kind of food (106-108). Also, some studies investigated the aspect of supplements (110-113).

Intake of carbohydrates

Carbohydrates are the main source of energy intake in ultra-endurance athletes (2,23,39,103). When the intake of carbohydrates, fat and protein was analysed for ultra-endurance athletes, the highest percentage was found for carbohydrates. Ultra-endurance athletes consume ~68% of ingested energy as carbohydrates (Table 4).

Intake of fat

An increased pre-race fat intake leads to an increase in intramyocellular lipids in ultra-endurance athletes (16). Increased intramyocellular lipids might improve ultra-endurance performance; however, there are no controlled data in field studies whether fat loading improves ultra-endurance performance. In a case report, ultra-endurance performance in a rower was enhanced following a high fat diet for 14 days (114). An increased fat intake during an ultra-endurance competition might improve performance. However, also for this aspect, no controlled data of field studies do exist. In a case report on an ultra-marathoner competing in a 6-day ultra-marathon, the athlete consumed 34.6% of fat in his daily food intake (6). Nonetheless, body fat decreased within the first two days and remained unchanged until the end of the race. In addition, performance slowed down after the first two days. Ultra-endurance athletes consume ~19% of ingested energy as fat, which is higher than energy consumed in the form of protein (Table 4).

Intake of protein

Regarding protein intake, athletes consume ~19% of ingested energy as protein during racing. An observational field study at the 'Race across America' showed that ultra-endurance cyclists ingest rather large amounts of protein (106). One might assume that athletes experienced a loss in skeletal muscle mass and try to prevent this loss by the use of amino acids. A recent study tried to investigate whether an increase in amino acids during an ultra-marathon may prevent skeletal muscle damage (115). However, the intake of amino acids showed no effect on parameters related to skeletal muscle damage.

Intake of ergogenic supplements, vitamins and minerals

Vitamin and mineral supplements are frequently used by competitive and recreational ultra-endurance athletes during training (107,108,111,112) and competition (105-108). In some studies, the intake of ergogenic supplements, vitamins and minerals in ultra-endurance athletes and its effect on performance has been investigated (110,111,113). In long-distance triathletes, over 60% of the athletes reported using vitamin supplements, of which vitamin C (97.5%), vitamin E (78.3%), and multivitamins (52.2%) were the most commonly used supplements during training. Almost half (47.8%) the athletes who used supplements did so to prevent or reduce cold symptoms (113). The regular intake of vitamins and minerals seems, however, not to enhance ultra-endurance performance (110,111]. In the 'Deutschlandlauf 2006' of over 1,200 km within 17 consecutive stages, athletes with a regular intake of vitamin and mineral supplements in the four weeks before the race finished the competition no faster than athletes without an intake of vitamins and minerals (109). Also in a Triple Iron ultra-triathlon, athletes with a regular intake of vitamin and mineral supplements prior to the race were not faster (111).

Fluid intake during endurance performance

Ad libitum fluid intake seems to be the best strategy to prevent from EAH and to maintain plasma sodium concentration (36,68,79,116-119). A rather low fluid intake between 300 ml/h and 400 ml/h seems to prevent EAH (36,91,116). A mean *ad libitum* fluid intake of ~400 ml/h maintained serum sodium concentration in a 4 h march (116) and fluid consumption of ~400 ml/h prevent from EAH in a 161-km race in the cold (88).

Sodium supplementation during endurance performance

One might argue that the supplementation with sodium during an endurance race might prevent from EAH. However, two studies on Ironman triathletes showed that *ad libitum* sodium supplementation was not necessary to preserve serum sodium concentrations in athletes competing for about 12 hours in an Ironman (120,121).

Conclusions and implications for future research

Regarding these findings we see that ultra-endurance athletes face a decrease in body mass most probably due to a decrease in both fat mass and skeletal muscle mass. During racing, the athletes are not able to cover the energy deficit. Athletes tend with increasing length of an ultra-endurance performance to an increased fluid intake which seems to lead to both an increased risk for exercise-associated hyponatremia and limb swelling. In summary, an energy deficit seems to be unavoidable in ultra-endurance performances. Potential strategies might be to increase body mass by a pre-race diet to fat mass and strength training to increase skeletal muscle mass. Another possibility could be to increase energy intake during racing by consuming a fat-rich diet. However, future studies are needed to investigate these aspects. Regarding fluid metabolism, the best strategy to prevent both exercise-associated hyponatremia and limb swelling is to minimize fluid intake to ~300-400 ml per hour.

