Energy Expenditure in the Race Across America (RAAM)

Authors

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Key words

- doubly labelled water
- energy expenditure
- ultra endurance exercise

Abstract

Energy Expenditure was measured with doubly labelled water technique during heavy sustained exercise with an official finishing team in the Race Across America. Energy Intake was also calculated to produce an energy balance for the race. A team of 4 cyclists (Mean $\pm$ SD age: 37 $\pm$ 4 yr; body height: 182 $\pm$ 8 cm; body mass: 80.8 $\pm$ 6.6 kg) completed the race in a relay fashion. The team completed the race in 6 days 10 h and 51 min. Total mean energy expenditure was found to be 43 401 kcal (181 711 kJ) with a mean daily energy expenditure of 6420 kcal (26 879

kJ). Total mean energy intake from all food and drink consumed was calculated at 29 506 kcal (123 536 kJ) with a mean daily energy intake of 4918 kcal (20 591 kJ). This resulted in a total mean energy deficit of 13 878 kcal (58 104 kJ) with a mean daily energy deficit of 1503 kcal (6 293 kJ). The high energy expenditure highlights the need for correct and practical dietary strategies and challenges nutritionists to devise high energy diets that not only contain the correct macronutrient balance, but are also palatable to the cyclists, thus encouraging a high energy intake.

Introduction

Ultra endurance cycling events such as the Race Across America (RAAM), Tour de France and XXAlps cycle race place huge physiological and psychological demands upon the body. In order to maintain the intensity throughout these races strict dietary strategies need to be employed to maximise the body's glycogen stores and preserve hydration status, thus eliminating the onset of fatigue and any decrements in performance. Investigating energy intake (EI) of successful ultra endurance athletes can provide useful information for future performance. Furthermore, advanced knowledge of the likely energy expenditure (EE) during such events provides the general athletic community, coaches and nutritionists with a better guide and enhances preparation to improve appropriate energy intake.

There are many different techniques for measuring EE, all of which have advantages and limitations. The doubly labelled water (DLW) method is used to validate other methods and is considered the 'gold standard' of EE measurement [1]. This method, for measuring EE in free-living subjects, has been used in human studies for over two dec-

ades. A previous author conducted a validation of the measure and demonstrated that the method was accurate to 1–2% [18]. More recently the same author concluded that the DLW method has a relative accuracy of 1%, a laboratory-dependent analytical precision of 3% or greater, and a within-subject repeatability of 5–8% [19]. Its precise accuracy and ease of use during testing, which does not cause any interference with the subjects, are advantages that easily outweigh the costs associated with this technique.

There have been many studies that have attempted to investigate the energy expenditure of ultra endurance events using non-stop races and multi stage races. Non-stop races, such as the RAAM (which can be completed as a solo rider or as part of a team) and the XXAlps, require participants to complete the race with no scheduled stops, whereas multi stage event races, such as the Tour de France, are split into several stages with stage finishing times accumulating until the end of the event. A previous study estimated EE for a solo RAAM cyclist to be 17 965 kcal using continuous heart rate (HR) monitoring. While a similar study with cyclists competing in the XXAlps [5] found a mean daily EE of 13 467 kcal

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measured with continuous HR monitoring compared to a mean daily EE of 9726 kcals measured with the more accurate individual relationship between HR and VO_2 . A further two studies have used professional cyclists competing in the Tour de France [17, 25] to measure EE, one of which did not use the DLW method and recorded a daily mean EE of 6066 kcals for 4 cyclists [17], while the authors of the second study found that EE increased steadily from 7027 kcal/day at week one to 8532 kcal/day during the third and final week measured with DLW [25].

Although a similar study [25] has explored the EE of ultra endurance cyclists, this study differs as it investigates a non-professional ultra endurance team event during a non-stop race with no professional support. Therefore the aim of this study was to measure energy expenditure, using the gold standard method, for an ultra endurance team event. In addition EI was measured to calculate an energy deficit throughout the race, although EI can be difficult to accurately monitor as errors in reporting are common. These data will provide valuable information for cyclists, coaches and nutritionists for future events.

