Study on Food Intake and Energy Expenditure During Extreme Sustained Exercise: The Tour de France

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Abstract

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Food intake and energy expenditure (EE) were studied in five cyclists during the 22-day race of the Tour de France. The course is about 4000 km including 30 mountain passages (up to 2700 m altitude) and can be considered as one of the most strenuous endurance endeavors. Nutritional intake was calculated from daily food records. EE was estimated from sleeping time and the low activity period. EE during cycling was predicted based on detailed information.

Mean energy intake (EI) was 24.7 MJ with a highest mean daily EI of 32.4 MJ. Mean EE was 25.4 MJ with a highest mean daily EE of 32.7 MJ. Relative contribution of protein, CHO, and fat was 15, 62, and 23 En% resp. 49% of EI was taken during the race resulting in a CHO intake of 94 $g \cdot h^{-1}$ representing 69 en%. It is questioned whether this amount of CHO is optimal in relation to CHO oxidation and performance.

About 30% from CHO intake came from CHO-rich liquids. High EI resulted in high Ca and Fe intake. For vitamins, especially B_1, this relation was not found. Vitamin B_1 nutrient density dropped to 0.25 mg/4.2 MJ during the race caused by a large intake of refined CHO-rich food items. However, vitamin supplementation was high. Daily water intake was 6.7 l with extremes up to 11.8 l. Therefore, the strategy of intake of large quantities of CHO-rich liquids seems to be the appropriate answer to maintain energy and fluid balance under these extreme conditions.

Key words

energy expenditure, food intake, endurance athletes, cycling, carbohydrate metabolism, vitamins

Introduction

The mechanization of occupational work has reduced daily energy demands drastically and man nowadays tries to reach the limits of human endurance capacity just to prove that he can. English channel swimmers do double crossings; runners run 100 miles.

Also in more regular types of sport, performance levels have become so high that endeavors to make further progress have pushed training efforts to the limits of human tolerance.

Under these conditions nutrition has an important impact. Without the proper balance between energy expenditure and consumption the athlete's competitive capabilities will be hindered.

The need for energy and more specifically carbohydrate is essential to restore glycogen levels and to keep energy balance day after day (9, 25, 26). At the same time, physical and psychological stress have an adverse influence on appetite and digestive function (5). The athlete has to deal with these problems, and it can be assumed that food habits will change dramatically.

There are a few studies that describe the dietary intake and patterns of "elite" athletes who undergo training for competition in prolonged exercise. However, hardly no information is available on extreme endurance competition over several days or weeks. Dressendorfer et al. (10) reported on marathon runners during a 20-day road race with distances avering 28 km/day. Estimated energy intake (EI) was 20.2 MJ. On the average CHO made up 61% of total EI, fat 27%, and protein 12%.

In the Tour de France competing cyclists must pedal about 4000 km over a period of 3 weeks with only 1 day allowed for rest. The course includes 30 mountain passages, the highest of which reaches an altitude of approximately 2700 m. Therefore, it can be considered as the most strenuous endurance endeavor. During this event it was possible to gather data to describe the food habits of these cyclists.

Therefore, the purpose of this study was to quantify the dietary intakes and to find out whether this intake met requirements.

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Tab. 1 Characteristics of the four cyclists before and after the race

Subject	Length (m)	Aerobic power $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	Weight (kg) Before	Weight (kg) After	Body fat (%) Before	Body fat (%) After
I	1.81	75.2	71.6	71.5	13.2	13.2
II	1.80	79.0	75.2	74.0	11.1	10.6
III	1.69	80.8	61.4	61.9	9.8	10.0
IV	1.81	82.4	68.7	68.3	12.1	11.8
Mean	1.78	79.4	69.2	68.9	11.6	11.4

Methods

Eight male cyclists, all from one of the leading professional teams, were recruited to participate in this study. Five of them were willing to record their daily food and nutritional supplement consumption during the race in a specially designed diary. After 4 days of racing, one of the subjects had an accident and was forced to stop. Therefore, during the 2nd and 3rd week another cyclist of the group was asked to participate in this part of the study. Each of them had competed in the Tour de France at least three times previously.

