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Energy Balance During a Self-Sufficient, Multistage Ultramarathon

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Abstract

Endurance athletes are recommended to maintain energy balance and ensure adequate energy availability (EA) so that endurance performance is not compromised. Purpose: Describe and evaluate the energy balance of an athlete competing in a self-sufficient, multistage ultramarathon (MSU). Methods: A male endurance athlete (age 35 years; height 183.0 cm; body mass 78.4 kg; VO_{2max} 66 ml/kg/min) volunteered to take part in this observational case study prior to competing in the Marathon des Sables (MdS) 2016. The subject self-reported energy intake (EI) by reviewing his dietary plan following each stage. Basal metabolic rate (BMR) was estimated prior to the MdS based on fat-free mass. Distance and moving speed were recorded using a GPS device throughout the race. Exercise energy expenditure (EEE) was calculated using the GPS device algorithm. Total energy expenditure (TEE) was calculated by adding the athlete's BMR to the recorded EEE. Energy balance was calculated by subtracting EI from TEE. Results: Mean daily EI was 2946 $\pm$ 358 kcal and daily EEE was 3006 $\pm$ 1030 kcal. This resulted in a total energy deficit of 9609 kcal with a daily energy deficit of 1922 $\pm$ 952 kcal/day. The athlete did not report any subjective feelings of hunger at any point during the event. Conclusions: The athlete did not consume enough calories to meet estimated energy requirements, resulting in a negative energy balance and low EA throughout the event. Relying on subjective perception of hunger to modulate energy intake is an ineffective strategy during a MSU.

Keywords: nutrition, ultra, endurance, Marathon des Sables, performance

Introduction

The Marathon des Sables (MdS) is a multistage ultramarathon (MSU) that takes place in the Sahara Desert of Morocco, with temperatures reaching over 50℃, it has been described as "the toughest footrace on earth" (http://marathondessables.co.uk). Over six days, competitors cover ~156 miles, with one rest day following the longest stage (~55 miles). Although daily water rations are provided, a unique aspect of MdS is that competitors must be self-sufficient throughout the race, which entails carrying all food, clothing, and equipment for the entire event. In addition to thorough training preparation, optimal performance in the MdS requires appropriate nutrition and hydration strategies to be implemented. Athletes are required to ingest sufficient energy to compensate for the high energy expenditure of prolonged running in hot conditions, whilst also maintaining adequate levels of hydration (Rehrer, 2001).

The average speed maintained during a multiday ultramarathon has been proposed to correspond to maintaining a sufficient energy intake (Rontoyannis, Skoulis, & Pavlou, 1989). Therefore, an inadequate energy intake, resulting in a large energy deficit, could compromise performance (Mahon, Hackett, Stott, George, & Davies, 2014). Previous research indicates that it is possible to maintain energy balance over the course of a five-day (960 km) ultramarathon (Rontoyannis et al., 1989). However, the self-sufficient nature of the MdS means that athletes are faced with a complex challenge of carrying a sufficient quantity of food to maintain energy balance without carrying an excessively heavy pack, which would reduce comfort and performance. Despite thirty previous editions, there are few studies which have evaluated energy balance during MdS or similar MSUs (Costa et al., 2013a, 2013b; Toner, Wardle, Mews, & Costa, 2011). The aim of the current observational study was to describe and evaluate the energy balance of an athlete competing in a self-sufficient MSU in relation to the current nutrition recommendations for endurance athletes.

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Method

Subject

One subject agreed to volunteer in this observational case study. The subject was an experienced male, amateur endurance athlete (age 35 years; height 183.0 cm; body mass 78.4 kg; VO_{2max} 66 ml/kg/min) who regularly competes in endurance running: five previous marathons, three Ironman triathlons, and two ultramarathons (November 2015 [33 miles] and February 2016 [50 miles]). The subject's marathon personal best was 03 hr: 26 min in a mixed terrain marathon. The subject had no prior experience of a MSU. Prior to the study, the subject provided written informed consent and completed a pre-activity readiness questionnaire. The study was approved by the St Mary's University Ethics Committee.

Design

This was an observational case study, whereby the subject's MdS race pace and nutritional intake data were recorded during the six-day event. A subjective journal was also completed. The data from the rest day (day 5) and 17 km charity stage (day 7) did not count towards the overall race classification and was omitted from analysis.

