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Article

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Case study: Energetics of a world tour female road cyclist during a multi-stage race (*Tour de France Femmes*)

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ABSTRACT

Despite the increased popularity of female elite road-cycling, research to inform fuelling requirements of these endurance athletes is lacking. In this case study we report for the first time the energetics of a female world-tour cyclist competing in the 2023 *Tour de France Femmes,* an 8-day race of the *Unione Cicliste Inernationale*. The 29-year-old athlete presented with oligomenorrhea and low T3 prior to the race. Total daily energy expenditure assessed with the doubly labelled water technique was 7572 kcal/day (~4.3 PALs), among the highest reported in the literature to date for a female. Crank-based mean maximal power was consistent with female world-tour cyclists (5-min, mean 342 W, 4.8 W/kg; 20-min 289 W, 4.1 W/kg). Average daily energy intake measured with the remote food photography method (stages days 1-7) was 5246 kcal and carbohydrate intake 13.7 g/kg (range 9.7-15.9 g/kg), and 84 g/h during stages, with average fat intake 15% of daily energy intake. An estimated 2326 kcal/day energy deficit was evidenced in 2.2 kg decrease in body mass. Notwithstanding the high carbohydrate intake, the athlete was unable to match the energy requirements of competition. Despite signs of energy deficiency pre-existing (oligomenorrhea and low T3), and other further developing during the race (weight-loss), performance was in line with that of other world-tour cyclists and a best personal performance was recorded for the last stage. This case study emphasizes the need for further research to inform energy requirements for female athletes' optimal performance and health.

INTRODUCTION

Despite the increased popularity of elite women's sport over the last century, female athletes remain significantly under-represented in sport and exercise sciences (Cowley et al., 2021) and in sports nutrition research (Areta & Elliott-Sale, 2022). Female elite road-cycling experienced an 80% increase in athletes registered with *Unione Cycliste Internationale* (UCI) between 2012 and 2020 (Erp, 2019; Herrero-Molleda et al., 2023) and yet female-specific research to inform fuelling requirements of female endurance athletes is lacking (Moore et al., 2021).

Road cycling is a sport with high energy demands. In male athletes, multi-day competitions, the pinnacle of which is '*grand tours*' or daily stages completed over ~3 weeks, extremely high total daily energy expenditure (TDEE), that is 3.9 to 5.3 times the resting metabolic rate (physical activity level; PAL) have been observed throughout the competition (Plasqui et al., 2019; Van Hooren et al., 2022; Westerterp et al., 1986). In females, there are no data reporting TDEE in these multi-day events and hence sex-specific nutritional requirements are not presently available. Due to potential negative effects of low energy availability for female athletes (Areta et al., 2021; De Souza et al., 2014; Mountjoy et al., 2023), understanding energetic demands required by female athletes in scenarios where they may be likely to unintentionally under-fuel will inform nutritional strategies to optimise performance, recovery and health.

Herein we report for the first time the TDEE of a world tour female cyclist competing on the second edition of *Tour de France Femmes* (an 8-day cycling event of the *Unione Cicliste Internationale* calendar) together with daily dietary intake throughout the race, crank-based power meter data and other physiological and anthropometric parameters.

ATHLETE CHARACTERISTICS AND METHODS

Athlete Characteristics

The professional cyclist, classified as an *all-rounder* and *individual time-trial* specialist, was 29 years old at the time of the race in July 2023. Laboratory and field-based physiological testing collected between January and July 2023 yielded the following results: body mass, 71.5 kg; DXA (Lunar Prodigy, General Electric, Boston, MA, USA) percent fat 20.8% and bone mineral density Z-scores for femur neck and lumbar spine (L1-L4) -0.3 and -0.9, respectively; VO_{2max} (Quark CPET, Cosmed, Rome, Italy), 4.49 L/min; 5-min mean maximal power (MMP), 351 W; 20-min MMP, 303 W. The athlete reported oligomenorrhea and exhibited clinically low triiodothyronine (0.6 µg/L, laboratory normal range 0.7-2 µg/L; June 2023) but was otherwise healthy at the time of the event.

