Taylor, HL, Garabello, G, Pugh, JN, Morton, JP, Langan-Evans, C, Louis, J, Borgersen, R and Areta, JL

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Routledge
Taylor & Francis Group

Journal of Sports Sciences

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rjsp20

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To cite this article: Harry L. Taylor, Giacomo Garabello, Jamie Pugh, James Morton, Carl Langan-Evans, Julien Louis, Reidar Borgersen & Jose L. Areta (2022): Patterns of energy availability of free-living athletes display day-to-day variability that is not reflected in laboratory-based protocols: Insights from elite male road cyclists, Journal of Sports Sciences, DOI: 10.1080/02640414.2022.2115676

To link to this article: https://doi.org/10.1080/02640414.2022.2115676

Published online: 05 Sep 2022.

JOURNAL OF SPORTS SCIENCES
https://doi.org/10.1080/02640414.2022.2115676

PHYSIOLOGY AND NUTRITION

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Patterns of energy availability of free-living athletes display day-to-day variability that is not reflected in laboratory-based protocols: Insights from elite male road cyclists

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ABSTRACT
The physiological effects of low energy availability (EA) have been studied using a homogenous daily EA pattern in laboratory settings. However, whether this daily EA pattern represents those of free-living athletes and is therefore ecologically valid is unknown. To investigate this, we assessed daily exercise energy expenditure, energy intake and EA in 10 free-living elite male road cyclists (20 min Mean Maximal Power: 5.27 ± 0.25 W · kg^{-1}) during 7 consecutive days of late pre-season training. Energy intake was measured using the remote-food photography method and exercise energy expenditure estimated from cycling crank-based power-metres. Seven-day mean ± SD energy intake and exercise energy expenditure was 57.9 ± 10.4 and 38.4 ± 8.6 kcal · kg FFM^{-1} · day^{-1}, respectively. EA was 19.5 ± 9.1 kcal · kg FFM^{-1} · day^{-1}. Within-participants correlation between daily energy intake and exercise energy expenditure was .62 (95% CI: .43 – .75; P < .001), and .60 (95% CI: .41 – .74; P < .001) between carbohydrate intake and exercise energy expenditure. However, energy intake only partially compensated for exercise energy expenditure, increasing 210 kcal · day^{-1} per 1000 kcal · day^{-1} increase in expenditure. EA patterns displayed marked day-to-day fluctuation (range: −22 to 76 kcal · kg FFM^{-1} · day^{-1}). The validity of research using homogenous low EA patterns therefore requires further investigation.

ARTICLE HISTORY
Accepted 15 August 2022

KEYWORDS
Nutrition; endurance; exercise; training

Introduction

Laboratory-based research investigating the causal effects of low energy availability (*LEA*) on endocrine, and physiological dysregulations has typically reduced energy availability (EA) to between 10 and 30 kcal · kg Fat Free Mass (*FFM*)$^{-1}$ · day^{-1} for periods of 3–6 days, incorporating a steady pattern of LEA with no variation in EA values between days (Areta et al., 2021; Loucks, 2020). However, to date, there is limited evidence available systematically assessing the daily pattern of the 2 key parameters determining energy availability, namely exercise energy expenditure (EEE) and dietary energy intake (EI) in athletes training under free-living conditions. Thus, the patterns of EA that athletes experience during consecutive days of regular training remain poorly characterised, and there is little direct scientific evidence to support the idea that athletes with increased EEE experience reduced EA.

LEA, or insufficient dietary energy to maintain normal physiological function, is currently considered the key aetiological factor underpinning the female and male athlete triads, and the "Relative Energy Deficiency in Sport" (RED-S) models (Areta et al., 2021). However, most of the research describing the causal effects between LEA, endocrine and physiological dysregulations is based on well-controlled laboratory-based studies in sedentary females, which induce a homogenous and constant state of LEA (Areta et al., 2021; Loucks, 2020). Furthermore, limited field-based research available in athletic populations suggests that this pattern of energy availability does not reflect what athletes may be experiencing in the field (Heikura et al., 2019; Langan-Evans et al., 2020; Louis et al., 2020; Moss et al., 2020). For example, we have shown a high variability of EA with fluctuating daily training load in recent case-studies of a male combat sport athlete and a master's triathlete (Langan-Evans et al., 2020; Louis et al., 2020). Similar observations have also been reported in female football players (Moss et al., 2020), and in professional cyclists during competition (Heikura et al., 2019). However, the typical daily EA patterns of athletes under free-living conditions have not been addressed directly.