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Distance and/or time	Subjects	Total energy intake (kcal)	Total energy expenditure (kcal)	Total energy deficit (kcal)	Energy deficit in 24 hours (kcal)	Energy deficit per hour (kcal)	Reference
Swimming							
26.6 km	1 male	2,105	5,540	- 3,435	-	- 429	15
26.6 km	1 male	-	-	-	-	- 500	32
24-h swim	1 male	3,900	11,460	- 7,480	- 7,480	- 311	33
Mean ± SD						*- 413±95*	
Cycling							
12 hours indoor-cycling	1 male	2,750	5,400	- 2,647	-	- 220	19
557 km in 24 hours	1 male	5,571	15,533	- 9,915	- 9,915	- 413	24
617 km in 24 hours	1 male	10,000	13,800	- 3,800	- 3,800	- 158	13
694 km in 24 hours	1 male	10,576	19,748	- 9,172	- 9,172	- 382	10
24 hours cycling	6 males	8,450	18,000	- 9,590	- 9,590	- 399	11
1,000 km in 48 hours	1 male	12,120	16,772	- 4,650	- 2,325	- 96	21
1,126 km in 48 hours	1 male	11,098	14,486	- 3,290	- 1,645	- 65	34
2,272 km in 5 d 7 h	1 male	51,246	80,800	- 29,554	- 5,585	- 232	2
4,701 km in 9 d 16 h	1 male	96,124	179,650	- 83,526	- 8,352	- 360	7
Mean ± SD					*- 6,298±3,392*	*- 258±134*	
Running							
160 km in 20 h	1 male	9,600	8,480	- 1,120	-	- 56	35
320 km in 54 h	1 male	14,760	18,120	- 3,360	- 1,493	- 62	8
501 km in 6 days	1 male	39,666	54,078	- 14,412	- 2,402	- 100	6
Atacama crossing	1 male	37,191	101,157	- 63,966	- 3,046	- 127	22
100 km	11 female	570	6,310	- 5,750	-	- 452	36
100 km	27 male	760	7,420	- 6,660	-	- 580	37
Mean ± SD					*- 2,313±780*	*- 229±227*	
Triathlon							
Triple Iron ultra-triathlon	1 male	15,750	27,485	- 11,735	- 6,869	- 286	38
Triple Iron ultra-triathlon	1 male	22,500	28,600	- 6, 100	- 3,404	- 141	16
Gigathlon multi-stage triathlon	1 male	38,676	59,622	20,646	- 9,937	- 414	14
10 x Ironman triathlon	1 male	77,640	89,112	- 11,480	- 7,544	- 314	39
Mean ± SD					*- 6,938±2,699*	*- 288±112*	

Table 1: Energy balance in ultra-endurance athletes in swimming, cycling, running and triathlon