Preliminary Exercise Assessment

Five days prior to the first day of the MdS the subject reported to the laboratory to undergo a physiological evaluation, following a 24-hour rest period. This consisted of a body composition assessment, a submaximal and maximal running protocol on a motorized treadmill (Woodway, ELG 70, Weil am Rhein, Germany). The submaximal protocol consisted of six, four-minute stages whereby the treadmill speed was increased by 1 km/hr at the start of each stage. Expired, breath-by-breath, gas measurements were recorded throughout the test using an open spirometric system (Oxycon Pro, Jaeger, Hoechburg, Germany). At the end of each stage a capillary blood sample was drawn and analyzed using a blood lactate/glucose analyzer (Biosen C_Line, EKF Diagnostics, Barleben, Germany). There was a five-minute period of passive recovery after the submaximal assessment before a stepwise incremental VO_{2max} test was performed.

Body Composition Assessment

Skinfold measures were taken before the preliminary exercise assessment and five days after the MdS at the same time of day. The skinfolds were measured using skinfold callipers (Harpenden, Baty International, West Sussex, UK) according to International Society of the Advancement of Kinanthropometry (ISAK) guidelines. The skinfolds were taken by an ISAK certified practitioner at seven sites (biceps, triceps, subscapular, iliac crest, abdominal, medial-thigh, medial-calf). Technical error was less than 5% for all skinfold measurements. Body fat and fat-free mass were calculated using Durnin and Womersley (1976) equations.

Nutrition Plan

As the subject had no prior experience of a MSU, he followed the nutritional guidelines recommended by the MdS organizers (http://marathondessables.co.uk). This consisted of 3000–4000 kcal/day composed of 15% protein, 30% fat, and 55% carbohydrate. The authors did not suggest a specific macronutrient breakdown, other than suggesting protein intake should be slightly higher than the recommended 15% in order to aid recovery (Koopman et al., 2004). Subjective advice relating to palatability and food enjoyment was provided. For example, the subject was advised not to include a large volume of artificial sweet foods (energy gels, sports drinks) as these can be unpalatable in hot conditions and often have a low nutrient density. An example of a daily food plan is presented in Table 1.

Energy Balance

The subject self-reported his actual energy intake (EI) by reviewing the dietary plan in the evening after each stage, noting if any additional food/drink was consumed and where items were not or only partly consumed. The dietary record was used to calculate energy and macronutrient intake using dietary analysis software (Dietplan v6.60, Forestfield Software, Horsham, West Sussex, UK).

Basal metabolic rate (BMR) was estimated prior to the MdS based on fat-free mass (Cunningham, 1980). Distance and moving speed were recorded using a GPS device (Garmin Forerunner 920XT) throughout the race. Exercise energy expenditure (EEE) was calculated using the Garmin Firstbeat algorithm, which incorporates distance, heart rate, and the user profile. Total energy expenditure (TEE) was calculated by adding the subject's BMR to the recorded EEE. Energy balance was calculated by subtracting EI from TEE. Energy availability (EA) was calculated using the following equation (Loucks, 2013):

$$EA = \frac{Energy\ intake - exercise\ energy\ expenditure}{Fat\text{-}free\ body\ mass}$$

Pacing and Performance

Average moving speed was calculated in 5 km splits retrospectively using GPS data. Overall mean moving speed was calculated from the moving time taken to cover the stage distance for each day. The variation in pace was

Table 1.
Example daily food plan.

Day 2 (41.43 km)	Food	Energy (kcal)	Carbohydrate (g)	Protein (g)	Fat (g)
Breakfast	Thai green curry with rice	587	42	23	32
Snack	Wiggle energy bar	235	40	3.2	3.5
Snack	Bounce energy ball	178	46	9	2.6
Snack	Clif Energy Bloks	192	48	0	0
Snack	Pepperoni	268	0.6	6	11
Snack	Ultra-Fuel Energy 4.1	192	38.4	10	0
Recovery	SiS Recovery Rapid	368	23	20	1.3
Dinner	Potato, salmon in dill sauce	1115	41	16	36
	Total	3135	279	87	86

Table 2.
Heat acclimation training data from eight sessions performed prior to MdS. Data presented as mean ± SD.