Thus, the potentially variable nature of daily EA in free-living athletes warrants further investigation. At present, the ecological validity of laboratory-based evidence establishing a causal link between EA and endocrine, metabolic and physiological responses using constant exposure to LEA is unclear. Direct extrapolation of laboratory-based findings and EA threshold values to the field could therefore be troublesome (Heikura et al., 2021), given that the physiological responses to sustained LEA may not be the same as to when LEA is induced intermittently. Therefore, characterising the patterns of EA athletes typically experience in the field is pertinent to inform future laboratory-based LEA research. This will ensure that future experimental protocols more closely resemble field conditions, enhancing ecological validity.

With this in mind, we sought to characterise the relationship between EEE and EI, and the resultant variability in patterns of daily EA in athletes following their regular training and

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nutrition practices during 7 days of late pre-season training under free-living conditions. We performed the current assessment on elite road-cyclists due to (1) their typically high daily EEE (Jeukendrup et al., 2000), (2) the typically heterogenous nature of their daily EEE (Saris et al., 1989) and (3) the capacity to accurately estimate EEE in real-world conditions using crank-based power meters (Haakonssen et al., 2013). We hypothesised that athletes would fail to sufficiently match EI with EEE, with resultant EA patterns showing high day-to-day variability.

Methods

Participants

Ten highly trained elite road-cyclists of international standard, affiliated with a professional cycling team (continental level), took part in the assessment. Participant characteristics were as follows: (mean ± SD): age 22 ± 8 years, body mass 75.1 ± 8.5 kg, height 1.84 ± .05 m, absolute 5 min mean maximal power (*MMP*) 490 ± 46 W, absolute 20 min MMP 395 ± 37 W, relative 5 min MMP 6.54 ± .25 W· kg^{-1}, relative 20 min MMP 5.27 ± .25 W· kg^{-1}. Season's mean maximal power (MMP) values were determined from the athletes' online training logs (*TrainingPeaks*, Boulder, CO), based upon individual participants' power meter data (7 athletes = *Shimano*, Shimano Inc., Osaka, Japan; 2 athletes = *Quarq*, Quarq/SRAM LLC, Chicago, IL, USA; 1 athlete = *4iiii*, 4iiii Innovations Inc. Cochrane, Alberta, Canada). Based upon the criteria presented by McKay et al. (2022), all participants were classified as Tier 4 athletes.

Study design

Using an observational study-design, 10 male road cyclists completed a seven consecutive day period of assessments during a late pre-season training block. Participants' dietary and training habits were monitored remotely as part of athlete support undertaken by a professional cycling team over this period. Participants were following their coach's individualised training programme and all participants were living and training separately from each other. For this specific cycling team, the "late pre-season" training period is a phase of heavy training load (~20 hr · $week^{-1}$, ~900–950 Training Stress Score [*TSS*] · $week^{-1}$) typically undertaken between January to March. This precedes a "specific preparation" phase (~17 hr · $week^{-1}$, ~850–900 TSS · $week^{-1}$) undertaken in March/April, prior to the start of the racing in the following weeks (data provided by team coach). Comparatively, the "early pre-season" and annual (summary) training loads for the team were ~16 hr · $week^{-1}$, ~750–800 TSS · $week^{-1}$ and ~17 hr · $week^{-1}$, ~700–750 TSS · $week^{-1}$, respectively. The current study is a retrospective analysis of data systematically collected in observation of the nutritional practices of our cohort of athletes. Individuals were encouraged to continue their normal dietary practices to provide a baseline assessment of their typical dietary intake. No experimental interventions were applied during the observation period. Ethical approval was granted by Liverpool John Moores University's Research Ethics Committee (Ref: 20/SPS/052).

Training

All participants were undertaking late pre-season training and following individualised training plans (for training duration and intensity) designated by their team coach and there was no purposeful change of the training schedule during data collection. Weight-management was not an aim of the training period, as detailed by the head coach, and there was no direction to restrain dietary intake in combination with the training plans provided. The prescribed training plans varied between individuals but typically included 6 days of training, including interval sessions, low intensity short cycling sessions (<3 hr) and long cycling sessions (>3 hr), with 1 day of recovery. Most training sessions were allocated to road cycling. All training details were recorded online (*TrainingPeaks*, Boulder, CO, USA).

