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Human Kinetics
CASE STUDY

Case Study: Resumption of Eumenorrhea in Parallel With High Training Load After 4 Years of Menstrual Dysfunction: A 5-Year Follow-Up of an Elite Female Cyclist

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The female athlete triad is a condition where low energy availability is typically observed together with menstrual dysfunction and/or low bone mineral density. How this condition affects maximal work capacity in endurance athletes is not clear, and the recovery time course of menses with increased energy availability with concomitant high training load is unknown. This case study of an amenorrheic elite road cyclist reports resumption of normal menstrual function after weight gain during a 5-year period (2014–2019), while engaged in high training load and competition. The athlete ($\dot{V}O_2$max 3.54 L/min, 64 ml·min^{-1}·kg^{-1}, aerobic peak power output 300 W, 5.4 W/kg) reported amenorrhea (2013–2015) and oligomenorrhea (2015–2018). Training load increased from 2014 to 2019 (584–818 hr/year and 26,707–41,945 training stress score/year). Regular menses (every 23–35 days) resumed in June 2018, ~5–6 months after a weight gain episode. During the period of menstrual dysfunction, body mass was 51.3 ± 2.25 kg (mean ± 95% confidence limit) and fat percentage was 19% (dual-energy X-ray absorptiometry, 2016), and after weight gain, body mass was 56.8 ± 2.63 kg and fat percentage was 25% (dual-energy X-ray absorptiometry, 2019). Crank-based power meter data showed absolute mean maximal power (in watts) improvement over the 5 s to 4 hr range through the 2014–2019 period, while relative mean maximal power (in watts per kilogram) likely peaked in the 2015–2016 season for 5 min, 20 min, and 30 min, but remained mostly unchanged across seasons. Results suggest that (a) the best relative power output associated with aerobic capacity (5 min to 1 hr) can be achieved during menstrual dysfunction, (b) high performance achieved despite an increase in body mass, and (c) resumption of menses is achievable while maintaining high training loads when coupled with high energy availability.

Keywords: endurance performance, energy availability, female athlete triad, menstrual function

The female athlete triad has been identified as a condition where chronic low energy availability (LEA) is typically concomitant with menstrual dysfunction and/or low bone mineral density (Nattiv et al., 2007). Elements of the triad are often observed in athletes from sports focusing on leanness and low body weight (Torstveit & Sundgot-Borgen, 2005), likely as a consequence of not providing enough energy to maintain normal function of physiological processes (Loucks et al., 2011). Although the effects of LEA on physiological processes such as those related to reproductive function and bone formation/resorption are well established (De Souza et al., 2019), it is less clear what may be the other physiological effects linked to physical capacity (De Souza et al., 2014; Mountjoy et al., 2018). The "relative energy deficiency in sport" model emphasizes negative effects of LEA on performance (Mountjoy et al., 2018), but there is currently little evidence supporting this.

In addition, the recovery time course for resumption of menses with changes in energy status is not well characterized. Evidence suggests that increased energy availability (EA) slowly restores the normal hormonal milieu of energy disrupted women (Loucks & Verdun, 1998), but proofs for the effectiveness of increased energy on actual resumption of menses in amenorrheic athletes over prolonged periods are limited (Stickler et al., 2019). Moreover, the interaction between the energy status, menstrual function, and the heavy training load of elite athletes has never been addressed longitudinally.

This is the first case study that provides detailed information on body mass and body composition data in relation to reported menstrual status together with detailed training records and markers of physical performance through the use of crank-based power meter data of an elite female cyclist over a period of 5 years, evidencing resumption of regular menses after a prolonged period of menstrual dysfunction.

Athlete Characteristics and Methods

The Athlete

The athlete was 23-years-old in 2014. In mid-2014, after a 3.5 years break in training, she had been competing in road cycling at a club level for <8 months. Through 2014–2019, she progressed to compete at a national level in Australia and international level in Oceania, consistently achieving podium finishes in major cycling road races and time trials in these circuits.

