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ENERGY BALANCE DURING 24 HOURS OF TREADMILL RUNNING

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ABSTRACT

ENERGY BALANCE DURING 24 HOURS OF TREADMILL RUNNING. **Linderman, Jon K., Laubach, Lloyd L. JEPonline.** 2004;7(1):37-44. The purpose of the present investigation was to assess energy expenditure (EE) and energy intake (EI) during a continuous 24-hour treadmill run. EE was determined from heart rate (HR) telemetry, utilizing a linear relationship between VO_2 and HR obtained during a maximal exercise test. EE was also estimated using a common metabolic calculation. The 51 year-old male ultra-marathon runner completed 160 km in 21 hours 59 minutes, and amassed 172 km in 24 hours. Subject's HR averaged 119 ± 8 beats/min and average hourly HR changed as a function of hourly velocity ($r = 0.80$). Total EE estimated from HR telemetry and a metabolic equation was 12,820 and 12,425 Kcals, respectively. Total EI, 4590 kcal, came almost exclusively from carbohydrate. Blood glucose ranged between 8.2 and 4.1 mmol/L, averaging 5.6 ± 1.1 mmol/L. Estimated lipid oxidation accounted for 5,000 Kcals, and oxidation of carbohydrate accounted for another 1,900 Kcals. Remaining energy was likely supplied through direct oxidation of lactate as well as gluconeogenesis. Our results indicate that the subject experienced a substantial caloric deficit similar to that seen in other ultra-marathon runners, but did not exhibit hypoglycemia. We conclude that EI was sufficient to supplement endogenous substrate utilization and maintain euglycemia for the duration of the 24-hour run.

Key Words: Ultra-endurance, Carbohydrate, Lipid, Nutrition

INTRODUCTION

Ultra-endurance sports such as ultra-marathons (> 42 km), triathlons, and bike races necessitate large caloric expenditures to complete these prolonged events. Using indirect calorimetry O'Brien et al. estimated that energy expenditure (EE) running a marathon at a pace of 15-17 km/h, corresponding to 65-73% of VO_2 max, was 2500-4300 Kcals, the majority of which came from carbohydrate (1). However, unlike marathon runners Davies et al. have indicated that ultra-marathon runners compete at ~50% of VO_2 max (2), where a greater fraction of caloric expenditure may be met by fat (2). Caloric expenditure for running 160 km events has been estimated to be 10-13,000 Kcals (3,4). However, to date measurements of exercise intensity such as indirect calorimetry or heart rate telemetry have not been utilized to assess EE during an ultra-endurance

run. Further, research to date indicates that there is a large deficit between EE and energy intake (EI) during ultra-endurance events.

Collectively, research in ultra-marathon runners indicates that the rate of EI (Kcal/hour) is inversely related to average running velocity. Glace and co-workers (8) reported that EI averaged 230 Kcal/hour in runners covering 160 km at an average velocity of ~7 km/hour. In contrast, Fallon et al. reported that EI averaged 100 Kcal/hour in athletes who ran 100 km at a rate of 10 km/hour (5). Further, ultra-endurance athletes are frequently plagued by gastrointestinal discomfort that may negatively affect performance and caloric intake (3).

During ultra-endurance events athletes reportedly consume both solid and liquid foods in response to caloric demands and thermoregulation (3,6). In hot humid environments cumulative fluid intake may be considerably greater than when ultra-endurance athletes compete in more moderate climates. Large volumes of fluid intake may contribute to the frequent reports of gastrointestinal discomfort in ultra-marathon runners (3). It is reasonable to suspect that GI discomfort may decrease EI from solid food. Therefore, a comparison of EI during ultra-endurance events should consider the effect of variable environmental conditions on dietary intake. Further, due to the reported imbalance in caloric intake and caloric expenditure during ultra-endurance events (3,5), it has been suggested that hypoglycemia may contribute to reports of deteriorating cognitive function (3) or perceived mental state (6). However, although EE, EI, and fluid intake have been measured during ultra-endurance events, little is known about substrate changes or hypoglycemia during ultra-endurance events.