Quantification of dietary intake

Self-reported energy and macronutrient intakes were assessed across the 7 days using a modified version of the remote food photography method (RFPM), which has been shown to accurately measure the EI of free-living individuals (Martin et al., 2009). In short, athletes provided a photograph of their food and drinks before and after consumption. Photographs were timestamped alongside a description of the food/drink (including information on quantities, brands, preparation and cooking methods) and a known-size visual reference (e.g., credit card or tennis ball) and then sent to a smartphone app-based group chat (*WhatsApp*, Dublin, Ireland) with 2 trained researchers (athlete and 2 researchers per group).

Prior to data collection, all participants attended an online video meeting, during which the RFPM was explained in detail and all athletes were provided with the opportunity to ask questions. To ensure athletes did not omit any foods/drinks and increase the accuracy of the food records, researchers prompted the athlete for further information on any items that were difficult to identify, but no feedback was provided regarding type and/or quantity of foods selected during recording. Dietary intake was analysed individually by the 2 members of the research team (<2 years' experience as a registered nutritionist) assigned to that participant, using dietary analysis software (*Nutritics*^{TM}, Dublin, Ireland), which calculated energy and macronutrient intake for each athlete. A third practitioner checked all inputs independently. Output values from the 2 practitioners were averaged to provide estimates of EI in kilocalories per day (kcal · day^{-1}) and macronutrient intakes, reported in grams (g) and grams per kg body mass (g · kg^{-1}).

To further assess the athlete nutrition behaviour, dietary intake data was also stratified into 4 categories dependent on daily training volume, based upon the current consensus of carbohydrate requirements for training load (Thomas et al., 2016). Based upon these guidelines, data were grouped into intakes from: rest days (<45 min exercise), moderate training days (45–90 min exercise), high training days (90–210 min exercise) or very high training days (>210 min exercise).

Exercise energy expenditure

Metabolic energy expenditure was estimated from mechanical work values recorded from the participant's crank-based power meters, using validated methodology (Haakonssen et al., 2013). Whilst acknowledging the existence of inter-individual variation in athletes, an estimated gross efficiency (GE) of 20% was used for all cyclists for the calculation of metabolic energy expenditure. This GE value was based upon the assumption that average GE would be equal to 20%, in line with reported values from similar populations (Coyle et al., 1992; Moseley et al., 2004). EEE from non-cycling sessions was estimated using the compendium of physical activity (Ainsworth et al., 2000) using the corresponding exercise type, multiplied by the session duration.

Calculation of energy availability

Energy availability (EA) was calculated using the most recent definition of EA, [EA = *(Energy Intake – Net Exercise Energy Expenditure)/Fat Free Mass*] (Areta et al., 2021; Loucks et al., 1998). Net EEE (EEE_{net}) was estimated by subtracting the contribution of estimated RMR (Harris & Benedict, 1918) from calculated gross EEE (EEE_{Gross}), based upon exercise session duration. Due to limitations in access to equipment, only body mass data were accessible for anthropometric assessment of the cyclists. Participants were asked to measure their body mass at home (various weighing-scale brands, undisclosed) in the morning upon waking, after voiding, on the first day and immediately after the assessment period. FFM was calculated based upon an assumed 13% body fat for all participants. Thirteen percent body fat was selected based upon reference data from the DXA scans of 5 former team athletes, averaging 12.8% body fat, alongside reported body fat percentages ranging from 9% to 14% in similar populations (Campion et al., 2010; Klomsten Andersen et al., 2018).

Statistical analysis

Statistical analyses were conducted using IBM SPSS Statistics (v. 28.0.0.0, IBM, Armonk, NY, USA) and GraphPad Prism (v. 8.2.1, GraphPad Software Inc., San Diego, CA, USA). The mean change in body mass was quantified using a paired *t*-test. Within-participant correlations (Bland & Altman, 1995) were calculated using a general linear model to assess the relationships over time between total EEE with EI, carbohydrate, fat and protein intakes. Magnitudes of correlation were classified as : r = 0.1–0.29 = small; 0.3–0.49 = moderate; 0.5–0.69 = large; 0.7–0.89 = very large; and 0.9–0.99 = extremely large (Hopkins et al., 2009). A sensitivity analysis was conducted on all within-participant correlations to ensure regression dilution was not unduly influencing the statistical models (Ludbrook, 1997). Furthermore, a sensitivity analysis was conducted on the within-participant correlations to ensure that a residual outlier did not unduly influence the estimates from the statistical models. Significance was set at $P < .05$ for all statistical tests and data are reported as means ± SDs.

