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Energy Turnover at the Race Across AMerica (RAAM) – a Case Report

Abstract

We report about energy intake and energy expenditure in an official finisher of the Race Across AMerica (RAAM) in 2003. Energy intake from nutrition was continuously recorded. Energy expenditure was measured by continuous heart rate recording with a portable heart rate monitor POLAR® S710 to estimate energy expenditure during physical activity. Our athlete (33 years, 179 cm, 73 kg, VO_2max 60 ml · min^{-1} · kg^{-1}, lactate threshold at 77% VO_2max) finished the 4701-km cycling race with altitude differences amounting to 25 826 meters in 9 days 16 hours and 45 minutes in 4th place. He completed 470 ± 72.9 km (372 – 541 km) per day with 2582 ± 1576 (683 – 5047) meters of altitude. During the whole race, he expended a total energy of 179 650 kcal with 17 965 ± 2165 (15 100 – 23 280) kcal per day. Total energy intake was 96 124 kcal with an average of 9612 ± 1500 (7513 – 12 735) kcal per day. Of total ingested calories, 75.2% derived from carbohydrates, 16.2% from fat, and 8.6% from protein. He ingested an energy of 9612 ± 1550 (7513 – 12 735) kcal daily, consisting of 1814 ± 310 (1336 – 2354) g of carbohydrates, 172 ± 47 (88 – 251) g of fat, and 207 ± 52 (128 – 286) g of protein. The average daily energy deficiency amounted to 8352 ± 2523 (4425 – 13 631) kcal. A total deficiency of 83 526 kcal resulted after the race while the athlete lost 5 kg of body weight. These results provide data about energy intake and energy expenditure in the RAAM for future athletes, nutritionists and coaches. Further investigation should be performed in order to determine whether either muscle mass or body fat will be lost in extreme endurance cycling.

Introduction

The Race Across AMerica (RAAM) is considered to be the hardest cycling race all over the world. Cyclists cover a distance of nearly 5000 km from the Pacific Coast to the Atlantic Coast within eight to ten days, competing about 20 hours per day.

To finish this event as official finisher, an enormous effort has to be performed and huge amounts of energy have to be ingested and digested. As far as we know, there are two case reports about energy intake in cyclists finishing the RAAM [7,20]. In these reports, intake of nutrition is reported, but energy expenditure was not determined.

The aim of our case study was to assess energy expenditure and energy intake during the RAAM.

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Methods

Subject

Our subject was a non-professional well experienced endurance cyclist (33 years, 179 cm, 73 kg). He started for the first time in the RAAM having completed several 24 hours cycling races before and cycling about 900 to 1000 hours per year. The athlete gave written informed consent for collecting data during the race.

Laboratory testing before the race

One month before the race, a VO_2max was performed on a stationary cycle ergometer (Ergoline 900®, Ergoline, Bitz, Germany) to assess VO_2peak. Exercise protocol started at 100 W and was increased 30 W every 3 minutes until exhaustion. During exercise, oxygen uptake (VO_2) was measured continuously (Oxycon Pro, Jaeger, Würzburg, Germany). The portable heart rate monitor POLAR® S710 (POLAR Electro Oy, Kempele, Finland) was properly programmed with gender, age, weight, and the VO_2max in order to determine energy expenditure (EE) during physical exercise [12,13]. Due to the fact that measurement of EE during exercise with POLAR® S710 starts at 90 beats per minute (bpm), we had to determine resting metabolic rate (RMR) by indirect calorimetry. The athlete was sitting on the cycle ergometer at rest. VO_2 and VCO_2 were continuously calculated from inspiratory oxygen concentration (FIO_2), expiratory oxygen concentration (FEO_2), and ventilation (VE). VO_2 and VCO_2 during 10 min were used to calculate the oxidation rate of carbohydrate and fat. Oxidation rate of fat and carbohydrate were calculated using the stoichiometric equations of *Frayn* (10), where oxidation of carbohydrates is $4.55 \cdot VCO_2 - 3.21 \cdot VO_2 - 2.87\,n$ and oxidation of fat is $1.67 \cdot VO_2 - 1.67 \cdot VCO_2 - 1.92\,n$. According to the study of Romijn et al. [25], nitrogen excretion rate (n) was assumed to be $135\,\mu g \cdot kg^{-1} \cdot min^{-1}$. Energy expenditure from fat and carbohydrate were converted into $kcal \cdot min^{-1}$ by multiplying the oxidation rate of fat with 9.1 and the oxidation rate of carbohydrate with 4.2 using the *Atwater* general conversion factor [4].