The purpose of the present investigation was to assess caloric expenditure and caloric consumption in a single athlete running for 24 hours on a treadmill in a moderately cool environment (16-18° C). Blood glucose and lactate were assessed hourly throughout the event. Our results indicate that estimates of caloric expenditure and caloric intake during 24 hours of treadmill running to be similar to those estimated previously for ultra-marathon running. Further, although the subject experienced a substantial caloric deficit similar to that seen in other ultra-marathon runners, the subject did not demonstrate hypoglycemia.

METHODS

Subject

The subject was a 51 year-old male who was an experienced ultra-marathon runner. The subject had competed in 27 events greater than 42 km in distance (Table 1) and was attempting to break a world record for distance run on a treadmill in 24 hours.

Procedures

Maximal Exercise Testing

Two weeks prior to the 24 hour treadmill run the subject underwent a progressive discontinuous maximal exercise test for determination of VO_2 max, lactate threshold (T_{lac}), and to develop a mathematical

relationship between VO_2 and heart rate. The subject ran for 4 minutes at each stage to assure steady state measures of VO_2 (ParvoMedics MMS-2400; East Sandy, UT) and heart rate (Accumen TZ Max 50; Sterling, VA), and rested for a period of 1 minute for the collection of blood lactate (Accusport; Boehringer Mannheim; Indianapolis, IN). In addition to maximal exercise testing, the subject's body fat was assessed using skin fold calipers (Lange; Cambridge, MD), utilizing a generalized equation for men (7).

Performance

The subject ran or walked continuously at a self-selected speed on a Landice treadmill (Landice, Inc.; Randolph, NJ) for a period of 24 hours. Subject performance was tracked hourly as the cumulative distance run. Instantaneous velocity (V_i) was calculated from the distance run in each hourly interval.

Energy Expenditure

Table 1. The number of marathons, ultra-marathons, and personal records by distance for a 51 year-old male subject.

	Distance (km)		
	42	42-160	≥160
Completions	11	23	4
Personal Record by distance	2:44	8:14 (50)	21:31 (100)

Values in parentheses indicate the distance run

Energy expenditure was determined from heart rate telemetry, utilizing an equation for the linear relationship between VO_2 and heart rate ($y=30.3x + 63.7$; $r^2 = 0.99$), obtained during the maximal exercise test (Fig. 1). Heart rate was averaged for each 5 min interval during the 24 hr treadmill run. Using the above equation VO_2 was determined for each 5 min period, and converted to calories assuming a caloric equivalent of 4.875 Kcal/L O_2 . This caloric equivalent for VO_2 corresponded to an RER value (0.86) at 50% of the subject's $\text{VO}_{2\text{max}}$. The subject's average heart rate during the event (119 ± 8 beats/min) corresponded to 50% of the subject's $\text{VO}_{2\text{max}}$, and previous work by Davies et al. indicated that subjects average 45-50% of $\text{VO}_{2\text{max}}$ during ultra-marathon running (2). As both HR and VO_2 drift occur during prolonged exercise, the validity of the HR- VO_2 relationship is maintained during prolonged exercise.

Nutrition/Hydration

All food consumed by the subject during the treadmill run was weighed immediately prior to being consumed. Total consumption of calories was then determined from the mass of the food consumed using USDA tables for commonly consumed foods. Fluid volume was determined from the weight of the fluid consumed, and whether the subject drank water or a commercial 6% carbohydrate electrolyte beverage (Conquest; Pensacola, FL). The caloric content of the carbohydrate electrolyte beverage was included in the determination of caloric consumption.