Duration (min)	Speed (km/hr)	Gradient (%)	Heart rate (B/min)	RPE (6–20)	TS (0–8)	Fluid deficit (ml)
55	9 ± 1	±2	156 ± 21	11.5 ± 1	4	2943 ± 872

Note. RPE, rating of perceived exertion; TS, thermal sensation.

therefore described as the percentage variation between each 5 km split and the overall mean moving speed (Santos-Lozano, Collado, Foster, Lucia, & Garatachea, 2014).

Results

Race Preparation

In the 12 weeks leading up to the MdS, mean running-based training volume was 65 km/week. To prepare for the terrain challenges, the subject also performed a weekly stair climbing training session ($n = 4$) consisting of climbing 20 flights of stairs for 1.5–3 hr whilst wearing a 30 kg weighted vest. The running volume peaked (74 km/week) three weeks before the MdS. In addition to training outdoors (mean temperature 9℃) the subject performed heat acclimation sessions (35–40℃) on three consecutive weeks before the MdS (see Table 2).

Energy Intake and Expenditure

Mean daily EI was 2946 ± 358 kcal and daily EEE was 3006 ± 1030 kcal. This resulted in a total energy deficit of 9609 kcal with a daily energy deficit of 1922 ± 952 kcal/day. Total EA was −0.97 ± 15.4 kcal/kg-FFM/day. The daily EI, EEE and macronutrient profile during each competitive race day are presented in Tables 3 and 4. A Pearson correlation shows a strong relationship between stage distance and energy intake ($r = 0.61$), indicating the subject consumed more calories on the longer distance stages. Planned EI for the five race days was 14,591 kcal, of which 14,732 kcal was consumed. Therefore, the subject consumed marginally (0.1%) more energy than planned due to the consumption of ad hoc items donated from other competitors.

Fluid Intake

The mean (± SD) fluid intake during the five competitive days was 1.84 ± 0.57 l/hr. Daily fluid intake was 11.35 ± 1.24 l.

Body Composition

Body mass decreased by 2% from 78.04 to 76.8 kg. The sum of seven skinfolds decreased by 11% from 92.7 mm to 82.5 mm following the MdS.

Pacing and Performance

The subject completed the race in 10 hr: 51 min with an average moving speed of 7.4 km/hr (range 6.22–8.51 km/hr) finishing within the second quartile of 264 finishers. Daily performance data are presented in Table 5. We are only able to comment on observations in pacing strategy from GPS data and acknowledge confounding variables, such as heat and elevation, will likely have influenced this.

Overall, we observe the fastest speeds within the first 10 km throughout the MdS and apart from stage one, there was an increase in speed for the final 5 km of each stage (see Figure 1).

Stage one had the greatest average elevation which coincided with the slowest running speed (Figure 2). Noticeably the greatest variation in speed occurred during the longest stage, which also had the largest variation in elevation and highest calorie deficit (Figure 3).

Table 3.
Daily energy intake and expenditure during the MdS.

Stage	Exercise EE (kcal)	Total EE (kcal/day)	Energy intake (kcal/day)	Energy availability (kcal/kg-FFM/day)	Energy balance (kcal/day)
(1) 33.8 km	2850	4712	2522	−5.30	−2190
(2) 41.4 km	2680	4542	2929	4.02	−1613
(3) 36.5 km	2376	4238	2674	4.81	−1564
(4) 82.8 km	4806	6668	3272	−24.78	−3396
(5) Rest	500	2362	2305	29.17	−57
(6) 40.4 km	2319	4181	3335	16.41	−846
Total	15031	24341	14732		−9609
Average	3006.20	4868	2946	−0.97	−1922
SD	1030	1030	358	15	952

Note. EE, energy expenditure; FFM, fat-free mass.

Table 4.
Macronutrient intake.

Stage	Carbohydrate (%)	Protein (%)	Fat (%)
(1) 33.8 km	49	29	22
(2) 41.4 km	54	22	24
(3) 36.5 km	54	24	23
(4) 82.8 km	69	22	9
(5) Rest	59	28	13
(6) 40.4 km	63	18	19
Average	58	24	18
SD	7	4	5