Distance and/or time	Subjects	Change in body mass (kg)	Change in fat mass (kg)	Change in muscle mass (kg)	Change in body water (l)	Reference
Swimming						
24-h swim	1 male	- 1.6	- 2.4	- 1.5	- 3.9	33
12-h swim	1 male	- 1.1	-	- 1.1	-	32
Cycling						
12-h indoor cycling	1 male	- 0.4	- 0.9	+ 0.2	-	19
617 km in 24 hours	1 male	+ 4.0	+ 0.9	+ 2.9	-	13
1,000 km within 48 hours	1 male	+ 2.5	- 1	+ 0.4	+ 1.8	21
2,272 km in 5 d 7 h	1 male	- 2.0	- 0.79	- 1.21	-	2
4,701 km in 9 d 16 h	1 male	- 5	-	-	-	7
Running						
12-h run	1 male	+ 1.5	- 4.4	+ 1.0	+ 4.9	41
320 km in 54 h	1 male	- 0.4	- 0.3	- 1.0	-	8
501 km in 6 days	1 male	- 3.0	- 6.8	-	-	6
100 km in 762 min	11 females	- 1.5	-	-	+ 2.2	36
100 km in 11:49 h:min	39 males	-1.6	- 0.4	- 0.7	+ 0.8	40
338 km in 5 days	21 males	-	-	- 0.6	-	43
1,200 km in 17 days	10 males	-	-3.9	- 2.0	+ 2.3 l	42
Triathlon						
Triple Iron ultra-triathlon	1 male	- 1.1	- 0.4	+ 1.4	+ 2.0	38
Triple Iron ultra-triathlon	1 male	+ 2.1	+ 0.4	+ 4.4	-	16
Deca Iron ultra-triathlon	1 male	+ 3.2	+ 2.4	+ 2.4	-	44
Quintuple Iron ultra-triathlon	1 male	- 0.3	- 1.9	-	+ 1.5	20
10 x Ironman triathlon	1 male	- 1.0	- 0.8	- 0.9	+ 2.8	39
Ironman triathlon	27 males	- 1.8	-	- 1.0	-	45
Triple Iron ultra-triathlon	31 males	- 1.7	- 0.6	- 1.0	-	46
10 x Ironman triathlon	8 males	-	- 3	-	-	47
Mean ± SD		*- 0.45±2.5*	*- 1.41±2.31*	*+ 0.08±1.94*	*+ 1.51±1.30*	

Table 2: Change in body composition in ultra-endurance athletes competing in swimming, cycling, running and triathlon

Distance and/or time	Conditions	Subjects	Pravalence of EAH	Reference
Swimming				
26-km open-water ultra-swim	Moderate	25 males and 11 females	8 % in males and 36% in females	80
Cycling				
665-km mountain bike race	Moderate	25 cyclists	0 %	83
109 km cycle race	Moderate	196 cyclists	0.5 %	84
720-km ultra-cycling race	Moderate	65 males	0 %	85
Running				
161-km mountain trail run	Hot	45 runners	51 %	60
161-km mountain trail run	Hot	47 runners	30 %	81
60-km mountain run	Moderate	123 runners	4 %	86
100-km ultra-marathon	Moderate	50 male runners	0 %	68
100-km ultra-marathon	Moderate	145 male runners	4.8 %	79
24-hour ultra-run	Moderate	15 males	0 %	87
90-km ultra-marathon	Moderate	626 runners	0.3 %	73
160-km trail race	Hot	13 runners	0 %	26
Multi-disciplines				
100-mile Iditasport ultra-marathon	Cold	8 cyclists and 8 runners	44 %	76
161-km race	Cold	20 athletes	0 %	88
Kayak, cycling and running	Moderate	48 triathletes	2 %	89
Ironman triathlon	Moderate	330 triathletes	1.8 %	90
Ironman triathlon	Moderate	330 triathletes	18 %	91
Ironman triathlon	Moderate	95 triathletes	9 %	92
Ironman triathlon	Moderate	18 triathletes	28 %	93
Triple Iron ultra-triathlon	Moderate	31 triathletes	26 %	94

Table 3: Prevalence of EAH in ultra-endurance athletes competing in swimming, cycling, running and multi-sports disciplines

Distance and/or time	Subjects	Intake of carbohydrates (%)	Intake of fat (%)	Intake of protein (%)	Reference
Cyclists					
617 km in 24 hours	1 male	64.2	27	8.8	13
2,272 km in 5 d 7 h	1 male	75.4	14.6	10.0	2
4,701 km in 9 d 16 h	1 male	75.2	16.2	8.6	7
Runners					
100 km	7 males	88.6	6.7	4.7	104
501 km in 6 days	1 male	40.0	34.6	25.4	6
1,005 km in 9 days	1 male	62	27	11	107
Triathletes					
Deca Iron ultra-triathlon	1 male	67.4	15.6	17.0	105
Gigathlon	1 male	72	14	13	14
Triple Iron ultra-triathlon	1 male	72	20	8	16
Mean ± SD		*68.5±13.2*	*19.5±8.5*	*11.8±6.1*	

Table 4: Intake of energy in ultra-endurance athletes in different disciplines