Standard laboratory testing (Hawley & Noakes, 1992) determined 300 W and 5.39 W/kg of absolute and relative aerobic peak power output respectively, and 3.54 L/min and 63.6 ml·kg^{-1}·min^{-1} of absolute and relative $\dot{V}O_2$max respectively in June 2014.

The athlete read the case study in its entirety and provided written record of approval of this article.

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Body Mass

Body mass was recorded repeatedly by the athlete throughout the period of October 2014 through June 2019 using bathroom scales (October 2014 to July 2016, analog scale, unbranded; July 2016 to June 2019, Tanita BC-582; Tanita, Tokyo, Japan) in the morning upon waking and after voiding, wearing minimal clothing, and recorded online (TrainingPeaks, Boulder, CO). These data were analyzed using a dedicated tool to determine the likelihood of individuals' changes from a trend (Hopkins, 2017).

Training Log and Data Collection

Training logs were kept for all training/racing sessions from June 2014 to June 2019 including recordings of crank-based power output, heart rate, global positioning system-based speed and altitude, and rate of perceived exertion and relevant notes.

Five different crank-based power meter units were used through the recording period, such as SRM power meter (SRM, Jülich, Welldorf, Germany), Power2max (two units; Saxonar GmbH, Nieder Seifersdorf, Germany), Pioneer (Pioneer, Tokyo, Japan), and 4iiii precision (4iiii Innovations Inc., Cochrane, AB, Canada). Integrity and consistency of units was checked when changed by comparing power data with heart rate and climbing times.

Power data were analyzed using a specialized software (WKO4; TrainingPeaks), and training load was quantified using training stress score (Allen & Coggan, 2010).

Weight Loss Interventions

Two weight loss interventions lasting 6 weeks were devised for competitions (Figure 1). For Intervention 1, a food plan aimed at achieving ~1,845 kcal/day (range 1,040–3,443 kcal/day, depending on training demands) and ranges of macronutrients as follows: protein 1.9–2.8 $g{\cdot}kg^{-1}{\cdot}day^{-1}$, fat 0.45–1.85 $g{\cdot}kg^{-1}{\cdot}day^{-1}$, and CHO 0.6–8.8 $g{\cdot}kg^{-1}{\cdot}day^{-1}$. During Intervention 2, a color-coded plan indicated carbohydrate amounts of meals on a meal by meal basis to self-select food sources providing ~50–150 g CHO per meal and achieve 3–10 g $CHO{\cdot}kg^{-1}{\cdot}day^{-1}$ to match the demands of training (Impey et al., 2018), and instructed to repeatedly ingest ~25 g of high-quality protein spread every ~3 hr throughout the day (Areta et al., 2013; Moore et al., 2014), minimize fat intake, and manipulate fiber intake (Melin et al., 2016).

Body Composition

Body composition was assessed using narrow fan-beam dual-energy X-ray absorptiometry (Lunar iDXAs; GE Healthcare, Madison, WI).

Low Energy Availability in Females Questionnaire

Low Energy Availability in Females Questionnaire (Melin et al., 2014) assessment was conducted in June 2019.

Menses

Menstrual function was assessed based on the athlete's records, recalls, and reports of menstrual bleeding.

Results

Body Mass, Body Mass Index, and Body Composition

Body mass records are reported on Figure 1. From October 2014 up until November 2017, average body mass recorded was 51.3 ± 2.25 kg (arithmetic mean ± 95% confidence limit). Between November 2017 and February 2018, a body mass gain episode showed an increase of 58.2 kg and maintained at 56.8 ± 2.63 kg; thereafter, a very clear (100% chance) increase above the trend in body mass