Results

Training

Participants completed 8 ± 2 (range: 6–11) training sessions during the 7-day observation period, amassing 21.5 ± 3.8 (range: 16.0–26.4) hrs of training with an average of 3.1 ± 0.5 hr · day^{-1}. Most training hours (94.9% of total; 2.9 ± 0.6 hr · day^{-1}) were road-cycling sessions, with "other" training sessions (strength-training, yoga, walking, etc.) accounting for a minority of the total training time (5.1% of total; 0.2 ± 0.2 hr · day^{-1}). Mean power output during cycling training sessions was 212 ± 35 W. Cycling-specific training accounted for 98.9% of EEE, with athletes expending 17,199 ± 3421 kcal on the bike over the 7-day observation period during data collection. The remaining 1.1%, equating to 186 ± 259 kcal over the observation period, arose from "other" training. Four out of the 10 participants only performed cycling for their training sessions.

Energy availability

Daily EEE displayed a wide range from 0.0 to 99.8 kcal · kg FFM^{-1} · day^{-1}, averaging 38.4 ± 25.9 kcal · kg FFM^{-1} · day^{-1}. EI displayed a narrower range from 28.5 to 95.0 kcal · kg FFM^{-1} · day^{-1}, with average values of 57.9 ± 13.3 kcal · kg FFM^{-1} · day^{-1}. Accordingly, EA was highly variable, with values ranging from −21.9 to 76.0 kcal · kg FFM^{-1} · day^{-1}. Mean daily EA was 19.5 ± 22.0 kcal · kg FFM^{-1} · day^{-1} for all athletes and the 7-day average within athletes was 19.5 ± 9.1 kcal · kg FFM^{-1} · day^{-1}.

There was a large positive within-participants correlation between EEE and EI (r = .62; 95% CI: .43 – .75; $P < .001$; Slope = .21, 95% CI .14 – .28; Figure 1). This would translate into an increase in athlete EI of 210 kcal · day^{-1}, for every 1000 kcal · day^{-1} increase in EEE. Figure 2 highlights the effects of this mismatch, providing a summary graph for each participant's EI, EEE and resultant EA over the observation period.

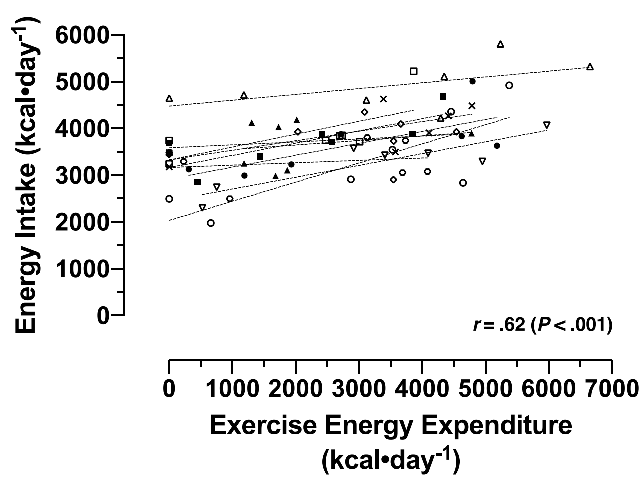

Figure 1. Within-participant relationship between exercise energy expenditure and energy intake in elite male road-cyclists over 7 days of late preseason training. Within-participant (n = 10) correlations are represented by dashed lines and individual symbols (r = .62; 95% CI: .43 – .75; $P < .001$; Slope = .21, 95% CI .14 – .28).