Method

Participants

Four non-professional, experienced ultra endurance cyclists were recruited for the study (Mean $\pm$ SD: age: 37 $\pm$ 4 yr; body height: 182 $\pm$ 8 cm; body mass: 80.8 $\pm$ 6.6 kg). Subjects formed the 4 man team and all gave prior written informed consent to participate in the study. The study was performed in accordance with the ethical standards of the International Journal of Sports Medicine [10].

Exercise

The ultra endurance event used in the current study was the four man team event in the RAAM. This annual event was established in 1982 and is regarded as the toughest cycling race in the world. The RAAM is a continuous cycle event that can be completed by either solo riders or as part of a two, four or eight person team. The 2008 race covered 3014 miles (4851 km), starting on the west coast of America in Oceanside CA, and finishing on the east coast in Annapolis MD. In addition to the long duration, cyclists had to deal with a huge range of climatic changes throughout the event, with temperatures ranging from -3°C to 37°C with highly variable humidity. They also faced arduous climbs through the Rockies and Appalachians with a cumulative climb of 110 000 ft (33 528 metres).

The four cyclists were split into two groups of two cyclists each. Each group followed a 24 h work-rest approach consisting of two periods of 3 h cycling and 3 h recovery, and one period of 6 h cycling and 6 h recovery (see **Fig. 1**). Cyclists would alternate,

15 min on, 15 min off, during their exercise period. These tactics were employed to enable the cyclists to maintain a high power output and the target speed of 20 mph throughout the event. The two cyclists who were not racing would rest, sleep and eat in a mobile home during their resting periods. All support vehicles were equipped with a satellite navigation system and the official road book in order to follow the official route.

Energy intake (EI)

Weighed food diaries were recorded by the investigators from the start of the race until completion. Details recorded were mass/quantity of all food and drink consumed. Nutrition consisted exclusively of food bought during the race and cooked at the mobile home. Diaries were analysed using the dietary analysis software MicroDiet Plus for Windows Version 11 (MicroDiet, UK). No food restrictions were in force during the RAAM as food and fluids were constantly available to the cyclists in an *ad libitum* manner, whether they were in the support vehicle on a 15 min rest period between exercise bouts, or in the mobile home during a 3 or 6 h rest period. As carbohydrate is the preferred fuel during ultra endurance exercise to maintain glycogen stores [20], the majority of food available was high energy snacks and CHO electrolyte drinks, with more substantial carbohydrate meals prepared for the cyclists on return to the mobile home and again prior to the cyclists leaving.

Energy expenditure (EE)

EE was determined by using the DLW method. Baseline urine samples were collected following an overnight fast on the morning of the race. Following collection of baseline samples the isotope dose was administered. Subjects consumed a mixed oral dose of a 10% enriched H_2^{18}O (1.5 g/kg body weight) and 99% enriched $^2\text{H}_2\text{O}$ (0.06 g/kg body weight). Urine samples were then collected 4 h post dosing, every 24 h thereafter and a final sample collected on completion of the race. All samples were collected between 06:00 and 12:00 and frozen at -20°C .

The measurement of ^2H (deuterium) was analysed by a Europa Hydra 20/20 continuous flow isotope ratio mass spectrometer (Metabolic Solutions, Inc, Nashua, NH), following equilibration with hydrogen gas in the presence of a platinum catalyst. The results of the isotope ratio analysis were reported as a change (delta value) relative to a reference gas. The International Atomic Energy Agency (IAEA) in Vienna, Austria has recommended that all deuterium measurements be expressed relative to the Vienna Standard Mean Ocean Water (V-SMOW). The percentage coefficient of variation was typically 0.75% daily and varied no more than 2%. Quality control standards were run throughout the analytical run every day.

A Europa Scientific 20:20 isotope ratio mass spectrometer (Metabolic Solutions, Inc, Nashua, NH) was used for the analysis of

Fig. 1 Schematic of the racing tactic for one cycle group during the RAAM. The other group would cycle during cycle group 1's rest period.

^{18}O following equilibration with carbon dioxide gas. Known reference materials were analysed in an identical manner before and after batches of samples. The results were reported as delta V-SMOW, similar to the ^2H analysis. The percentage coefficient of variation for ^{18}O analysis was typically 0.2% daily and varied no more than 0.5%.

The delta deuterium and ^{18}O values for the pre-dose (d_{pre}) and post-dose samples (d_{post}) were determined. The doubly labelled dose was diluted with tap water. The amount of dose diluted and water used was recorded. The deuterium and ^{18}O content of the tap water (d_{tap}) and diluted dose (d_{dose}) were measured.