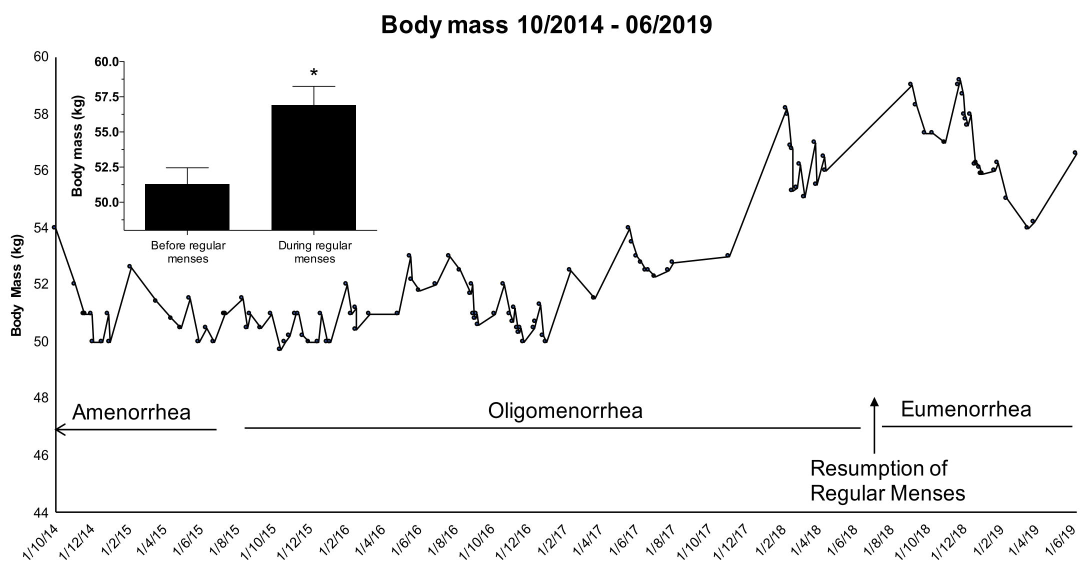

Figure 1 — Individual body mass measurements (in kilograms) between October 2014 and June 2019. The figure specifies period of no menses (amenorrhea), irregular menses (oligomenorrhea), and the period in which regular menses resumed (eumenorrhea). The insert in the figure reports the body mass (average ± *SD*) for the period prior to a body mass gain episode in November 2017 to February 2018 versus the body mass after regular menses resumed. *A *very clear* (100% chance) increase above the trend in body mass prior to body mass gain. WLI 1 = weight loss intervention 1; WLI 2 = weight loss intervention 2.

Table 1 Athlete's Body Composition Assessed With Two DXA Scans 3 Years Apart in Two Different Clinics Using Two Units of the Same Brand and Model of DXA Scanner

	Measurement date		Change	
	July 14, 2016	July 18, 2019	Absolute	%
%Body fat	18.8	25	6.2	
%Body fat *Z* score	−1.227	−0.524		
Body fat (kg)	9.9	14.8	4.91	49.8
Lean mass (kg)	42.66	44.37	1.71	4.01
BMC total (kg)	2.228	2.239	0.01	0.49
Total body BMD (g/cm^2)	1.102	1.121	0.02	1.72
Total body BMD *Z* score	0.7	0.6		
DXA total mass (kg)	54.8	61.4	6.6	12
BMI (kg/m^2)	19.5	22.4	2.9	13

Note. DXA results are shown mainly to indicate the large change in fat mass. The change in this parameter is well above any technical error of measurement between or within scan settings (Nana, 2013). The first scan corresponds to a period of oligomenorrhea and the second scan to a period of eumenorrhea. BMC = bone mineral content; BMD = bone mineral density; BMI = body mass index; DXA = dual-energy X-ray absorptiometry.