Discussion

A low EA can impair health and performance (Thomas, Erdman, & Burke, 2016); therefore, athletes are advised to maintain energy balance and adequate EA to prevent a decline in endurance performance. However, the maintenance of energy balance and adequate EA during ultra-endurance events is problematic due to the long durations of exercise and high levels of EEE involved. The subject in this case study experienced a large negative energy balance and a deficit in EA throughout the self-sufficient MSU. The daily EI in the present study was 2946 ± 358 kcal (38 kcal/kg/day), which is less than the relative value (49 ± 11 kcal/kg/day) previously reported during a five-day, 225 km ultramarathon (Costa et al., 2013a). This meant the subject experienced a mean energy deficit of 1992 ± 952 kcal/day (range: 846–3396 kcal) during the five competitive race days. Previous studies have also demonstrated that athletes were unable to consume enough food/fluid to meet estimated energy requirements during an Ironman triathlon (Kimber, Ross, Mason, & Speedy, 2002) and a 1230 km bike marathon (Geesmann, Mester, & Koehler, 2014). Despite the large negative energy deficit in the present study, the subject reported "*at no time did I feel hungry, I probably took too much food*". Interestingly, a lack of hunger was also reported in previous MdS competitors (McCubbin, Cox, & Broad, 2016), which suggests the long durations of exercise may suppress appetite, possibly through altering circulating levels of appetite-related hormones, such as leptin and acylated ghrelin (Vatansever-Ozen, Tiryaki-Sonmez, Bugdayci, & Ozen, 2011). This is an important consideration for athletes competing in MSUs, as it seems that relying on subjective feelings of hunger to guide EI is not an effective strategy and will likely result in large energy deficit and low EA, which may compromise performance. Indeed, a higher calorie intake has explained over 60% variation in performance during an ultramarathon (Mahon et al., 2014). Therefore, athletes unaccustomed to a MSU event are likely to benefit from a strategic diet plan to minimize energy deficit and maximize performance.

During prolonged exercise adequate dietary protein intake in the range of 1.2 to 2.0 g/kg/day is required to support metabolic adaptation, repair, and remodeling (Thomas et al., 2016). This is particularly important during a MSU as aerobic exercise increases protein oxidation and skeletal muscle protein turnover (Rodriguez, Vislocky, & Gaine, 2007). As indicated in Table 4, the subject was able to achieve the recommended protein intake during the event (1.7 g/kg/day).

Fat is an important energy substrate during prolonged submaximal exercise (Volek et al., 2016). Fat intake was 1.4 g/kg/day which was below the macronutrient profile advised by the MdS. However, this is unlikely to have had a large impact on the subject's performance when compared to a reduced carbohydrate availability.

Carbohydrate (CHO) is an important fuel for skeletal muscle, particularly as exercise intensity increases. A significant depletion of liver and muscle glycogen stores is associated with fatigue and a reduction in the exercise intensity during sustained exercise (Thomas et al., 2016). When food content is aimed to maximize CHO content there is an observed increase in success during ultra-endurance events (Stuempfle, Hoffman, Weschler, Rogers, & Hew-Butler, 2011). Therefore, endurance athletes are typically advised to ensure pre-exercise CHO intake enables glycogen stores to equal the estimated energy cost of the exercise; hence, the recommended CHO intake for an endurance event lasting 4–5 hr is 8–12 g/kg/day (Thomas et al., 2016). This requirement may be even greater during an event like the

Table 5.
Observations in speed and elevation in relation to energy deficit.

Stage	Average moving speed (km/hr)	Speed CV (%)	Elevation CV (%)	Daily energy deficit (kcal)
(1) 33.8 km	6.3	14.8	1.9	−2190
(2) 41.4 km	7.9	16.4	2.2	−1613
(3) 36.5 km	7.6	19.1	2.4	−1564
(4) 82.8 km	7.7	19.7	5.4	−3396
(5) 40.4 km	8.8	12.3	5.5	−846

Note. CV, coefficient of variation.