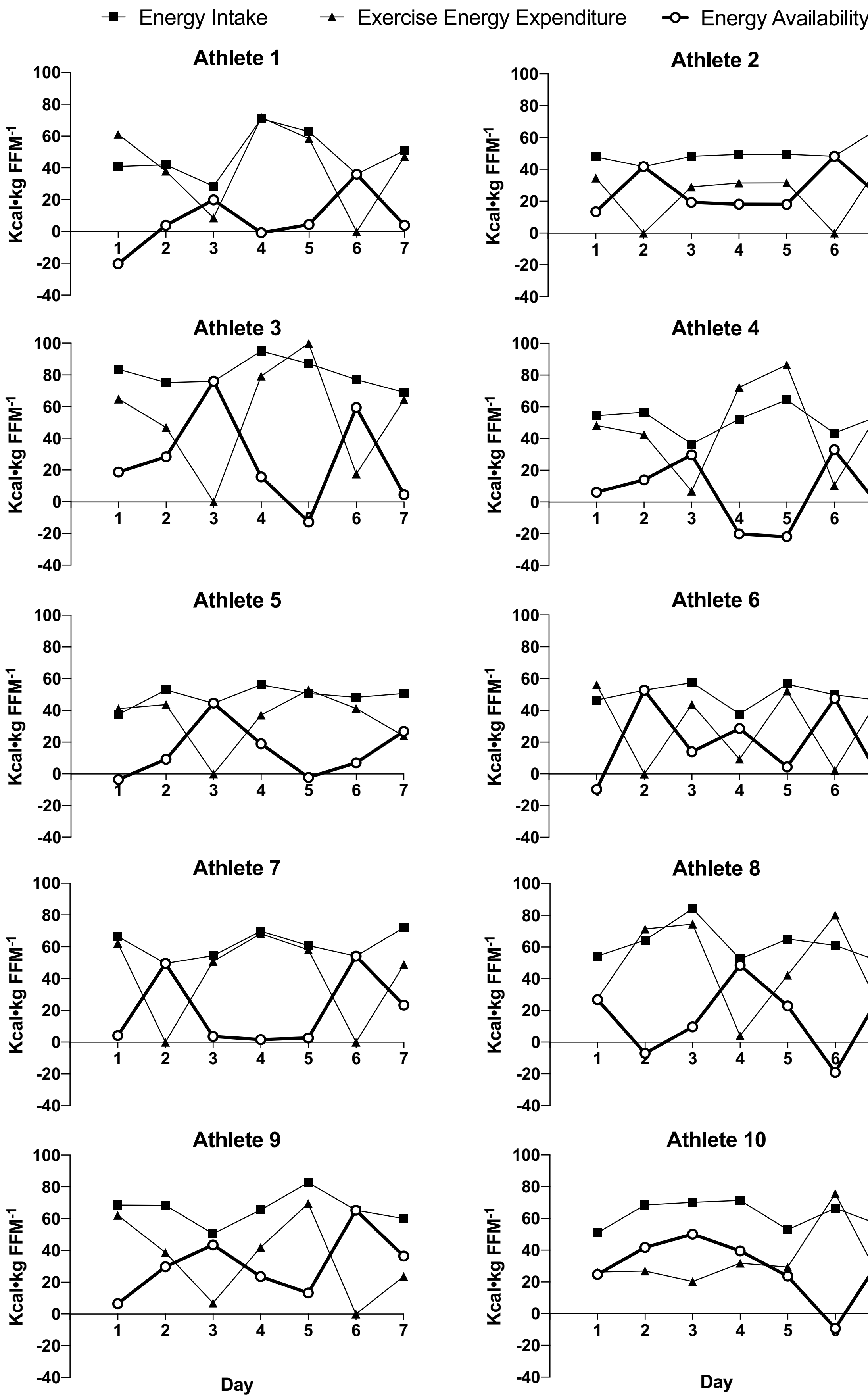

Figure 2. Individual participants' daily energy intake (thin black line, square markers), exercise energy expenditure (thin black line, triangular markers) and energy availability (thick black line, circular markers) over 7 days of late pre season training.

Macronutrient intake

Carbohydrate, fat and protein accounted for 54.1 ± 8.0, 28.7 ± 7.0 and 17.2 ± 3.9% of daily EI, respectively throughout the assessment period. In relative terms, carbohydrate, fat and protein intakes were 6.9 ± 2.2 , 1.6 ± 0.5 and 2.1 ± 0.6 g · kg^{-1} · day^{-1}, respectively. We found a large positive within-participant relationship between EEE and energy intake from carbohydrates (r = .60; 95% CI: .41 − .74; P < .001; Slope = .16, 95% CI .10 − .21). This translates into an increased carbohydrate intake of 160 kcal · day^{-1}, for every 1000 kcal · day^{-1} increase in EEE. Conversely, only a small and not statistically significant within-participant correlation was apparent between EEE and fat intake (r = .21; 95% CI: −.04 – .44; P = .099; Slope = .03, 95% CI −.01 - .07), and between EEE and protein intake (r = .24; 95% CI: −.01 - .47; P = .058; Slope = .02, 95% CI −.00 - .04).