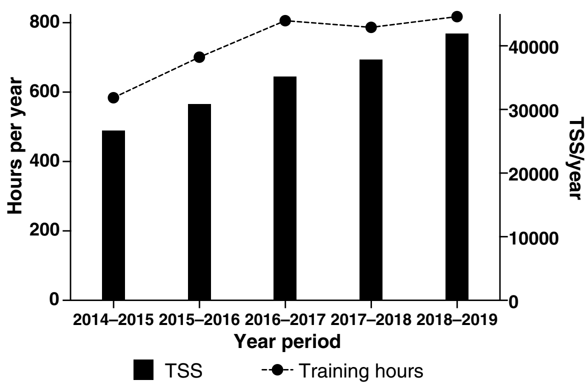

Figure 2 — Yearly training load in hours and TSS from June of one year to June of the following year. TSS = training stress score.

prior to body mass gain was observed. For the respective periods, body mass index was 18.8 ± 0.83 and 20.8 ± 0.97 kg/m^2. Body composition results are detailed in Table 1.

Weight Loss Interventions

Body mass reduced from 54 to 52.3 kg (1.7 kg decrease, 6-week intervention, rate of weight loss 0.28 kg/week) during Intervention 1 and from 59.2 to 55.9 kg (3.3 kg decrease, 6-week intervention, rate of weight loss 0.56 kg/week) during Intervention 2.

Total Training Load and Mean Maximal Power

The data presented a summary of 2,384 cycling (96%) and 50 running (2%) training log files between June 2014 and June 2019. In addition, the athlete completed a total of 49 strength training (2%) sessions.

Data exclusion. Data for 4iiii power meter (December 14, 2018 to April 14, 2019) were excluded from mean maximal power (MMP) analysis due to reporting ~20 W higher in all durations, but was kept for training stress score calculation.

Training load. Total annual training hours increased between 2014 and 2017 from 584–806 hr/year and plateaued for the 2017–2019 period, but training stress score increased linearly at an average of 3,809 per year (Figure 2).

Mean maximal power. Absolute MMP of all durations (5 s to 4 hr) showed mostly improvements in absolute power (in watts) through the 2014–2019 period (Figure 3). Relative power (in watts per kilogram) seemed to peak in the 2015–2016 season for 5 min, 20 min, and 30 min durations, whereas MMP seemed to improve throughout this period for 1 min and 2–4 hr durations.

Low Energy Availability in Females Questionnaire Score

Total score was 9 points (0 points from injuries, 2 points from gastrointestinal function, and 7 points from menstrual cycle). A score over eight qualified the athlete as *at risk*.

Menses

The athlete did not use birth control hormonal replacement throughout the period, reported late onset of menarche (17 years) and being amenorrheic from 2013 to 2015, and oligomenorrheic from 2015 to 2018 reporting irregular cycles every 2–8 months with light bleeding. In late June 2018, the athlete reported one significantly heavier bleeding and regular periods of 23–35 days and 2–5 days bleeding since then; therefore, it is considered that she entered into a state of eumenorrhea then.

Discussion

The main findings of this case study are (a) regular menses resumed after >4 years of menstrual dysfunction and ~5–6 months after body mass gain while maintaining high training load; (b) the highest relative MMP durations of 5 min to 1 hr were achieved during the period of menstrual dysfunction, whereas best absolute MMPs across a range of durations were achieved after body mass gain and during eumenorrhea; and (c) a short (6 week) weight loss intervention did not affect menses during the period of eumenorrhea.

This is the first long-term longitudinal analysis of an elite female endurance athlete resuming normal menses after a prolonged period of menstrual dysfunction, while concomitantly