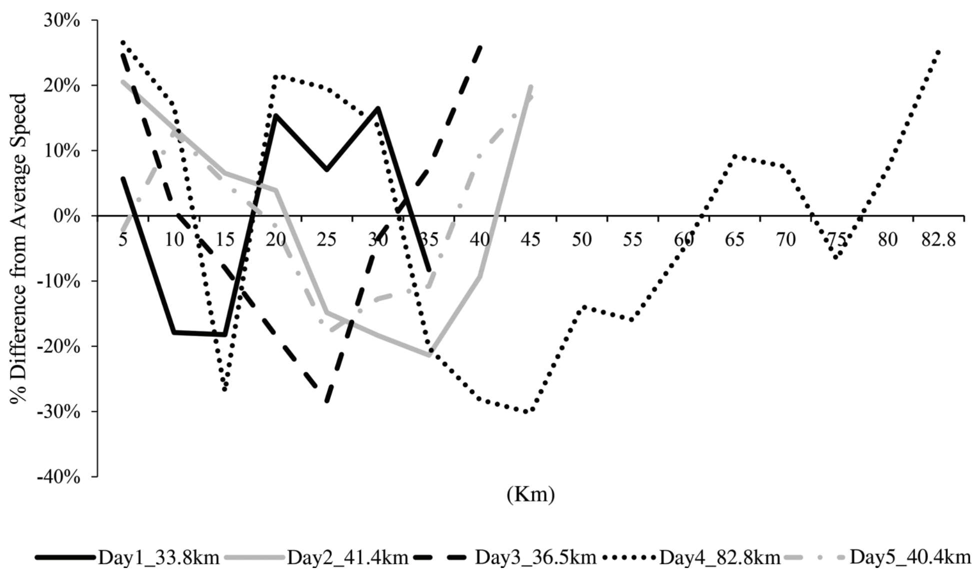

Figure 1. Percentage difference from average speed for each stage.

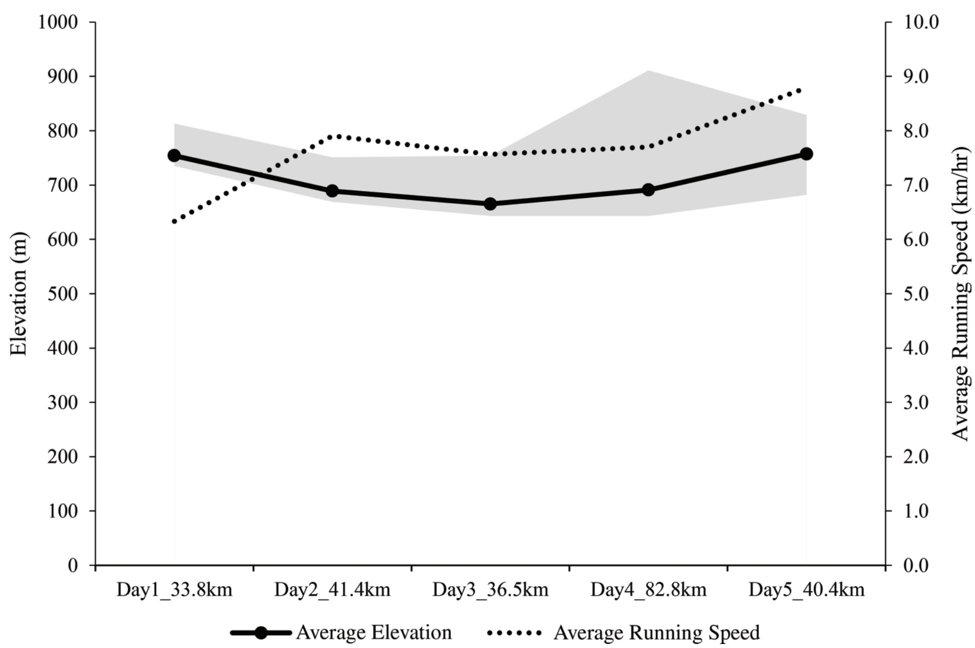

Figure 2. Representation of average elevation and average running speed. Shaded area shows variation in elevation between each 5 km split.