Whilst athletes partially compensated for increasing EEE with increased EI from CHO, on the majority of training days they failed to fall within the recommended CHO intake guidelines (Thomas et al., 2016; Figure 4). This is reflected in under-consumption of CHO on 1 out of 9 (11%) "Rest" days, 3 out of 8 (38%) "Moderate", 7 of 23 (30%) of "High" and 21 of 30 (70%) "Very High" volume training days. In contrast, the athletes consumed CHO exceeding the recommended intake (3–5 g · kg^{-1} · day^{-1}) on 6 out of 9 (67%) "Rest" days.

Body mass

Body mass reduced from 75.1 ± 8.5 kg to 74.7 ± 8.5 kg (Δ −0.4 ± 0.4 kg; P < 0.05) between the first day of the assessment and immediately upon finishing the assessment.

Discussion

The aim of this study was to assess the relationship between EEE and EI and determine daily patterns of EA in a cohort of free-living road cyclists during late p re season training. In agreement with our hypothesis, athletes failed to compensate for increases in EEE with EI (Figure 1). This resulted in high heterogeneity of day-to-day EA, with EA values ranging from −21.9 to 76.0 kcal · kg FFM^{-1} · day^{-1} (Figure 2). Within the scope of the measurements employed in this study, these fluctuations appear to be dictated by daily changes in EEE. From a practical perspective, our data demonstrate that this cohort of athletes do not adjust daily EI in accordance with fluctuations in daily training volume. As such, these data also suggest that laboratory models of LEA are likely not representative of the patterns of LEA experienced by elite athletes. These findings highlight the need for further research regarding the effect of intermittent vs continuous LEA upon endocrine, metabolic and physiological responses. Such research would provide insights into the ecological validity of existing laboratory-based studies on LEA.

This study provides a detailed characterisation of daily EA patterns across 7 uninterrupted days of late pre season training of elite athletes under free-living conditions using estimations of EEE and EI. The high ecological validity of the setting in which our assessments were conducted provide greater depth to our understanding of the daily EA patterns that elite athletes are likely to experience in the field. Whilst we have shown a positive relationship between EEE and EI, compensatory EI appeared insufficient to offset days of high EEE, as reflected by the heterogenous nature of recorded EA values ranging from −21.9 to 76 kcal · kg FFM^{-1} · day^{-1}. This is in agreement with the findings of previous research observing significantly lower EA values (Heikura et al., 2019; Langan-Evans et al., 2020; Moss et al., 2020), or greater energy deficits (Vogt et al., 2005), on days in which athletes had greater EEE through training and/or competition. These data, in conjunction with our findings, suggest that increasing EEE was the cause of variation in daily EA values. Athletes in the field seem to experience high variation in day-to-day EA values based on their daily training load (Figure 2). The fluctuating patterns of EA observed therefore indicate a need for laboratory-based studies investigating the relationship between LEA and physiological dysregulations to adapt future methodology to more closely reflect the patterns of EA that athletes experience daily.

The mismatch between EEE and EI may be due to a lack of compensatory increases in appetite to drive greater EI in response to increasing EEE (Loucks, 2004; Thivel et al., 2021; Westerterp & Saris, 1991). Despite a large positive within-participant correlation between EEE and EI (Figure 1), there was still a large gap between the 2 parameters, with each 1000 kcal · day^{-1} increase in EEE corresponding to only a 210 kcal · day^{-1} increase in EI. In healthy adult males, acute energy deficits induced through exercise have been shown as unable to trigger compensatory increases in *ad libitum* EI over 2 days (King et al., 1997), 3 days (Cameron et al., 2016) and over 7 days (Stubbs et al., 2002). This idea is also in line with the findings of Edholm et al. (1970) who reported no discernible relationship between energy expenditure and EI across 3 non-consecutive weeks of initial training in army recruits. The authors also noted that days of high energy expenditure tended to lead to suppressed food intake, with energy expenditure exceeding EI on 70% of days classified as high energy expenditure. However, longer (14-day) periods have also shown increased compensation of EI of up to 30%, albeit with high variability between participants (Whybrow et al., 2008). Nonetheless, given that the population of our study are typically highly conscious of body mass (Hoon et al., 2019) we cannot overlook the possibility that athletes may have restrained EI despite an increase in hunger. Moreover, the measurement of dietary intake may have affected EI (Stubbs et al., 2014), even if participants were instructed to continue their regular nutritional practices. Therefore, either appetite cues were insufficient to drive greater EI as EEE increased, or other factors such as body composition management, lack of nutritional knowledge, reduced opportunities to feed (Burke, Close et al., 2018), or reporting of dietary intake (Stubbs et al., 2014) inhibited our cohort's EI.