The unprocessed mass spectrometric data was expressed as a fraction of the initial dose given as suggested by the consensus report by the International Dietary Energy Consultancy Group at the 1990 Vienna Austria Meeting [16]. This is achieved using the formula:

$$X = ((d_{\text{post}} - d_{\text{pre}}) / (d_{\text{dose}} - d_{\text{tap}})) \times (18.02a / WA)$$

Where W = Amount of water (grams) used to dilute the dose, A = Amount of dose (grams) administered to subject, a = amount of dose (grams) diluted for analysis.

Linear regression was used to calculate the slope and intercept of the linear relationship between the time in days and the normalized data for each isotope. The pool sizes N_D ($^2\text{H}_2\text{O}$) and N_O (^{18}O) are derived as the reciprocal of the intercept (or plateau value). The intercept of the regression line was the ratio of the pool size spaces N_D/N_O . The multipoint data were plotted to inspect for any outliers. Any outliers were re-analyzed. The rate constants k_D ($^2\text{H}_2\text{O}$) and k_O (^{18}O) were represented by the slope of the regression line. N_D/N_O ratios lying outside the range of 1.015 and 1.06 were treated as suspect and samples were re-analyzed.

The mean daily CO_2 production ($r\text{CO}_2$, mol/day) was calculated according to the revised equations [21]:

$$r\text{CO}_2 = (N / 2.196) \times (k_O - 1.0427k_D)$$

$$\text{Where } N = [(N_O) + (N_D / 1.0427)] / 2$$

The estimate of energy expenditure was calculated from the carbon dioxide production assuming 127.5 kcal/mol carbon dioxide (a typical Western diet will produce a respiratory quotient of 0.85, with 15% of energy from protein oxidation [16]).

Actigraphy

Actigraphy is a commonly used technique employed to study sleep-wake patterns by assessing movement, most commonly of the wrist, but also used on the ankle or trunk. It has been stated

that actigraphy is based on the principle that during sleep there is a reduced movement [14]. Actigraphy is a relatively accurate instrument for measuring sleep-wake parameters in a number of situations [22] and has been correlated against polysomnography in a number of studies [12]. Studies have shown an accuracy of up to 80% correlation with polysomnography [3]. For the current study total sleep was measured in minutes every 24-h throughout the entire duration of the RAAM. Total sleep time was an accumulation of all rest periods when the cyclists were able to remain stationary to sleep during the 24-h period. Measurements were obtained from an Actiwatch and Sleepwatch software (Version 5.28; Cambridge Neurotechnology Ltd, Cambridge, UK) secured to the right ankle of the cyclists. Data was recorded in 1-min epochs (the period of time that the actiwatch data is averaged).

Results

Performance

The cycling team used in this study completed the race in 6 days 10 h and 51 min with an average speed of 19.47 mph (31.33 km/h). The team finished in third place (out of eleven) in the 4 man team event. The winning team completed the race in 6 days 4 h and 12 min.

Energy expenditure

Total mean ($\pm$ SD) EE for each cyclist was $43,401 \pm 3175$ kcals with a mean ($\pm$ SD) daily EE 6420 ± 470 kcals. **Table 1** gives each cyclist's mean daily EE and total EE of the entire race.

Energy intake

During the race the total mean ($\pm$ SD) EI from all food and drink consumed for each cyclist was 29506 ± 4856 kcals with a mean ($\pm$ SD) daily EI of 4918 ± 810 kcals. The average percentage macronutrient intake was 59% carbohydrate, 25% protein and 16% fat. The percentage of macronutrient intake and mean macronutrient intake measured in grams can be seen along with EI for cyclists in **Table 2**. Mean ($\pm$ SD) daily fluid intake consisting of sports drinks, water and soft drinks was 5.23 ± 0.12 L.

Energy deficit

Results from mean EI and EE resulted in a total mean ($\pm$ SD) energy deficit of 13878 ± 2672 kcals with a mean ($\pm$ SD) daily

Tab. 1 Average daily energy expenditure and total energy expenditure.