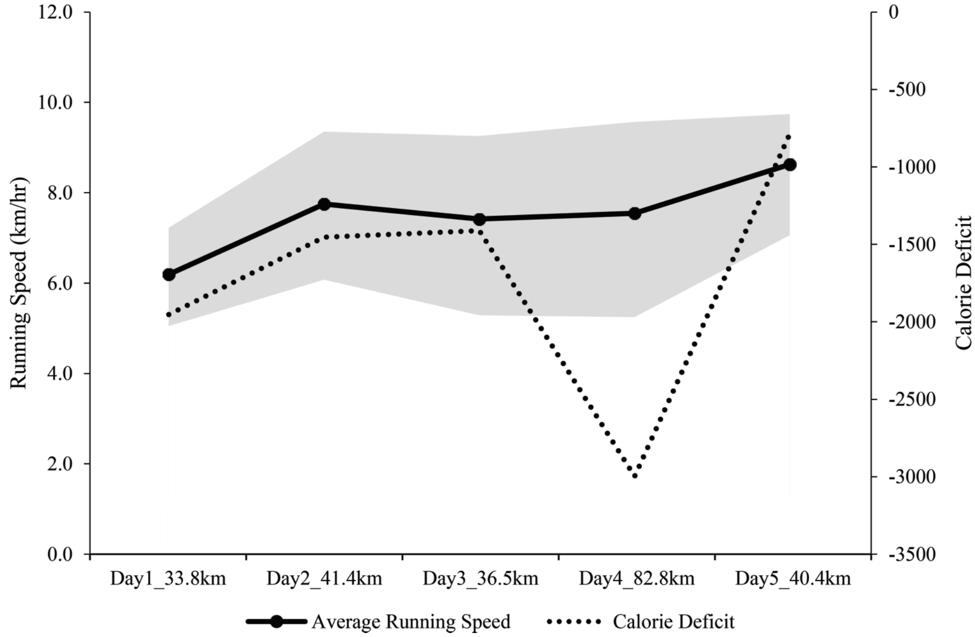

Figure 3. Representation of average running speed and day-to-day calorie deficit. Shaded area shows variation in speed between each 5 km split.

MdS, as the additional thermal stress likely increases CHO metabolism (Febbraio, 2001). The subject's mean CHO intake was 4.5 g/kg/day, which corresponds to previous findings that athletes competing in ultra-endurance events consistently fail to meet recommendations for CHO intake (Costa et al., 2013a; Stuempfle et al., 2011). This is likely due to practicality issues in applying the general CHO intake recommendations during MSUs or similar ultra-endurance events. The maximum quantity of CHO that can be absorbed during exercise is 60–90 g/hr (Jeukendrup, 2014), which limits EI to approximately 240–360 kcal/hr. Consequently, an energy deficit is inevitable if the athlete is using CHO alone during exercise and the EEE is greater than ~360 kcal/hr. Additionally, achieving this upper range of CHO intake (90 g/hr) would be problematic during self-sufficient, multistage ultra-endurance events, as the required food/drink could substantially increase pack mass. Furthermore, consuming the upper range of CHO during competition increases the potential for gastrointestinal discomfort (Jeukendrup et al., 2000). A possible solution to overcome this latter issue is the implementation of a low-carbohydrate, high-fat (LCHF) diet before and during multistage ultra-endurance events.

The implementation of LCHF diets for endurance athletes has recently been the subject of renewed interest, as lipid stores have been demonstrated to provide a majority of the energy necessary to fuel low- to moderate-intensity exercise (Volek et al., 2016). Due to the abundance of lipid stores within the human body, a LCHF diet may enable prolonged, moderate-intensity exercise to be maintained without the need for CHO ingestion (Volek et al., 2016). Theoretically, if an athlete has adapted to a LCHF diet prior to an ultra-endurance event, they may not need to consume any foods during exercise. However, this could exasperate the energy deficit experienced during ultra-endurance events. One possible solution is to ingest foods high in medium-chain triglycerides (MCT), although ingesting > 30 g of MCT during exercise is associated with severe gastro-intestinal distress (Jeukendrup, Saris, Schrauwen, Brouns, & Wagenmakers, 1995). Whilst there is a conceptual basis for ultra-endurance athletes to adopt a LCHF diet, there is a lack of empirical evidence that the strategy improves performance compared to a diet higher in carbohydrate. Consequently, ultra-endurance athletes wishing to experiment with a LCHF diet should proceed with caution, particularly if the event involves periods of high-intensity ($\geqslant 75\%\ VO_{2max}$) exercise (e.g. hill climbing), as a chronic LCHF diet can potentially lead to a reduction in exercise performance (Burke et al., 2017; Zajec et al., 2014) and potentially impair metabolic flexibility (i.e. the capacity to oxidize carbohydrates) (Burke & Kiens, 2006).

The subject did not experience any issues with food, such as unpalatability or excessive hunger. The choice of what and when to eat the planned meals is challenging for competitors, as a number of factors such as the environmental temperature, sleep deprivation, hunger, and fatigue influence food and fluid intake. For example, the subject decided to consume his main meal in the morning for breakfast, as his palatability for this type of "real" food was higher at this time.