A trained nutritionist gave instructions on filling in the diaries, made weekly checks, and cross-checked with the information about the food supply during the race including caloric beverages. Energy drinks, making up a substantial part of daily energy intake, were provided in standard bottles. From the daily records, energy and nutrient intakes were calculated using the computerized Dutch nutrient data bank (12).

The energy expenditure under these extreme conditions was calculated through the 22 days of the race using the following procedure: Actual sleeping time was recorded and a value of 0.074 kJ $min \cdot^{-1} kg^{-1}$ was used to calculate sleeping energy expenditure (20). Activities during non-racing, non-sleeping time were kept by the cyclists at a minimum so that they could rest, eat, and recover for the next cycling day. Our subjects kept no diary of these activities; we assumed non-racing energy expenditure at 1.5 times the sleeping level. For the race itself, detailed information was available about the length of each race day, altitude difference, road paving, etc.

Energy expenditure was calculated according to Eq. 1 (14, 24):

$$E\,cycl = (K1\,V^3 + K2\,V) \cdot T \pm K3H \qquad \text{Eq. 1}$$

where E cycl is the energy output (Joules); V is the cycling speed ($m \cdot s^{-1}$); T is the cycling time (s); and H is the change (±) in altitude (m). K1, K2, and K3 are factors for air resistance, rolling resistance, and weight, respectively, including weight of the subject and cycle, length of the subject, road pavement, posture, and shielding.

Within 1 week before and 1 week after the tournament, data were gathered on the body composition of the cyclists. Percentage body fat was estimated according to Durnin and Womersley (11) using the sum of four skinfold.

Tab. 2 Mean (± SD) calculated energy expenditure and intake of four cyclists over the total period of 22 days including highest recorded average values and resting day average values

	Energy exp.	Energy intake
Overall mean $MJ \cdot day^{-1}$	25.4 ± 1.4	24.7 ± 2.4
Highest $MJ \cdot day^{-1}$	32.7 ± 1.6	32.4 ± 4.4
Resting day $MJ \cdot day^{-1}$	12.9 ± 0.9	16.1 ± 3.9

Tab. 3 Relative contribution (%) of macronutrients to energy intake

Subject	Protein	Fat	Carbohydrate
1	14	24	61
2	12	23	65
3	16	21	58
4	17	23	58
5*	18	21	61
Mean	15	23	61

*Based on days 8–22

Maximum aerobic power of each subject was measured before the race on an electrically braked cycle ergometer using the continuously increasing stress test (25 $W \cdot min^{-1}$). Oxygen consumption was measured using a face mask connected to an automatic metabolic analyzer (Fynyves and Gut, Switzerland).

Results

In Table 1 the characteristics of the four cyclists who completed their food intake diary over the event are given. Body weight and percentage body fat did not change significantly.

The calculated energy intake and expenditure of the four subjects (Table 2) was balanced very well over the total period, including the rest day. Only a 2.5% difference was calculated, representing a 14 MJ excess in expenditure. The lowest calculated average energy expenditure was 12.9 MJ while energy intake did not drop below 16.1 MJ. The highest mean values per day for EE and EI during one of the mountain days were 32.7 and 32.4 MJ, respectively. In Fig. 1 the calculated mean (± SD) energy intake and expenditure are shown from day to day. Energy intake follows energy expenditure over the full period. During days on which there were sharp increases or decreases in expenditure, intake at first lagged, then changed in order to achieve the balance.

The contribution of macronutrients to energy intake of the subjects is given in Table 3. Remarkable is the relatively large range in the energy percentage of protein. Relative contribution of carbohydrates was high (62 En%) and of fat was low (23 En%) compared with the generally observed values for nonathletic populations (45–50 En% and 40–45 En%, respectively).

The calculated intake of macro- and micronutrients from food and energy containing food supplements such as carbohydrate-rich formula drinks are presented in