Event characteristics

The *Tour de France Femmes 2023* was held July 23 – 30, 2023 in France. Athletes completed a 956 km road race in stages over 8 days: 1st, 124 km (~700 m elevation gain (EG)); 2nd, 152 km (~2100 m EG); 3rd, 148 km (~1600 m EG); 4th, 178 km (~2000 m EG); 5th,127 km (~1400 m EG); 6th 122.5 km (~1000 m EG); 7th, 90 km (~2400 m EG); 8th (individual time trial): 22.6 km (~200 m EG). The cyclist role in the team was mainly to support a cyclist of the team with chances to win general classification, as well as to aim for best possible individual performance on stage 8.

Physiological & Dietary Assessments

Body mass and hydration assessments: Body mass was measured daily with digital scales (NVR-3327, Nevir, Madrid, Spain) in the morning after waking and voiding, wearing minimal clothing. Urine refractive index (Metria, RSD200, Labbox, Barcelona, Spain) was taken as a proxy marker of hydration, with urine sampled upon waking.

Dietary intake assessment: Dietary intake was recorded meal-by-meal for 8.5 days (day pre-race, until end of stage 8) in real time using a modified version of the remote food photography method (Martin et al., 2008) (see further details elsewhere (Foo et al., 2022)) and with foods weighed when possible. Dietary intake during daily stages was recalled immediately upon stage completion.

Crank-based mechanical power output and other cycling data: Relevant cycling racing data (time, distance, speed, ascent, etc) were collected with a cycling computer (Edge 850, Garmin, Olathe, KS), which was paired to a crank-based power meter (Di2 Dura Ace, Shimano, Sakai City, Osaka) and a heart-rate monitor (Garmin, Olathe, KS). Data were recorded second-by-second and subsequently uploaded to a data analysis software (TrainingPeaks, Boulder, CO).

Doubly Labelled Water Assessment of TDEE: On the day prior to the event the athlete provided a baseline urine sample and was dosed with 3g per Kg of DLW (10% $H_2{}^{18}O$ 0.1425 g $H_2{}^{18}O \cdot kg$ total body weight and 99% ^2H_2O 0.075 g $^2H_2O \cdot kg$). Urine samples were collected daily during the race and enrichments of ^2H and ^{18}O were measured using isotope ratio mass spectroscopy (Delta V, Thermo Fisher Scientific, Waltham, MA, USA). Isotope elimination rates (kH and kO) were calculated by linear regression and total daily energy expenditure calculated using the rCO2 and a RQ 0.86. Resting metabolic rate (RMR) was estimated using Cunningham equation (Cunningham, 1980) and physical activity level calculated as TDEE/RMR.

RESULTS

Stage and cycling power-output characteristics:

Characteristics of the race demands for each stage are reported in **Table 1**.

Race performance

Cumulative official time for the race was 26 h, 41 min, 59 sec (position 96 of 123), and best performance was on stage 8 with official time 30 min 56 sec (position 15 of 123).

Total daily energy expenditure, dietary intake, body mass

Average daily expenditure for the race was 7572 kcal/day and PAL calculated as 4.32 (based on an estimated RMR of 1745 kcal/day).

Daily average energy intake for race days 1 through to 7 was 5246 kcal (intake for day 8 was recorded only until end of stage), with an average daily intake of 13.7 g/kg of carbohydrates, 2.4 g/kg of protein, and 15% of energy derived from fat (**Table 2**).

The difference between TDEE and energy intake produced an average daily deficit of 2326 kilocalories. Accordingly, body mass decreased from 71.2 kg on the morning of day 1 to 69 kg on day 8 (**Figure 1**). Estimates of energy deficit from tissue energy equivalents (7400 kcal/kg) (Redman et al., 2009), therefore predicted a daily average deficit of 2326 kcal/day over 7 days, which agreed with the difference between TDEE and dietary energy intake.