The race organizers provide 12 l of water each day in 1.5 l bottles. These are provided in the morning, at checkpoints during the stage, and at the finish. Competitors are also provided with salt tablets (0.1 g sodium each) at the beginning of the race which they take ad libitum. The subject's sweat rate was recorded during heat acclimation sessions (see Table 1). These data were used to recommend a minimum water intake of 1.7 l/hr to avoid significant dehydration (<2.5% loss in body mass). This drinking strategy was practiced during the final three heat acclimation sessions and well tolerated. The subject was able to achieve this minimum fluid intake guideline (average fluid intake = 1.8 l/hr). Nonetheless, the subject reported feeling dehydrated in the evening following stage one, but did not consume any additional fluids. This likely led to the symptoms of severe dehydration (dizziness) he experienced during stage two, when he needed to rest for 30 min after reaching the first checkpoint. This highlights the importance of hydrating adequately after each stage to prevent starting the next stage in a state of dehydration (Rehrer, 2001). Following this experience, the subject did not report any complications, which supports the notion that, provided an athlete begins a race in a euhydrated state, an ad libitum drinking strategy can be effective during ultra-endurance events (Costa et al., 2013b).

The subject achieved an average speed of 7.4 km/hr over the course of the MdS finishing within the second quartile of 264 finishers. We are only able to comment on observations in pacing strategy from GPS data (Table 4), and acknowledge confounding variables (i.e. heat and elevation) will likely have influenced performance. The subject's fastest speeds were recorded within the first 10 km throughout the MdS and, with the exception of stage one, there was an increase in speed for the final 5 km (shown in Figure 1) of each stage. Stage one had the greatest average elevation which could explain the slowest running speeds (Figure 2); additionally it is likely the subject used it as a "pace setting and trial stage". Noticeably the greatest variation in speed occurred during the longest stage, which had the highest variation in elevation and simultaneously the greatest calorie deficit (Figure 3), which may have influenced the average speed.

Although the subject self-reported "struggling for speed" on stage five, this was actually the fastest stage with an average speed of 8.8 km/hr and the lowest variation in speed, despite having the greatest variation in elevation. This was likely due to a combination of factors such as the previous rest day, a reduced pack mass, improved knowledge of endpoint (St. Clair Gibson & Noakes, 2004), and an intentional increase in intensity for the final stage. However, reductions in exercise performance are associated with suboptimal nutritional status and it is probable that nutritional factors may have also contributed to the improved performance on day five, as the negative energy balance was less (−713 kcal) than any of the previous days and average fluid intake was highest (2.3 l/hr). Overall, speed progressively increased throughout the week, suggesting an overall negative pacing strategy.

Body mass and fat mass decreased by 2% and 5.6%, respectively. This finding is similar to the reductions in body mass (2 kg) and fat mass (0.79 kg) reported in a cyclist following a five-day (2272 km) race (Bircher, Enggist, Jehle, & Knechtle, 2006). The sum of seven skinfolds decreased by 11% (−10.2 mm) indicating a marked reduction in subcutaneous body fat similar to reductions in body fat reported following another ultra-endurance event (Karstoft, Solomon, Laye, & Pedersen, 2013). Fat-free mass increased by 1.1 %, which is in contrast to previous studies which have reported reductions following multiple day cycling (Bircher et al., 2006) and running (Knechtle & Kohler, 2007) events. The maintenance of fat-free mass was likely achieved due to ingesting an adequate amount of protein (1.7 g/kg) throughout the event. However, as with the changes in total body and fat mass, these results must be interpreted with caution due to the methodological limitations associated with the skinfold method. For example, an increase in total body water caused by fluid shifts may have influenced the skinfold measures (Knechtle, Duff, Schulze, & Kohler, 2008).

Conclusions and Practical Applications

This study characterized the energy and fluid intake, as well as the estimated energy balance/availability, of a male athlete competing in the MdS. Despite encountering a large energy deficit, similar to values previously reported during multistage, ultra-endurance events, the subject did not report any subjective feelings of hunger. This indicates relying on sensations of hunger to regulate EI is ineffective in preventing a large energy deficit and low EA during a MSU. A large energy deficit may compromise endurance performance; therefore, athletes competing in MSUs should adopt a dietary strategy that involves consuming foods with a high calorific density at appropriate points in their events.

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