Cyclist	Mean daily EE	EE/kg BM/day	Total EE	Total EE/kg BM
cyclist 1	6774 kcals (28361 kJ)	81 kcals (339 kJ)	45792 kcals (191722 kJ)	548 kcals (2294 kJ)
cyclist 2	6752 kcals (28269 kJ)	75 kcals (314 kJ)	45644 kcals (191102 kJ)	507 kcals (2123 kJ)
cyclist 3	6387 kcals (26741 kJ)	82 kcals (343 kJ)	43176 kcals (180769 kJ)	554 kcals (2319 kJ)
cyclist 4	5768 kcals (24149 kJ)	79 kcals (331 kJ)	38992 kcals (163525 kJ)	534 kcals (2236 kJ)

Tab. 2 Daily macronutrient intake (grams and percentage), daily energy intake and total energy intake.

Cyclist	CHO		Protein		Fat		Daily EI	Total EI
	grams	%	grams	%	grams	%		
cyclist 1	664 g	56%	182 g	17%	142 g	27%	5244 kcals (21956 kJ)	31466 kcals (132742 kJ)
cyclist 2	788 g	59%	187 g	16%	150 g	25%	5898 kcals (24694 kJ)	35386 kcals (148154 kJ)
cyclist 3	646 g	57%	137 g	18%	92 g	25%	4412 kcals (18472 kJ)	26472 kcals (110833 kJ)
cyclist 4	581 g	64%	126 g	14%	94 g	22%	4116 kcals (17233 kJ)	24698 kcals (103406 kJ)

Tab. 3 Total and daily energy deficits.

Cyclist	Mean daily Energy Deficit	Total Energy Deficit
cyclist 1	1 530 kcal (6 406 kJ)	14 326 kcal (59 980 kJ)
cyclist 2	854 kcal (3 576 kJ)	10 258 kcal (42 948 kJ)
cyclist 3	1 975 kcal (8 269 kJ)	16 704 kcal (69 936 kJ)
cyclist 4	1 652 kcal (6 917 kJ)	14 224 kcal (59 553 kJ)

Fig. 2 Actual sleep per race day for each of the three cyclists.

energy deficit of $1\,503 \pm 471$ kcal. **Table 3** highlights the total and daily energy deficit for each cyclist.

Total sleep

Actigraphy data was only available in three riders due to a malfunction in cyclist two's device. The total mean ($\pm$ SD) sleep time was only 129.6 ± 16.9 min per race day for the three cyclists measured throughout the RAAM. **Fig. 2** illustrates a large intra-variation between the cyclists and a gradual decrease in sleep time towards the end of the race.

Discussion

The aim of this study was to investigate the EE using the gold standard method during the team event at the RAAM 2008. The findings of the current study were that the mean ($\pm$ SD) EE for each individual of a 4-man team was $43\,401 \pm 3\,175$ kcal, with a mean ($\pm$ SD) daily EE of $6\,420 \pm 470$ kcal. The team completed the race in third place in a time of 6 days 10 h and 51 min.

Energy expenditure

In comparison with the current study, a previous study measured EE during the RAAM with a solo rider and found that the subject expended a total energy of 179 650 kcal, with a mean ($\pm$ SD) of $17\,965 \pm 2\,165$ kcal per day, during the 9 days 16 h and 45 min [11]. However, the method used to measure EE was calculated based on heart rate measurement. This method has been shown to produce errors of up to 30% during 24 h assessment in individuals, as HR does not increase as steeply for given changes in EE at lower levels of EE, possibly due to postural changes in stroke volume [1]. Other limitations of HR monitoring for EE include psychological stress, hydration levels and environmental factors such as temperature and humidity, all of which are affected during the RAAM. It has been suggested that the HR method is best used to provide information on activity patterns

and levels of exercise intensity, and to be used in addition to DLW as HR measurements show large variation around the mean agreement with DLW method [7].

A previous study measured EE using DLW with 4 professional cyclists competing in the Tour de France and found that the mean daily EE over a three week period was 8 054 kcal ($1\,560 - 1\,750$ kJ/day $^{-1}$ /kg $^{-0.72}$) [25]. This equates to 4.3–5.2 times the basal metabolic rate (BMR). Another study also investigated EE during the Tour de France and recorded a mean EE of 6 066 kcal/day with four professional cyclists [17], calculated using previous equations [27,9] based on cycle speed, time, altitude and factors for air resistance, rolling resistance and weight.