Urinalysis

Urine volume was determined by the net weight of urine collected from the subject, as well as the time of urine collection. Urinalysis for determination of glucose, ketones, red blood cells (RBC's), as well as by-products of RBC breakdown: bilirubin and urobilinogen, was determined using Multistix® 10 SG (Bayer Corp.; Elkhart, IN).

RESULTS

Subject Characteristic

Laboratory testing indicated a very high relative (58 mL/kg/min) and absolute (3.6 L/min) $\text{VO}_{2\text{max}}$ (Table 2). The subject exhibited a low body mass (62.3 kg) with a very low body fat percentage (7.4%). During a progressive discontinuous treadmill test the relationship between heart rate (HR) and VO_2 (L/min) was linear (Fig. 1) and this relationship was used to generate an equation to estimate VO_2 from HR during the 24 hr treadmill run.

Performance

The subject's instantaneous velocity (V_i) was calculated for each hour segment. V_i ranged from a peak of 8.8 km/h during the second hour of the run to a nadir of 4.5 km/h during the final hour of the event (Fig. 2). Average velocity for the event was 7.2 km/h. The subject's average hourly HR (Fig. 3) changed as a function of V_i ($r = 0.80$). The subject completed 160 km in 21 hrs and 59 min and completed 172 km in 24 hours before ending his treadmill run.

Table 2. Age, body composition, and aerobic characteristics of a 51 year-old male subject.

Age	Body Mass (kg)	Body Fat	$\text{VO}_{2\text{max}}$ x (L/min)	$\text{VO}_{2\text{max}}$ (mL/kg/min)	T_{lac} (L/min)
51	62.3	7.4%	3.6	58	2.68

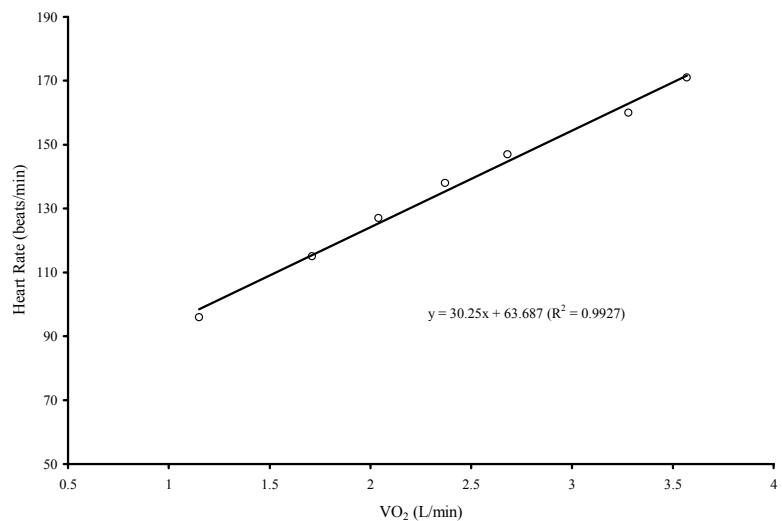


Figure 1. The relationship between heart rate (beats/min) and oxygen consumption (VO_2 ; L/min) measured during an incremental maximal treadmill test. The equation generated from this line was used to estimate energy expenditure during a subsequent continuous 24 hour treadmill run as described in Methods.