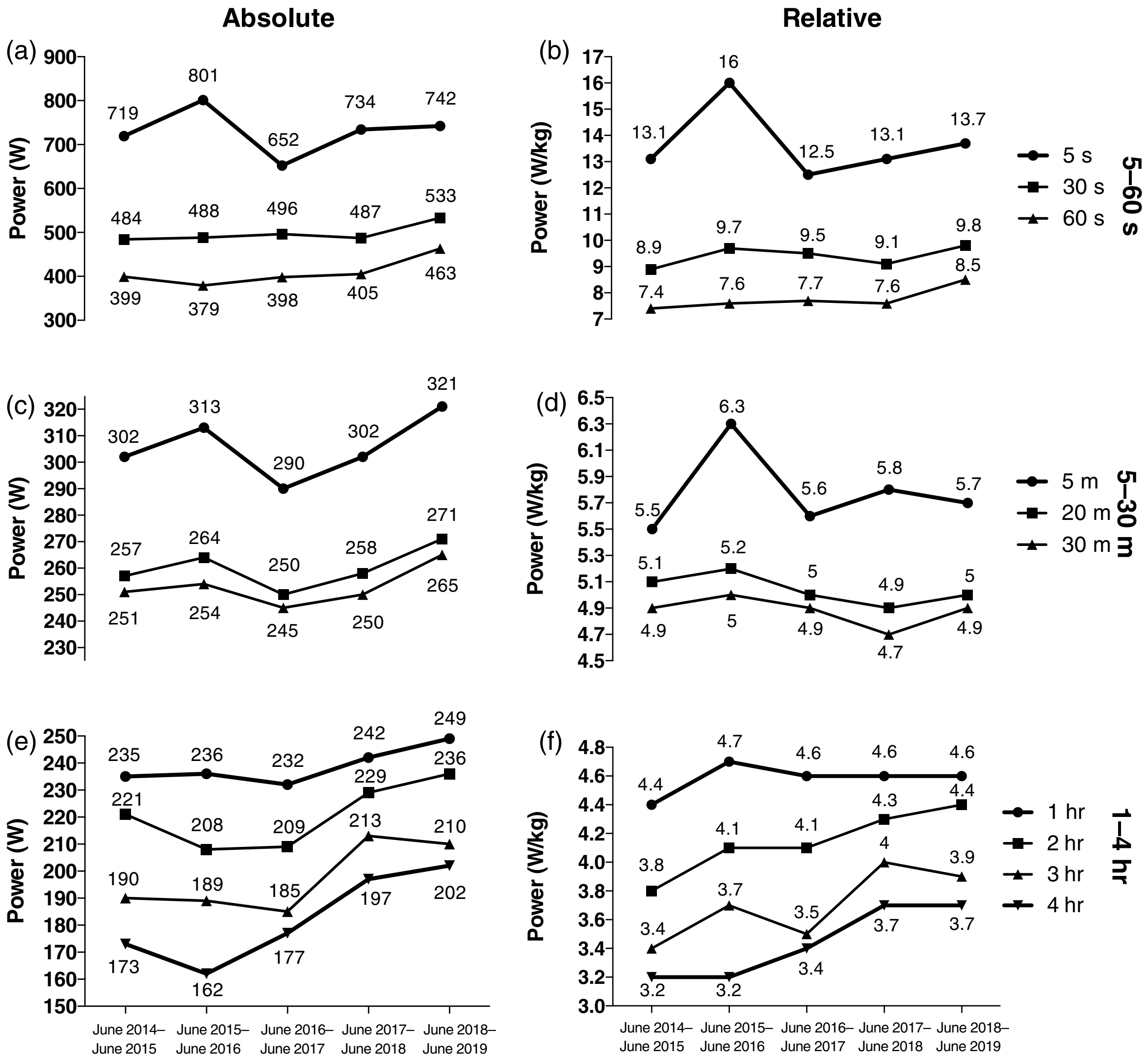

Figure 3 — Mean maximal power of durations 5 s to 4 hr in absolute values (a, c, and e) and relative to body mass (b, d, and f) for each year running from June of one year to June of the following year.

exposed to a high training load. These results are important for understanding the interaction between energy balance, body composition, training load, and physical capacity. In this context, these findings support prior laboratory-based research highlighting the importance of adequate EA for maintenance of normal physiological function of a range of systems (Loucks et al., 2011), as suggested by the triad and relative energy deficiency in sport models (Mountjoy et al., 2018; Nattiv et al., 2007), with field data.