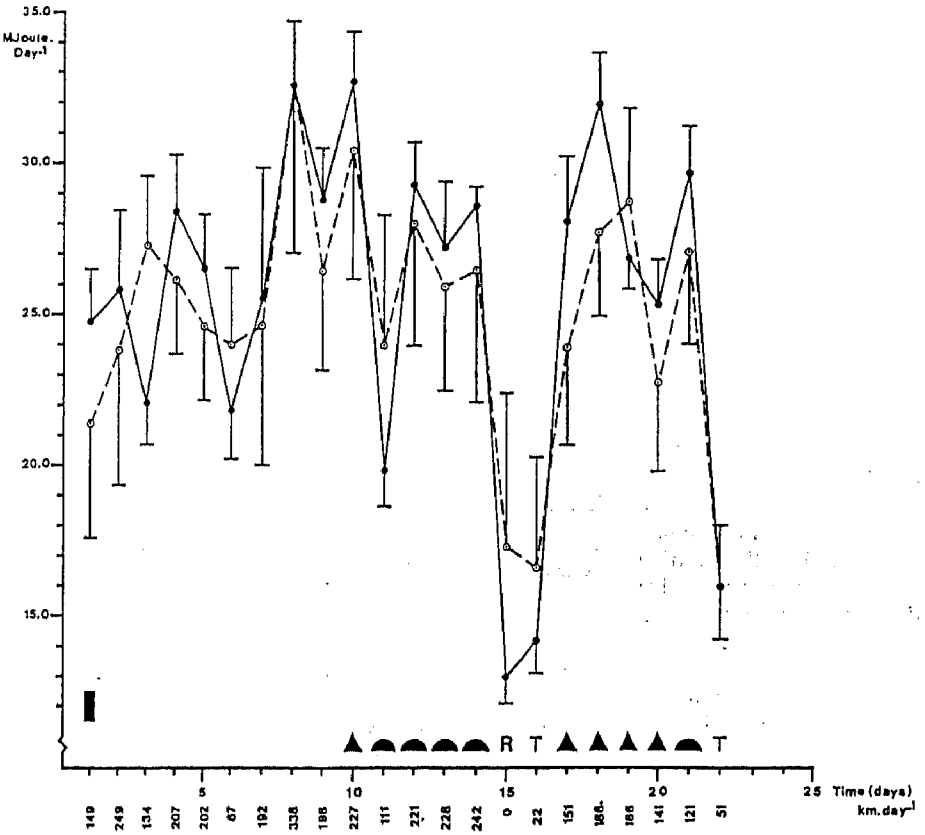

Fig. 1 Mean (± SD) energy intake (MJ · day^{-1}, O---O) and calculated energy expenditure (MJ · day^{-1}, ●----●) of four cyclists during the 22-day race of the Tour de France. Characteristics of the race are plotted on the X-axis. ▲ = mountain parcours; ● = hill parcours; R = resting day; T = time trail race over short distance. Each day cycling distance is given in km. For comparison, recommended energy intake for young adults doing light work is 9.6–13.0 MJ · day^{-1} with a mean intake of about 12 MJ · day^{-1} (10).

Tab. 4 Mean (± SD) daily intake of energy, protein, CHO, fat and micronutrients from food and energy containing food supplements by five cyclists (see note Table 3) and the relative intake (%) during the race

	Mean ± SD	% during the race
Energy (MJ)	24.3 ± 5.3	49
Protein (g)	217 ± 47	35
CHO simple (g)	463 ± 159	61
Complex (g)	386 ± 100	55
Fat (g)	147 ± 39	39
Calcium (mg)	3044 ± 1000	60
Iron Heme (mg)	5.3 ± 1.8	1
nonheme (mg)	24.9 ± 9.4	55
Vit B_1 (mg)	2.4 ± 0.7	44
B_2 (mg)	5.0 ± 1.6	61
B_6 (mg)	2.4 ± 0.7	46
C (mg)	158 ± 146	29
Water (l)	6.7 ± 2.0	61

Table 4. Mean water intake calculated from the water content of the different liquids was 6.7 l with a range from 4.2 to 11.8 l.

Because the RDA value for energy intake of hard physical work was far below the recorded intake, comparison of the micronutrient values with the RDAs is difficult. Especially for the macronutrient-related micronutrients such as vitamin B_1 comparison of absolute values can cover a relative deficit resulting in a decreased nutrient density. Per 4.2 MJ the vitamin B_1 intake is 0.35 mg. Analyzing the vitamin intake during the meals (breakfast, dinner) and intake from food and food supplements during the race resulted in a calculated vitamin B_1 intake per 4.2 MJ of 0.37, 0.25, and 0.41 mg, respectively.