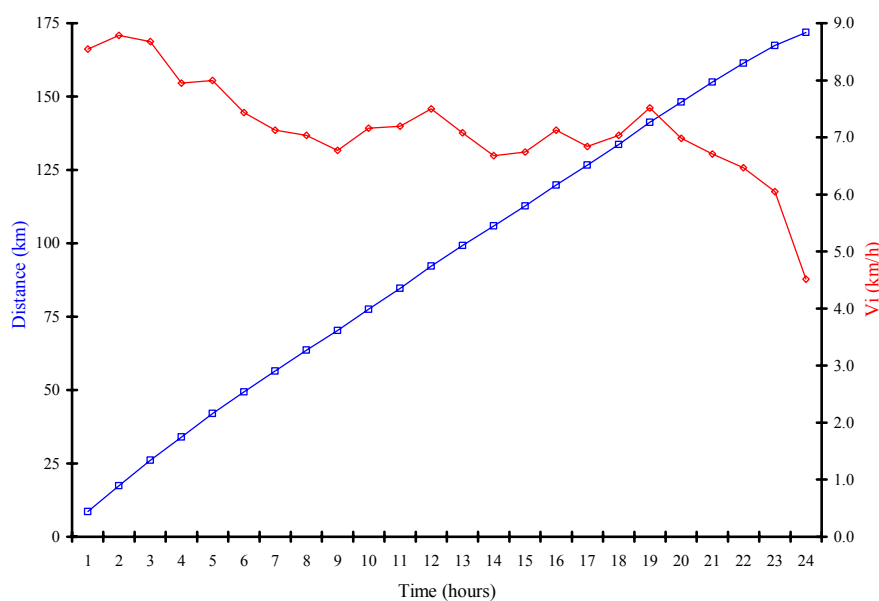


Figure 2. Instantaneous velocity (V_i ; km/h) and cumulative distance run (km) during a 24 hr treadmill run by a 51 year-old male athlete.

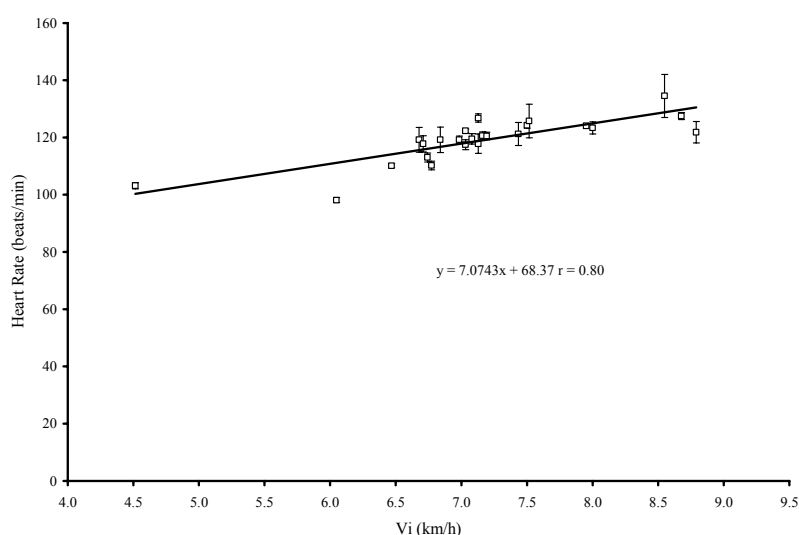


Figure 3. The effect of changes in instantaneous velocity (V_i) on HR during the course of a 24-hour treadmill run.

Energy

Total energy expenditure (EE) estimated from HR was 12,820 Kcal (Fig. 4). EE estimated from speed, distance and body mass was 12,425 Kcal (1). Hourly EE ranged from 684-332 Kcal/hour, averaging 534 ± 76 Kcal/hour. The total energy intake of 4590 Kcal came almost exclusively from carbohydrate. The subject's glucose levels averaged 5.6 ± 1.1 mmol/L, ranging from a nadir of 4.1 mmol/L at the conclusion of the 19th hour, to a peak of 8.2 mmol/L after the 23rd hour of running (Fig. 5). We contend that the maintained, and even increased blood glucose status of the subject suppressed amino acid oxidation, thus allowing for estimates of carbohydrate and lipid oxidation using the non-protein RER table. Estimated lipid oxidation accounted for 5,000 Kcal, and oxidation of carbohydrate accounted for another 1,900 Kcal. Remaining energy was likely supplied through direct oxidation of lactate as well as gluconeogenesis.