Collecting data during the race

All food supplied to the athlete during the race was continuously recorded. Nutrition consisted exclusively of commercial food with detailed description of content (E. C. Robins Switzerland GmbH, Cham, Switzerland). The athlete ingested mainly liquid carbohydrates in combination with protein. Heart rate (HR) was continuously monitored with the portable heart rate monitor POLAR® S710 and expenditure of calories recorded. The heart rate monitor POLAR® S710 was programmed and used according to the instructions of the manufacturer.

The race

On June 15th, 2003, the 22nd RAAM from San Diego (CA) to Atlantic City (NJ) over 4701 km took place. During the first three days, the athlete had to climb 12 000 meters in altitude, in the last two days again some 8000 meters. The weather was fair throughout the whole race. In the desert of New Mexico, temperature rose to 48° Celsius. During the night, lowest temperature was 5° Celsius. The cyclist had some minor problems with his buttocks, muscles, and joints. Low back pain and pain in both knees had no influence on performance. He suffered from the harsh ascents in the mountains resulting in problems with food intake. He had cycled for 20 hours per day with two hours of sleep per day. At the beginning of the race, he was in 5th position. Due to the above mentioned problems in the mountains, he dropped back to 11th place. Towards the end of the race he made up during the last 1600 km and finished in 4th position. A support crew in a pace car and a second support crew in a mobile home were responsible for the correct cycling direction and delivery of nutrition. The pace car was equipped with a satellite navigation system and a road book in order to find the correct way assigned by the organizer.

Results

Laboratory testing before the race

In the VO_2max test, our athlete completed 370 W ($5.28\,W \cdot kg^{-1}$) and reached a VO_2max of $60\,ml \cdot min^{-1} \cdot kg^{-1}$. Lactate threshold was 77% VO_2max. RMR was $2.42\,kcal \cdot min^{-1}$ resulting in 3480 kcal in 24 hours.

Performance and energy expenditure during the race

The cyclist covered the total distance of 4701 km with 25 826 meters of altitude in 9 days 16 hours and 45 minutes and finished in 4th place. He completed 470 ± 72.9 km (372 km – 541 km) per day with 2582 ± 1576 (683 – 5047) meters of altitude. During the whole race he expended a total energy of 179 650 kcal with 17 965 ± 2165 (15 100 – 23 280) kcal per day (Table **1**).

Energy intake

During the race total energy intake was 96 124 kcal with an average of 9612 ± 1500 (7513 – 12 735) kcal per day. Of total calories, 75.2% were from carbohydrates, 16.2% from fat, and 8.6% from protein. He ingested an energy of 9612 ± 1550 (7513 – 12 735) kcal per day, consisting of 1814 ± 310 (1336 – 2354) g of carbohydrates, 172 ± 47 (88 – 251) g of fat, and 207 ± 52 (128 – 286) g of protein (Table **2**).

Table **1** Performance and energy expenditure (EE)

Day	*Distance [km]*	*Altitude [m]*	*EE [kcal]*	*EE-EI [kcal]*
1	541.8	3932	23280	13631
2	340.3	5047	19080	10251
3	482.2	2975	18470	9288
4	526.5	933	17920	6370
5	570.2	683	17160	4425
6	372.2	1856	16680	7319
7	470.3	1225	17170	6934
8	502.3	1341	17970	9712
9	426.2	4429	16820	8009
10	469	3405	15100	7587
Average	470.1	2582.6	17965	8352
SD	72.94	1576.8	2165	2523
Total	4701	25826	179650	83526

Table **2** Energy intake (EI)

Day	*CHO [g]*	*FAT [g]*	*P [g]*	*CHO [kcal]*	*FAT [kcal]*	*P [kcal]*	*EI [kcal]*
1	1922	148	156	7691	1332	626	9649
2	1715	148	159	6860	1332	637	8829
3	1867	88	229	7468	795	919	9182
4	2192	251	128	8771	2266	513	11550
5	2354	243	282	9416	2191	1128	12735
6	1650	179	286	6601	1613	1147	9361
7	1947	164	243	7788	1476	972	10236
8	1463	182	190	5853	1642	763	8258
9	1695	172	194	6486	1548	777	8811
10	1336	150	203	5345	1353	815	7513
Average	1814.1	172.5	207	7227.9	1554.8	829.7	9612.4
SD	310.7	47.3	52.9	1259.1	427.5	211.9	1550
Total	18141	1725	2070	72279	15548	8297	96124

Table **3** Temperature and water intake

Day	*Lowest temperature [° Celsius]*	*Highest temperature [° Celsius]*	*Intake of water [l]*
1	17	42	19.1
2	20	48	14.7
3	20	38	11.8
4	10	30	14.4
5	12	30	17
6	13	33	11.8
7	17	34	13.2
8	15	30	13.4
9	12	28	10.7
10	15	31	14.3
Average			14.04
SD			2.5
Total			140.4

Energy deficiency

The athlete lost five kg of body weight. A total deficiency of 83 526 kcal resulted after the race, calculated from energy intake and EE. The average daily energy deficiency was 8352 ± 2523 (4425 – 13 631) kcal (Table **1**).