Urine refractive index

Measured on days 1,2,3,5,6 and 8, values were 1.3395, 1.337, 1.3384, 1.34, 1.3376 and 1.3383 (arbitrary units), respectively.

DISCUSSION

This case study shows for the first time the energetics of a female professional road cyclist completing a world-tour multi-day event. The most prominent findings include a high total average daily energy expenditure of 7572 kcal/day (4.32 PALs), high carbohydrate intake ranging from 9.7 to 15.9 g/day, and a negative energy balance with weight loss throughout the event. Our findings are comparable with reports of male athletes of this calibre, but the energy deficit experienced during racing appears to be more severe and highlights the need for further systematic research on energetic demands of female athletes in training and competition.

The average daily TDEE of 7572 kcal/day (4.32 PALs) may be the highest individual value to date in a female athlete reported in the scientific literature using the doubly labelled water method, surpassing absolute and relative values reported for female swimmers (Trappe et al., 1997), runners (Sjödin et al., 1994) and cross-country skiers (Sjödin et al., 1994). Notably, the TDEE falls within the range reported for male cyclists during 3-week long *grand tours* of 3.9 to 5.3 PALs (Plasqui et al., 2019; Van Hooren et al., 2022; Westerterp et al., 1986). These data suggest relative energy expenditure capacity between females and males in this sport is comparable.

The dietary intake reported (**Table 2**) is similar to those reported for male athletes during a grand cycling tour. For example, the average daily intake of 9 male cyclists during the 3-week long 2015 *Vuelta a España* was 872 g, 12.5 g/kg and 65% of energy for carbohydrate; 107g, 1.5 g/kg and 18% of energy for fat; and 230 g, 3.3 g/kg and 17% energy for protein (Muros et al., 2019). Similar to Muros et al. (2019) the dietary fat intake of the female athlete was below the recommended 20% of daily energy (Thomas et al., 2016), and the athlete experienced a 2.2 kg loss of body mass, which, based on hydration status (urine refractory index), is unlikely to be to explained solely by dehydration or loss of body water. Energy deficit appears evident throughout, though the steeper body mass decline in stages 7/8 may be explained by a combination of higher fiber intake early-race (leading to higher gut bulk retention (Foo et al., 2022)), and a lower energy/carbohydrate intake late-race (**Table 2**). Estimates of energy balance from tissue equivalents as well as, TDEE and dietary energy intake indicate an average energy deficit of 2326 kcal/day, or 31% energy deficiency.

The high energetic demands of competition led to unintentional under-fuelling of the athlete. It has been proposed that the capacity for food digestion and absorption represent a limiting factor in the acquisition of energy to match energy requirements of highly active individuals (Thurber et al., 2019). It is possible that due to the lower energy density of carbohydrates —compared to fat—, that the athlete may found difficult to physically ingest the large volumes of food represented by carbohydrate-rich diets. This case study suggests that greater attention to dietary fat may be needed in these scenarios. Given the limited body capacity of storage of carbohydrates (~500/600 g), it is arguable that ingestion of carbohydrates above this value during the recovery period (when carbohydrates are likely to be stored rather than oxidised) could be counterproductive. Instead, an additional ingestion of ~250 g/day fat may be easier to achieve if reaching energy balance is desired.

This athlete may have been chronically under-fuelling prior to the race, as evidenced by reported oligomenorrhea and low T3, both of which are indicators of low energy availability (Areta et al., 2021; Loucks & Heath, 1994). These are considered important markers in physiological models of under-fuelling such as the *female athlete triad* and *REDs* that predict negative health and performance consequences of chronic under-fuelling (De Souza et al., 2014; Mountjoy et al., 2023). Despite this, the athlete exhibited world-class performance achieving best personal performance on the race on the last stage. Moreover, the mean maximal power (MMP) (**Table 1**) matches exactly reported values for world-class female athletes in multi-day competitions (Van Erp & Lamberts, 2023), putting in question whether physical capacity was compromised despite the acute and chronic energy deficiency. Furthermore, the athlete placed 10th in the individual time-trial cycling world-championships less than two weeks after this event. Taken together, under-fuelling is not incompatible with top world-class performances, though further research is needed to determine if physical performance achieved with this magnitude of energy deficiency could be further improved when fuel availability more closely matches fuel utilization.