Tab. 5 Estimated extra daily intake of vitamin B complex, vitamin C, and iron, from tablets and injections in five cyclists

	Oral	IM/IV
Iron (mg)	225	100
Vit B_1 mg	30	10
B_2 mg	25	1
B_6 mg	10	0.5
Nicotinamide mg	45	8
B_{12} mcg	85	100
C mg	375	50

Besides the intake of vitamins and minerals from food and enriched food supplements, the cyclists took several concentrated vitamin/mineral supplements orally or by injection (IM/IV). In Table 5, this intake was estimated per day. Unspecified tablets such as liver extracts, ginseng, or royal jelly are not included.

Micronutrient intake from supplements far exceeded the levels of intake from food and food supplements. Especially iron and vitamin B_{12} intakes were extremely high compared with the RDA.

Tab. 6 Relative contribution (%) of food items to nutritonal intake in five cyclists

Energy	%	Protein	%
Sweet cakes	13.7	Meat	14.1
Maltodextrin formula drink[1]	9.8	Enteral formula drink[2]	12.6
Bread	9.0	Skimmed milk	9.2
Macaroni/spaghetti	6.4	Bread	8.2
Sugar	5.9	Sweet cakes	6.6
Enteral formula drink[2]	5.5	Fish	6.6
Skimmed milk	4.6	Macaroni/spaghetti	5.7
Soft drinks	4.1	Protein powder[4]	4.7
Marg/butter	3.5	Cheese	3.8
Isotonic drink[3]	3.5	Chicken	3.3
Meat	2.9	Curd	3.2
Muesli	2.4	Yoghurt	3.0
Cheese	2.1	Egg	2.2
Yoghurt	2.2		
	*		

Carbohydrate	%	Fat	%
Maltodextrin formula drink[1]	15.8	Sweet cakes	27.3
Sweet cakes	14.9	Marg/butter	15.3
Bread	11.3	Cheese	7.0
Sugar	9.4	Skimmed milk	6.8
Macaroni/spaghetti	8.1	Enteral formula drink[2]	4.7
Isotonic drink[3]	5.6	Yoghurt	4.5
Soft drinks	6.6	Meat	3.6
Enteral formula drink[2]	4.2	Bread	3.1
Skimmed milk	2.8	Soup	2.6
Muesli	2.6	Egg	2.4
	*	Chicken	2.4

*Items contributing < 2% are not presented

1. Per l: 2.7 MJ, 155 g CHO
2. Per l: 4.3 MJ, 132 g CHO, 38 g protein, 39 g fat
3. Per l: 1.3 MJ, 70 g CHO
4. Per 100 g: 1.6 MJ, 2 g CHO, 88 g protein, 2 g fat

Analyzing the importance of the different food products to the nutritional intake in Table 6 the most important food items, contributing for more than 2% to the total energy intake, are ranked. Important food items for the energy and carbohydrate intake were sweet cakes, a maltodextrin formula drink, and bread. With respect to protein intake, meat and a standard tube feeding drink were important and finally for the fat intake sweet cakes unexpectedly turned out to be the most important food item (27.3%).

Discussion

It is obvious that these cyclists must have an extraordinary high standard of physical fitness to finish the competition. In 1937 and 1955 data of eight internationally known distance runners and six cross-country skiers were published under the heading "New Records in Human Power" (1, 21). The maximal aerobic power values for these men ranged from about 70 ml O_2 $kg^{-1} \cdot min^{-1}$ to a maximum value of 81.7 ml O_2 $kg^{-1} \cdot min^{-1}$. Except for some individually outstanding values (2), it seems that levels of 75–83 ml O_2 $kg^{-1} \cdot min^{-1}$ represent the top of aerobic power for today's elite endurance athletes. It is interesting to note that these values have not changed essentially since the 1937 measurements, despite advance training methods.

The capacity of the body for hard muscular exercise maintained for several hours has a definite limit.

Up to now, in this respect lumbering has been referred to as perhaps the hardest physical work undertaken. Energy levels of 20–25 MJ have been reported with the absolute record of 33 MJ per day to the Maine lumbermen reported by Woods and Mainsfield (27).