Temperature and water intake

The highest temperature was measured in the desert of New Mexico (Table **3**). Water intake varied from 10.7 to 19.1 l per day with a daily average of 14.04 l (Table **3**).

Discussion

As far as we are aware, this is the first time, energy intake and energy expenditure have been described in an official finisher of the RAAM.

Performance

Our cyclist finished in 9 days 16 hours in 4th place, about 17 hours behind the winner finishing in 8 days 23 hours. The last official finisher of the race took 12 days 1 hour. The cyclist described by Lindeman in 1991 finished in 10 days 7 hours [20], the female cyclist described by Clark et al. in 12 days 6 hours [7]. Therefore, the performance of our cyclist can be rated as excellent.

Determination of energy expenditure (EE) during the race

In this case study, we used the method of HR monitoring in order to determine EE during exercise. The determination of EE in free living humans can be done with a variety of methods. In general, EE is determined with the method of doubly-labelled water [2], which can also be used under field condition [11]. The doubly-labelled water method is accurate, but expensive [2]. Other possibilities are telemetric systems for oxygen uptake measurements, motion sensors, and accelerometers. Most of these methods available for measuring EE in field settings are impractical and expensive [2]. HR recording was explored in an attempt to develop a simple and low-cost technique to predict EE during physical exercise [19]. HR recording is a feasible, reasonably priced, and an accurate method due to the new technology of portable HR monitors [12,13]. In addition to the other above mentioned methods, the relationship between HR and VO_2, which reflects EE, provides an accurate method for predicting EE. The relationship seems to be linear during dynamic muscle work up to about 85% of the individual maximal HR, after which point the relationship turns unlinear [19].

Compared with indirect calorimetry and doubly-labelled water, the HR method shows no differences, even when differences between subjects and within subjects are reported [19]. The satisfactory predictive power and low cost of the method makes is especially suitable for field applications and therefore we decided to determine EE with the portable heart rate monitor POLAR® S710. There are only a few results of EE in extreme endurance. Hill and Davis [11] reported in 2001 about an ultra runner running around Australia. EE was measured using the doubly-labelled water technique during a two-week period of the complete run. During these two weeks, the subject's total daily EE varied between 6095 and 6550 kcal. The runner completed the 14 964 km within 195 days, running 76.7 km per day. The same EE is reported in endurance cycling. During one day in the *Tour de France,* about 6069 kcal were expended [26]. The EE of around 6000 to 7000 is rather low compared to a cyclist, cycling for 24 hours, described by White et al. [29] in 1984. Their cyclist expended an estimated energy of 82 680 kJ equivalent to 19 756 kcal. This corresponds with our results of 17 965 kcal per day (Table **1**). The differences in daily EE between the runner in Australia and the cyclist in the 24-hour race were due to duration and intensity of exercise during 24 hours. The runner was active for about 10 hours per day while the cyclist cycled for 24 hours and our athlete for 20 hours. Also in the *Tour de France,* EE of cyclists cycling for about 6 hours per day was 7027 kcal to 8604 kcal depending upon the intensity of the race [26].

Intake of energy during extreme endurance

The cyclist at the RAAM described by Clark et al. [7] ingested around 7950 kcal per day, the cyclist from Lindeman [20] 8429 kcal per day. These two ingested less calories than our cyclist with 9612 kcal per day (Table **2**). These differences are probably due to the different performances as mentioned above. Our subject had an energy intake of 53% EE. Energy intake during extreme endurance is reported up to 54% of EE [29].

Although the most important fuel during prolonged exercise is fat [8] and intensity during extreme endurance is at around 60% VO_2max [22] where energy mainly derives from fat stored in the body, energy intake during extreme endurance consists mainly of carbohydrates [5] in order to maintain stable plasma glucose [20]. Intake of carbohydrates in percentage of ingested energy seems to be dependent upon the kind of exercise. Percentage of carbohydrates in energy intake lies around 70% [26] in cycling races. Carbohydrate intake is limited due to oxidation in exercising muscles. Maximal oxidation rates occur at exogenous intakes of 1.0 to 1.5 g per minute [15]. Our subject ingested 1.25 g carbohydrates per minute (Table **2**).