Energy intake

The average EI for the duration of the RAAM was 29 506 kcal, with an average daily EI of 4 918 kcal, which is similar to that reported with endurance runners during a 20 day 500 km road race who consumed 4 824 kcal per day [8]. However two previous studies have examined the EI of solo finishers from the RAAM [6,13] and reported EI of 7 950 and 8 429 kcal, respectively. From the current study the EI did not match that of the EE and resulted in an average energy deficit of 15 361 kcal for the entire race. This is in contrast to a previous study [17] that reported a well matched EI (6 138 kcal) and EE (6 066 kcal) with 5 professional cyclists competing in the Tour de France. However, the Tour de France is a multi stage event with more time available for the cyclists to refuel before and after each stage during the event. A possible suggestion for the low EI during this study could be related to the non-stop nature of the event. The cyclists struggled to consume larger more substantial meals during their rest periods, tending to rather constantly graze throughout the race which resulted in the cyclist struggling with the constant intake of sweet carbohydrate sports drinks, gels and bars. Even though the cyclists in the current study consumed the recommended macronutrient intake of between 6–10 g/kg body weight of carbohydrate [2] and approximately 1.6 g/kg body weight of protein [24] for ultra endurance exercise, the overall EI was significantly less than the overall EE. The cyclists in the present study failed to emulate the energy intake of another RAAM study [13] in which their solo rider successfully completed the RAAM consuming 8 429 kcal per day and a study in which a 24 h cycle event cyclist consumed 10 576 kcal [26]. Albeit the cyclists in the present study consumed less than the cyclists used by others [11,26], the percentage of EI to EE was more in the present study. The EI during the present study was 68% of the EE, which was greater than previous studies [11,26] who reported an EI of 53% and 54% of the EE, respectively.

Sleep

This study demonstrates that continuous ultra endurance events such as the RAAM, also act as sleep deprivation challenges. Riding in the 4-man team event was associated with significant disruption to the quantity of sleep, an example of which can be seen with one cyclist getting only 9 min sleep in over 24 h. The lack of sleep found with the cyclists in this study emphasizes a poor recovery between exercise bouts. Due to the wide variation between the cyclists in the amount of sleep disruption experienced, interventions to improve sleep quantity and quality during multi-day ultra-endurance events such as the RAAM should be individually based. It has been suggested that sleep may be related to recovery from fatigue and to assist in the build up of energy [15]. Furthermore, during sleep there is a reduction in

the metabolic requirements within the body [4]. The sleep deprivation accompanied with the energy deficit highlights the difficulty in completing such events as recovery is compromised throughout.

Limitation of the present study

Some limitations of the current technique are noteworthy, specifically DLW is unable to provide information about peak energy expenditure periods over short bouts of exercise throughout the race and this is a disadvantage of this method. The failure to measure body weight post race to identify any weight losses due to an imbalance in EI and EE was also a limitation. However, previous research [5, 11, 23] all successfully measured weight loss following ultra endurance exercise. One study [11] demonstrated a total body mass loss of 5 kg in a solo rider competing in the RAAM. This body mass loss resulted from a total energy deficit of 83 526 kcal and is significantly greater than the energy deficit found in the cyclists in the current study (11 878–18 237 kcal), albeit the present study participants completed the RAAM in a four man team.

There were no gastrointestinal complaints during the RAAM, but cyclists did suffer from feelings of fullness, likely exacerbated by the sleep deprivation observed in this study. Due to the continuous nature of the event, the cyclists did find it difficult to consume the same carbohydrate electrolyte drinks throughout and also found it arduous to keep consuming high numbers of energy gels and bars. Therefore the task for future coaches and nutritionists is to design diets that vary in taste, while maintaining a high energy intake. A difficulty putting this into practise during ultra endurance events like the RAAM is the fact that a lot of food and drink has to be bought on the road during the race and that cooking facilities are limited.

Conclusion

The high EE, three times that of a typical EI for males, highlights the need for correct and practical dietary strategies and challenges nutritionists to devise high energy diets that not only contain the correct macronutrient balance, but are also palatable to the cyclists, thus encouraging a higher EI. The findings from this study will be of benefit to cyclists, coaches and nutritionists participating in the RAAM and other ultra endurance events in the future.

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