The mean expenditure value observed in our study of 25.4 MJ is the highest over a period longer than 1 week reported so far. The mean EE during the 5-day period in the mountain stages was even 28.4 MJ per day. Recently, Dressendorfer et al. (10) reported on EI of marathon runners during a 20-day 500-km road race. On the average EI was 20.2 MJ. Based on data form mammals and birds under energy-demanding conditions such as rapid growth or hard physical work, Kirkwood (15) suggested that there is an interspecies limit in metabolic rate (4–5 times basal metabolic rate, BMR). Our data include average values for 24 h of 3.4 BMR over the total period with a highest value of 4.4 BMR. The results from the measurements with the doubly labeled water technique showed even higher values of 4.3 to 5.2 times BMR indicating that these cyclists are really on the edge of human endurance capacity (23).

Energy intake met energy expenditure very well. Apparently these cyclists have balanced their intake to expenditure on a day-to-day basis. A large negative balance on one day can hardly be overcome the next day due to the limited digestive capacity of the gastrointestinal tract.

From Fig. 1 one can see that over a period of about 3 days energy intake met energy expenditure. Especially the resting day was not used as a catch-up day for energy intake. In fact the possibilities for extra energy intake after days with a negative balance is limited due to the fact that expenditure already forced the digestive system to perform at relatively high levels. From Table 3 one can see that carbohydrates were the preferred energy source. From the studies on muscle metabolism, it is well known now that carbohydrates are the preferential fuel source to keep muscle glycogen on an acceptable level to have a maximal power output (19). It can be assumed that the need for carbohydrates is the most important concern of a cyclist under these extreme conditions. Therefore, the relative intake of fat was low in all five subjects. Digestive problems and the lowered preference for this type of fuel led to such a low intake despite the advantage of a higher energy content of fat.

However, it is remarkable to see that 27.3% of the fat intake came from sweet cakes which were eaten during the race. A better food choice can lead to a lower value in favor of the carbohydrate intake.

Another important aspect of the carbohydrate intake is the question about the desired upper level. Costill and Miller (8) suggested that for endurance exercise an intake of 65%–70% carbohydrates is optimal. Based on the idea that carbohydrate is the preferred fuel during a high power output, one should recommend CHO intake values as high as possible. In the study of Brouns et al., it was shown that endurance performance was increased remarkably when CHO intake was in-

creased from 60 En% to about 80 En% (7). To achieve such a high level of CHO intake specially designed CHO-rich liquid food supplements are essential.

Already in our cyclists with a CHO intake of 61 En% about one-third came from liquid CHO-containing food items. During such a competition the athlete must take measures for maintaining body carbohydrate stores during the race as well as repletion of the stores within 18 h for the race on the next day. Several recent studies have now demonstrated that glycogen stores can be normalized within 24 h, provided that the diet contains an adequate proportion of CHO. Costill and Miller (8) suggested that the consumption of a 70 En% CHO diet with 7 g CHO $kg^{-1} \cdot day^{-1}$ will replenish the glycogen stores between daily training sessions. Bergström et al. (3) and Kochan et al. (16) reported on values of 9.3 and 11.3 g CHO $kg^{-1} \cdot day^{-1}$. In our study a mean value of 12.3 g CHO $kg^{-1} \cdot day^{-1}$ was found at a 60 En% CHO level. In the comparable field study with marathon runners, Dressendorfer et al. found 10.1 g CHO $kg^{-1} \cdot day^{-1}$ at a 61 En% CHO level (10).

From the study of Brouns et al. (6, 7), it was shown that during a 2-day cycling exercise program with an expenditure of 26.8 and 25.2 MJ the amount of CHO oxidized was nearly 850 g CHO or 11.6 g CHO $kg^{-1} \cdot day^{-1}$ with a CHO intake of 8.6 g CHO $kg^{-1} \cdot day^{-1}$ (60 En%). Increasing the CHO intake with the same exercise protocol led to an oxidation rate of nearly 13 g CHO $kg^{-1} \cdot day^{-1}$ despite the fact CHO intake was 16 g CHO $kg^{-1} \cdot day^{-1}$ (80 En%).

Therefore, it is suggested that 12–13 g CHO $kg^{-1} \cdot day^{-1}$ under conditions of extreme endurance exercise is the range of maximal contribution of CHO to energy metabolism. If this hypothesis is true, further improvement of the cyclists' diet to 70 En% CHO is not required to perform at a maximal level.