Given the importance of locomotion for survival in human evolutionary history, it is possible that locomotive capacity (and therefore physical performance) may be prioritised over other functions that are not immediately necessary for survival during period of energy deficit (e.g. reproductive capacity), and therefore performance may be a poor marker of under-fuelling (Areta, 2023). However, we call for caution in the interpretation of our results and highlight our findings are limited to a single individual, in the context in which data for this case-study was collected, and subject to the limitations of error of measurement of the methods used. Therefore, we hope that these insights are a first step to carry further research on assessments of elite female endurance athletes in the future will allow to tease out the complex interplay between energy balance, health and physical performance. Such assessments would provide female athletes the opportunity to achieve their best performance, optimize recovery and maintain normal physiological functions.

In conclusion, this case study reports for the first time extremely high levels of total daily energy expenditure during an 8-day tour of a world-tour female cyclist, concomitant with high levels of daily carbohydrate intake, though with an energy intake that failed to match the high levels of energy expenditure, resulting in negative energy balance throughout the competition. This single assessment during a multi-day athletic pursuit highlights the need for further comprehensive research to characterise the energetic demands of female sports. Such studies will inform the energy prescription female athletes require to support optimal health and elite performances.

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TABLES & FIGURES

Table 1. Characteristic of stages and relevant physiological data for the athlete for each stage.

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
Duration (h:m:s)	3:11:41	4:27:32	4:05:33	4:59:29	3:25:09	3:00:01	3:26:32	0:30:53
Distance (km)	123	151	151	177	126	122	89.8	22.2
Average speed (km/h)	38.5	33.9	37	35.4	36.8	40.6	27.2	43
Heart Rate (Average)	161	151	150	144	149	No data	No data	No data
Elevation gain (m)	690	2145	1598	1986	1410	1011	2378	176
Training Stress Score	189	287	282	279	222	219	280	52
Intensity Factor	0.77	0.8	0.83	0.75	0.81	0.86	0.92	1
Mechanical Work (kj)	2417	3292	3172	3442	2629	2423	3099	551
Gross Metabolic work (kcal) *	3040	4141	3990	4330	3307	3048	3898	693
Average power (W (W/kg))	212 (3.0)	207 (2.9)	217 (3.0)	194 (2.7)	215 (3.0)	226 (3.2)	261 (3.7)	297 (4.3)
MMP 5 min (W (W/kg))	280 (3.9)	363 (5.1)	337 (4.7)	340 (4.8)	344 (4.9)	335 (4.7)	388 (5.6)	350 (5.1)
MMP 30 min (W (W/kg))	244 (3.4)	277 (3.9)	268 (3.7)	250 (3.5)	282 (4.0)	259 (3.7)	317 (4.5)	298 (4.3)
MMP 60 min (W (W/kg))	236 (3.3)	245 (3.4)	242 (3.4)	228 (3.2)	245 (3.5)	234 (3.3)	293 (4.2)	N/A

* Estimated from mechanical work, assuming an average gross efficiency of 19% (Haakonssen et al., 2013).MMP, mean maximal power

Table 2. Dietary intake.