Hydration

Total fluid consumption was 12.6 L, and consisted of 2.3 L of water and 10.3 L of a fluid electrolyte beverage (Fig. 6). Total urine output was 4.9 L. The subject lost 0.5 kg of bodyweight pre- to post-exercise.

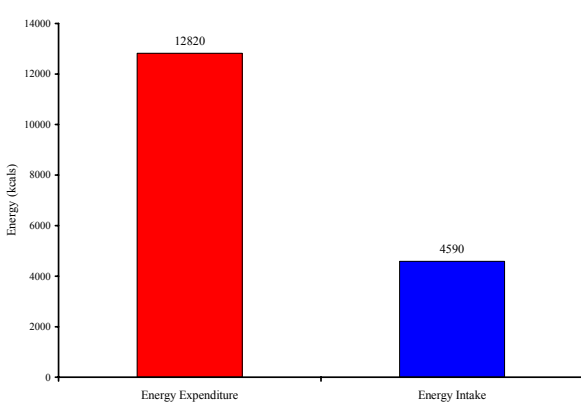


Figure 4. Energy expenditure (EE; Kcal) measured from HR telemetry, and energy intake (EI; Kcal) during a 24-hour treadmill.

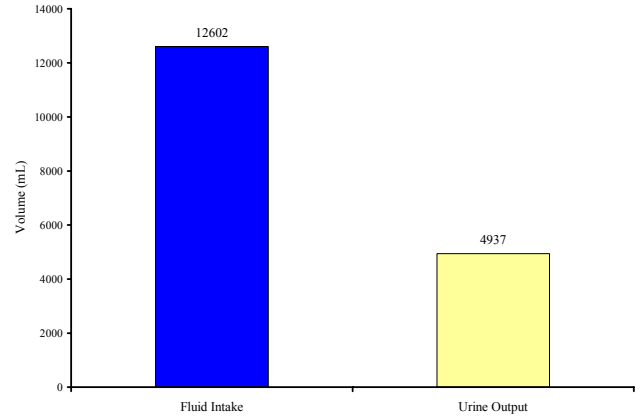


Figure 6. Fluid balance estimated from total fluid consumption (L) and urine output (L) during a 24-hour treadmill run.

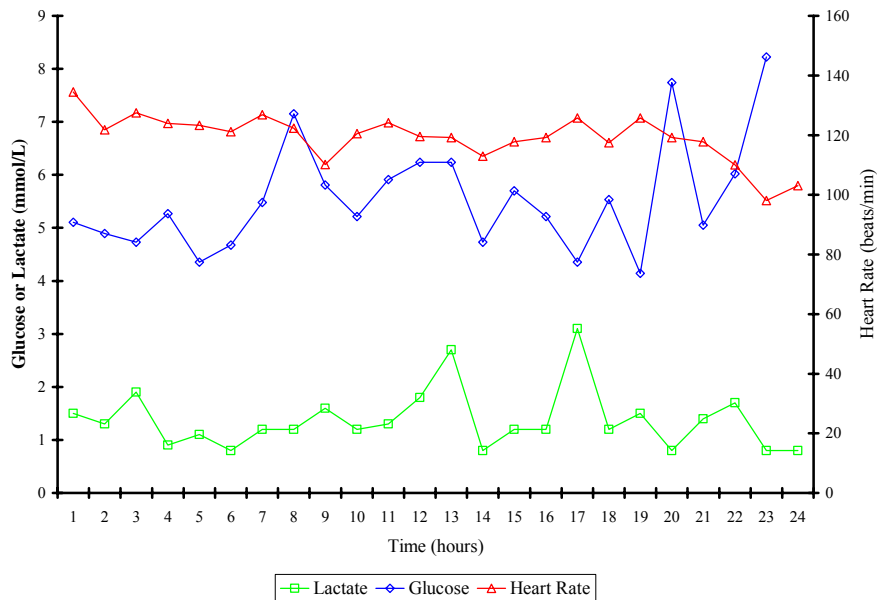


Figure 5. Average hourly heart rate (beats/min), as well as hourly measures of blood glucose and lactate (mmol/L) during a 24 hr treadmill run.