Based on the results in Table 4 and the total cycling time over 22 days (mean 115 h), it is possible to calculate food intake during the race. Energy intake was about 2.3 $MJ \cdot h^{-1}$ and CHO intake appeared to be 94 g $CHO \cdot h^{-1}$ or 1.37 g $CHO \cdot kg^{-1} \cdot h^{-1}$ representing 69 En%. In the study of Brouns et al. (6, 7), energy intake during exercise (4.8 h) was 2.4 $MJ \cdot ^{-1}$ and CHO intake contributed for 88% to energy intake representing 125 g $CHO \cdot h^{-1}$ or 1.72 g $CHO \cdot kg^{-1} \cdot h^{-1}$.

In a recent study by Kuipers et al. with highly trained cyclists (17), it was demonstrated that a CHO intake of 2.2 $g \cdot kg^{-1} \cdot h^{-1}$ during a 3-h exercise period at 40% Wmax promotes glycogen synthesis, especially in the previously depleted fast-twitch muscle fibers, which may enable an athlete to sprint even after 5–6 h of cycling.

From heart rate recordings (Sport tester PE 3000) in two cyclists during the Tour de France, it was observed that work intensity varied from 40% to 80% with a mean intensity of about 60%–65% (unpublished data).

It is interesting to speculate whether the observed values of 1.37–1.72 g $CHO \cdot kg^{-1} \cdot h^{-1}$ during such an exercise intensity will result in glycogen synthesis. However, this will require further investigation.

Remarkable is the observed range for protein intake. From studies investigating the protein needs during hard physical work, levels of maximal 1.5–2.0 $g \cdot kg^{-1} \cdot day^{-1}$ have been advised (18). Due to the high energy intake a 12 En% of protein results in an absolute value of 2.5 $g \cdot kg^{-1} \cdot day^{-1}$. Therefore, it can be concluded that levels of 14–18 En% protein have a negative effect on carbohydrate intake and probably the endurance capacity. The intake of protein supplements therefore becomes superfluous.

The general dietary change from fat to carbohydrate has its effect on the micronutrient intake. About 82% of the iron intake resulted from non-heme sources such as wheat. The absolute level of intake for calcium and iron was high. This is in agreement with the findings of Blix (4) and van Erp-Baart et al. (13) who suggested that for intake of both minerals there is a linear relationship with energy intake. A high energy intake resulted in a high iron and calcium intake. The higher intake of carbohydrate-rich food did not alter this relationship.

With respect to the vitamin intake, this linear relationship with energy intake was not found. Especially for vitamins B_1 and B_6 there was a tendency for a relatively lower intake. Differentiation between meals and food intake during the race showed a low nutrient density of vitamin B_1 in the sweet cakes. In principle, these food items contain refined carbohydrates to reduce under these conditions the not absolutely necessary nutrients such as fibers. However, due to the fact that the quantity of this type of food products is large, nutrient density for B_1 dropped to 0.25 mg per 4.2 MJ during the race. The food supplements fortified with vitamins prevents a drop below 0.25 mg per 4.2 MJ.

On the other hand, this question of food quality is of academic value if the micronutrient intake from pills and injections is taken into account. From Table 5 it is clear that the supplement intake of vitamins and minerals far exceeded that derived from food. However, the observed elevated dosages of intake are within acceptable levels in relation to detrimental effects.

As a result plasma vitamin concentrations were elevated up to 400% compared with controls and did not change significantly during the race (22).

Another critical nutrient in relation to prolonged exercise is water, especially if the exercise is undertaken in a hot environment. Sweat rates of $2 l \cdot h^{-1}$ are possible during prolonged exercise under these conditions. Individual values of more than 10 l intake per day were recorded in this study. Mean intake during the race was 6.7 l but varied considerably from day to day. No data about the weight just before and after the race are available but it is interesting to notice that body weight difference between evening (9:00 pm) and morning before breakfast (ca. 8:00 am) was 1.0 kg on days 7–8 and 1.5 kg on days 15–16 (23). These higher values in the evening indicate that a dehydration status was unlikely about 4 h after the race.

Therefore, the strategy of intake of large quantities of liquid carbohydrate-rich formulas seems to be one of the appropriate nutritional answers to optimize performance during extreme sustained exercise.

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