The menstrual disturbances observed through the period fell within a continuum ranging from amenorrhea to oligomenorrhea, as it has previously been reported in exercising women (De Souza et al., 2010). These conditions are stipulated to happen due to physiological dysregulation when EA is reduced chronically under a threshold of ~30 kcal·kg^{-1}·fat free mass^{-1} per day (Loucks & Thuma, 2003). Although this report includes no data on EA or hormonal status, the clinical signs documented the changes in body mass and composition, and menses frequency are considered as proxy markers of increase in EA (Hall, 2014) and readjustment of normal menstrual function, respectively.

The increase in body mass of ~5 kg from November 2017 to February 2018 was unplanned and a consequence of the athlete's lifestyle change but indicates a significant increase in EA/energy surplus, followed by a period of maintenance of body mass ultimately resulting in resumption of regular menses ~5–6 months later (Figure 1). The sequence of events and the time scales (in months) are strongly suggestive of an increase in EA being what drove the resumption of menses. Acutely, increasing EA in energetically disrupted women results in a slow readjustment of the reproductive hormone circadian rhythm (Loucks & Verdun, 1998), whereas chronically, interventions increasing EA have shown to have the capacity to restore menses in exercising women after 23 days to 16 months (Łagowska et al., 2014; Mallinson et al., 2013; Stickler et al., 2019).

It is noteworthy that the resumption of menses happened despite a high training load (Figure 2), which is on the upper end of that reported in a group of female cyclists of different levels (Sherk et al., 2014) and closer to that of one of the most successful female endurance athletes recorded (Solli et al., 2017). This again supports the concept that it is LEA and not high training load that disrupts normal physiological function (Loucks et al., 1998).

The maximal aerobic capacity of the athlete was comparable with that of female world class cyclists (Martin et al., 2001), matching her high-level performance. Interestingly, the relative MMP for durations directly related to maximal aerobic capacity (5 min to 1 hr) seemed to peak in 2015–2016, when the athlete presented low body mass and was amenorrheic (Figure 1). It is remarkable that despite a significant increase in the body mass of the athlete (~5 kg or ~10%; Figure 1, Table 1) that would be expected to decrease the relative power, a concomitant increase in absolute MMPs throughout the period (Figure 3a–3d) meant that relative MMP (Figure 3) remained practically unchanged (5 min to 1 hr) or even improved (30 s, 1 min, ≥2 hr). It is unclear, however, if the MMP improvement was due to an enhanced adaptation to training with increased EA, a response to an increased training load (Figure 2), or a combination of both. In any case, the relative MMPs ≤ 1 hr remained mostly unchanged over the last three seasons, whereas the absolute MMPs shown mostly improvements, which can be equated with a competitive advantage, particularly for cycling performance on flat cycling stages. Accordingly, despite the athlete consistently achieved podium finishes and wins in races of Australia competing at National level and in Oceania since 2016 with most meaningful performances (higher *Union Cycliste Internationale* points) were achieved in 2018–2019.

Finally, the intervention devised to decrease body mass during the period of eumenorrhea (Intervention 2; Figure 1), resulted in no disruption of menses despite energy deficit, though we did not test if during this period the menses were ovulatory or anovulatory. This lack of perturbation of menses is in accordance to what has been shown in some individuals during short-term LEA (Lieberman et al., 2018) and in a case study of periodic weight loss in an Olympic-level female middle-distance runner (Stellingwerff, 2018), supporting the idea that periodized weight loss may be an optimized approach to achieve peak performance while maintaining metabolic health.

In conclusion, this report shows novel data on the resumption of menses in parallel with increased training load and increased physical capacity and provides new insights into the understanding of the female athlete triad. The findings suggest that while best relative power may be achieved in periods of menstrual dysfunction, a balanced approach to health and performance would likely include periodized events of weight loss that can improve power/weight ratio with little or no perturbation to normal reproductive function.

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