Urinalysis

Trace amounts of red blood cells (RBC's) appeared during the 11th hour of the event. By the 14th hour of the event urinalysis revealed large amounts of RBC's which remained evident at this level for the remainder of the event. Trace quantities of protein were detected in the urine during the 12th hour of running, and up to 30 mg/dL of protein remained evident in the urine throughout the remainder of the event. Moderate traces of bilirubin were detected in the urine during the 14th hour of running, and remained evident in the urine at this concentration for the next 8 hours. Urobilirubin was not detected through urinalysis. Ketones ranging from trace (5 mg/dL) to small (15 mg/dL) appeared during the 22nd and 23rd hours of running, respectively, but were not evident at any other time.

DISCUSSION

Subject Characteristics

The subject had extensive experience competing in ultra-marathons (Table 1), and in the laboratory exhibited a very high aerobic capacity for a male his age (Table 2). Further, given his small total mass and high lean mass (Table 2), coupled with his high aerobic capacity, the subject appeared well suited for his treadmill record attempt.

Performance

The subject achieved his goal of running 160 km in less than 22 hours (21 hrs 59 min) and amassed a total of 172 km during the 24 hour run. Interestingly, the subject had previously run 160 km outdoors over variable conditions at a faster pace (Table 1) than on the treadmill. It is known that the mechanics of running on a treadmill differ from over ground running (8). Given the fact that the subject ran in a cool environment on an even surface, it is likely that the differences in treadmill performance when compared to over-ground running may be explained by the differences in treadmill running mechanics. However, energy expenditure (EE) as measured in the present investigation (Fig. 4) agrees with previous estimates of EE for ultra-marathon running similar distances (3,4).

Energy Balance

Previously Glace and co-workers (3) reported EE for a group of runners who ran 160 km ($n = 19$) to be 13,560 Kcals, factoring speed, duration, and time of running (9). Using the same equation we estimated EE to be 12,425 Kcals. In addition, using the relationship between VO_2 and heart rate (HR) as described in Methods (Fig. 1), we estimated EE each hour, and found that the subject expended 12,820 Kcals (Fig. 4). Although it is possible that estimations of EE from HR may be overestimated by heat-induced elevations in HR, this effect was minimized in the present investigation by maintenance of cool environment. Whether the metabolic equation underestimated EE or HR telemetry overestimated EE, this error was no more than ~3%. In addition, results of past and present investigations indicate that EE for 160 km running, whether over-ground or on a treadmill to be 12-14,000 Kcals. Further, we observed a similar deficit between EE and energy intake (EI) as previously reported.

It is well known that carbohydrate (CHO) ingestion prior to and during exercise can improve performance and prolong the onset of fatigue (10-14). In the present investigation EI was 4590 Kcals (Fig. 4), primarily from CHO. The subject, a vegetarian, ate mainly bagels, maltodextrin gel packets (GU; Sports Street Marketing: Berkeley, CA), boiled potatoes, and pretzels. The subject's average rate of EI (~200 Kcals/hour) is similar to that reported for ultra-marathon running at 7 km/h, and greater than when subjects ran at a faster velocity for a shorter distance (5). Although reports of gastrointestinal (GI) symptoms are apparently common in ultra-marathon runners (3), the subject reported no GI disturbances. Further, Glace et al. reported no significant relationship between frequency of GI disturbances and either total EI or intake of CHO (3).