	Day -1	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**	**Stage 6**	**Stage 7**	**Stage 8**	**AVG (1-7)***
Daily intake										
Energy (kcal)	3600	4673	5619	5100	6134	6068	4152	4517	1546	5246
CHO (g)	461	862	916	928	1129	989	683	803	252	973
Fat (g)	111	71	137	57	86	128	75	75	73	90
Protein (g)	162	151	161	181	192	218	149	149	100	171
Fibre (g)	44	34	45	54	45	41	35	34	8	41
CHO (g/kg)	6.5	12.1	12.9	13.0	15.9	14.0	9.7	11.5	3.7	13.7
Fat (g/kg)	1.6	1.0	1.9	0.8	1.2	1.8	1.1	1.1	1.1	1.3
Protein (g/kg)	2.3	2.1	2.3	2.5	2.7	3.1	2.1	2.1	1.4	2.4
CHO (% total E)	53	74	66	75	75	66	79	72	59	72
Fat (% total E)	29	14	22	10	13	19	11	15	26	15
Protein (% total E)	19	13	12	15	13	15	10	13	16	13
CHO intake during race										
CHO (g)	N/A	283	323	383	447	400	269	240	0	335
CHO (g/h)	N/A	83	68	93	84	105	84	71	0	84

*Dietary intake for stage 8 was measured only until the end of the stage, therefore average values are reported for stages 1 to 7.

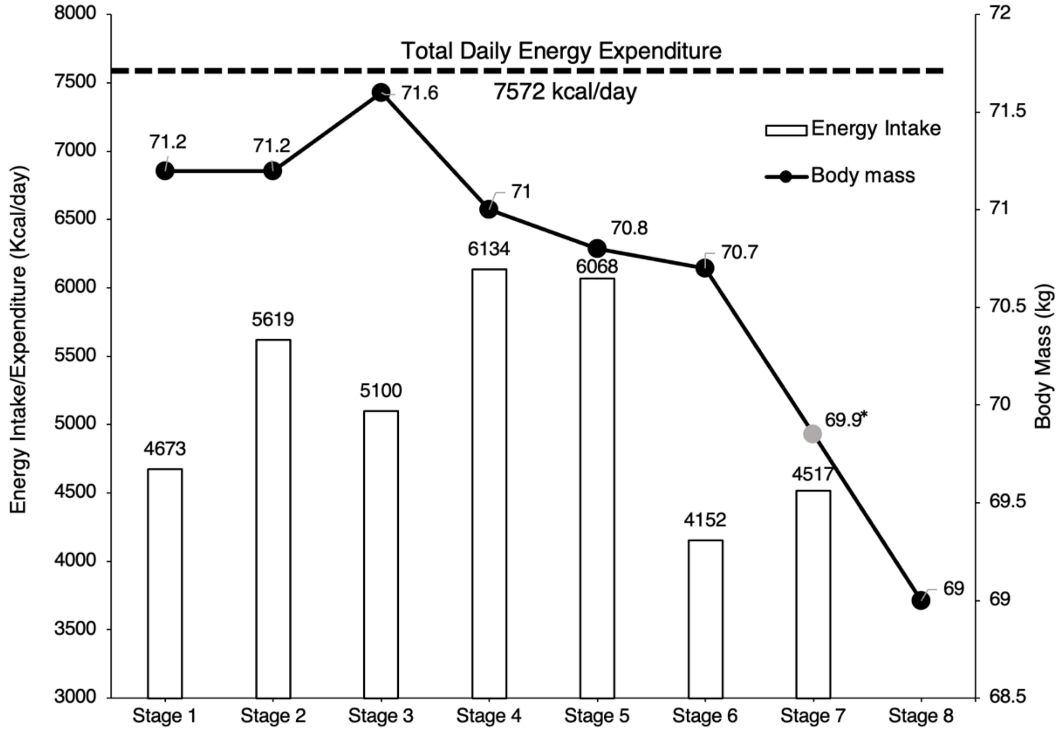

Figure 1. Average daily energy expenditure, daily energy intake and body mass. Average daily energy expenditure measured by the double labelled water technique includes stages 1 through to 8, inclusive; daily energy intake is derived from the remote food photography method technique and weights were recorded in the morning. Dietary intake for stage 8 was recorded only until end of stage and it has been excluded on this graph (not comparable to full-day energy intake). *, body mass was not recorded on this day and data were interpolated.