Loss of body mass and energy deficiency

We measured a loss of 5 kg body weight and calculated a deficiency of 84 000 kcal after the race. An energy deficiency of 5000 to 10 000 kcal corresponds to about 1 kg of fat or 2 to 4 kg of active tissue like muscle. During endurance exercise, energy mainly derives from oxidation of carbohydrates and fat [8]. During cycling at moderate intensity, 45% of consumed energy derives from fat and 55% from carbohydrates [16]. In long lasting endurance exercise, fat is the main energy source, but also oxidation of protein delivers around 10% of energy [17]. During extreme endurance, circulating amino acids decrease about 20 to 50% [18]. Now the question remains, whether the deficiency is either from loss of fat of subcutaneous adipose tissue or from protein of skeletal muscle. In the human body energy is stored in subcutaneous adipose tissue (80 543 kcal), in intramyocellular lipids (3597 kcal), in glycogen in the muscles (1434 kcal), in glycogen in the liver (360 kcal), in glucose in the plasma (76 kcal) and in protein (2103) [21]. It has been shown in several studies, that during extreme endurance running over hundreds and thousands of kilometers, muscle mass [23] and subcutaneous adipose tissue [24] are reduced. Due to the fact that running as an eccentric exercise leads to severe muscle damage [27], loss of body weight during extreme endurance may be a combination of loss of muscle mass and subcutaneous adipose tissue.

With increasing intensity and duration of exercise, more skeletal muscles will be destroyed and therefore less fat from subcutaneous adipose tissue will be oxidized [14]. When carbohydrates are burned in a calorimeter, 1 g of carbohydrates delivers 4.06 kcal, 1 g of fat 9.55 kcal, and 1 g of protein 5.49 kcal. Presuming a loss of muscle mass and adipose subcutaneous tissue during extreme endurance mainly, we could calculate to lose around 6 to 7 kcal in 1 g of body tissue. A loss of 5 kg body weight will therefore be equal to a loss of 30 000 to 35 000 kcal. Even when we would calculate that 5 kg fat are lost equal to 45 000 kcal, there is still a difference of 40 000 to 50 000 kcal in our cyclist which cannot be explained properly. This difference could be due to an overestimation of EE or influence of body weight by changes of fluid metabolism. Probably the EE determined by the portable heart rate monitor POLAR® S710 was slightly overestimated due to environmental factors like heat. Dehydration and ambient temperature may have a profound effect on the relationship heart rate – VO_2 [1] and may influence EE determined by heart rate monitoring. In the heat, elevation in heart rate during submaximal exercise is related with an increase in VO_2 [3]. Another reason could be that the body weight measured after the race was influenced due to changes in water metabolism. After extreme endurance body weight can decrease or increase due to changes of fluids. A decrease of body weight due to changes in water metabolism can occur in the state of dehydration. Extreme endurance may lead to dehydration with severe loss of water and remarkable decrease of body weight. But also an increase in body weight is possible after extreme endurance as a result of protein catabolism or fluid overload. It has been shown that extremely long endurance exercise results in protein catabolism leading to a decrease in serum protein [18]. This could lead to hypoproteinemia with peripheral edema [6]. Edema may result after hypoalbuminemia due to reduced oncotic pressure which could increase body weight. Peripheral edema becomes clinically visible after accumulation of several liters of water resulting in an increase of several kilograms of body weight [9]. In extreme heat, athletes should drink in order to prevent dehydration. Endurance athletes are at risk to develop hyponatremia which could be due to fluid overload [28]. It has been shown that hyperhydration can severely increase body weight [28].

Water intake during extreme endurance

Apart from energy, insufficient water intake would have detrimental effects of performance in ultra endurance due to dehydration. Depending upon duration of physical exercise and environment, water intake varies. Hill and Davies [11] reported for their runner an average daily water intake of 5.9 to 6.3 l where Lindeman [20] described a water intake of 15.7 l during the

RAAM. The water intake of our cyclist was at 14 l per day (Table **3**). He ingested regularly liquid carbohydrates according to the schedule of the support crew. The fluid intake of our athlete was higher than in the previously mentioned studies. This could be explained by the extreme heat and/or the higher speed of our cyclist compared to the athletes of Lindeman [20] and Clark et al. [7].

Conclusion

An official finisher of the RAAM faced an EE of 17 965 kcal per day with an energy deficiency of 8352 kcal per day due to the limited energy intake of 9612 kcal per day. Carbohydrates were the main energy source representing 75% of ingested energy. He lost 5 kg of body weight during the race. Further investigation should be performed in order to determine whether either muscle mass or body fat will be lost in extreme endurance cycling.

For determination of EE in highly trained endurance athletes, an own equation for heart rate and metabolic rate should be used. Intake and excretion of water should consequently be determined in order to measure changes of body weight correctly.

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