In the present investigation, the average rate of CHO intake (~0.8 g/min) was quite similar to the rate of CHO intake for both 160 km runners and cyclists competing continuously for 12 hours (0.8-0.9 g/min) (3,6). Rauch et al. indicate that the maximal rate of exogenous CHO oxidation to be 1 g/min (15). Oxidation of ingested CHO, measured from U-[^{13}C] glucose, was 1-1.2 g/min during prolonged treadmill running at 69% of VO_2 max (16). Similarly, oxidation of exogenous glucose, measured with U-[^{14}C] glucose was ~0.8 g/min during 6 hours of cycling at 55% of VO_2 max (17). Collectively, results of past and present investigations suggest that experienced ultra-endurance athletes may select a rate of EI that approaches maximal rates of utilization.

The deficit between EE and EI, ~8,000 Kcals, was also similar to that reported previously for ultra-marathon runners (3). In spite of the large caloric deficit the subject maintained euglycemia throughout the event. At the end of the 5th and 19th hours of running blood glucose was 4.1 and 4.4 mmol/L, respectively, indicating that the subject's blood glucose level was on the lower end of normal. In contrast, blood glucose exceeded 7 mmol/L at the end of the 20th, 23rd, and 24th hours. These high levels of blood glucose may have resulted from consuming maltodextrin gels preceding measurement of blood glucose. Therefore, although large

caloric deficits are incurred by ultra-marathon runners, hypoglycemia may be prevented by EI sufficient to supplement oxidation of endogenous energy stores.

According to Brooks and Mercier (18), fat oxidation accounts for ~40% of EE at 50% of VO_2max . Therefore, in the present investigation we estimate that fat oxidation would account for nearly 5,000 Kcals. Further, O'Brien et al. estimated total liver and muscle glycogen to be 475 g (1900 Kcals) (1). The remaining energy ($12820 - 4590 - 6900 = 1330$ Kcals) was likely supplied through direct oxidation of lactate, as well as gluconeogenesis (1,17). Direct oxidation of amino acids, as well as the use of amino acids such as alanine as gluconeogenic precursors likely contributed to endogenous energy supply, however, the overall lack of ketones in the subject's urine, suggest very little use of amino acids for energy. Generally speaking blood lactate changed very little during the 24 hour run. This observation is in contrast to the higher levels of lactate seen during treadmill marathon running at much faster paces than in the present investigation, but consistent with prolonged submaximal cycling at 50% VO_2max (17). In the present investigation, the subject ran well below his lactate threshold (T_{lac}) and although blood lactate did not change markedly, previous research suggests that lactate flux through direct oxidation, as well as through gluconeogenesis, are important routes of lactate disposal and important energy sources during prolonged exercise (1,17,19). Collectively, our measurements of EE, EI, and blood glucose, indicate that the subject's endogenous and exogenous fuel supplies were sufficient to maintain euglycemia while running continuously for 24 hours at an intensity corresponding to 50% of VO_2max .

Fluid Balance

Unlike many ultra-marathons that are run in warm to hot environments, the room remained relatively cool (16-18° C) for the entire event. The subject's fluid intake, 12.6 L (Fig. 6), was similar to that reported for runners competing 160 km outdoors (3). In the present investigation, body mass changed only 0.5 kg, suggesting minimal dehydration and urinary loss accounted for less than 50% (4.9L) of fluid intake. If it is assumed that the remaining fluid was lost through dehydration, sweat rate would have been 0.5-0.6 L/hour. This rate of sweat loss is consistent with the metabolic heat production and subsequent sweat loss expected from exercise at 50% of VO_2max in a cool environment (20,21).

CONCLUSIONS

The results of the present investigation indicate that EE measured either through HR telemetry or metabolic calculations yielded similar results during an ultra-marathon performed on a treadmill in a cool environment. Intake of fluid and energy appears to be similar for ultra-marathon running, whether run indoors in a cool environment or outdoors under variable environmental conditions. In addition, the subject consumed energy at a rate that was sufficient to supplement endogenous fuel stores while avoiding GI disturbance. Further, the combination of EI and exogenous oxidation of fat, carbohydrate, and lactate, was sufficient to meet energy requirements and maintain stable blood glucose levels.

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