Further analysis of the data shows that the lack of adjustment of daily EI in these athletes made them largely fall outside the nutritional guidelines for carbohydrate intake, particularly on the days classified as "Rest" days and "Very High" training days (Figure 4). Though there was a small increase in carbohydrate intake with increasing EEE (Figure 3), the athletes consumed excess carbohydrate on 67% of "Rest" days and

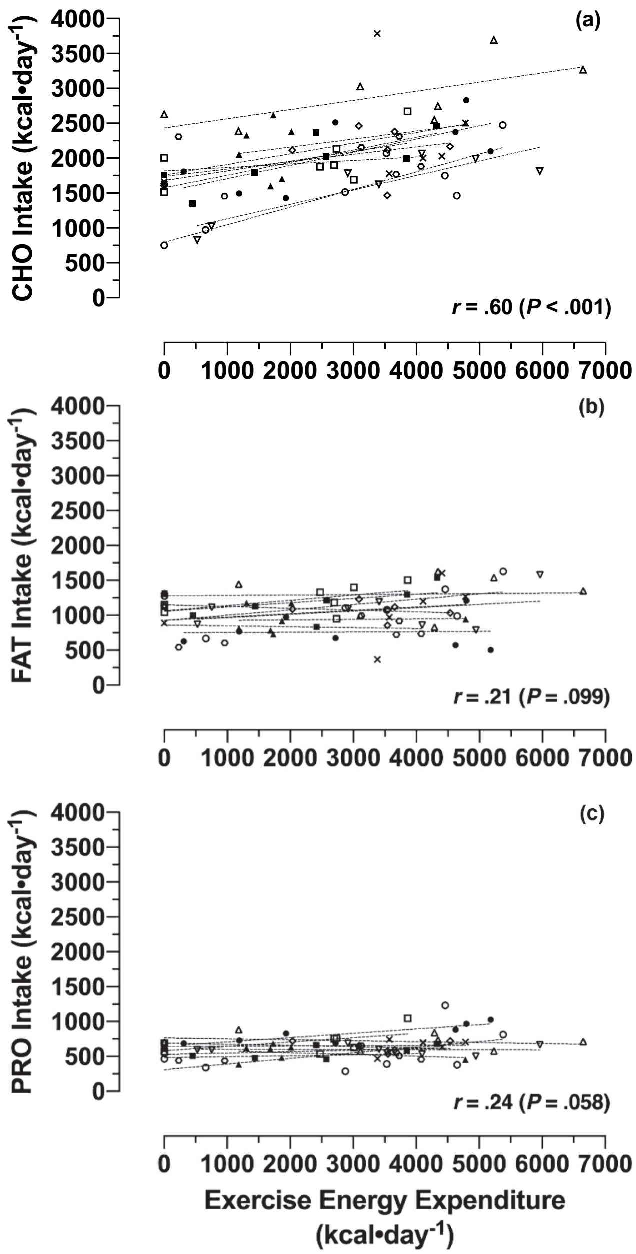

Figure 3. Within-participant relationships across the 7-day monitoring period between exercise energy expenditure and: (A) carbohydrate intake (*CHO: r* = .60; 95% CI: .41 – .74; *P* < .001; Slope = .16, 95% CI .10 – .21), (B) fat intake (*FAT: r* = .21; 95% CI: –.04 - .44; *P* = .099; Slope = .03, 95% CI –.01 - .07), (C) protein intake (*PRO: r* = .24; 95% CI: –.01 - .47; *P* = .058; Slope = .02, 95% CI –.00 - .04). Within-participant (n = 10) correlations are represented by dashed lines and individual symbols.

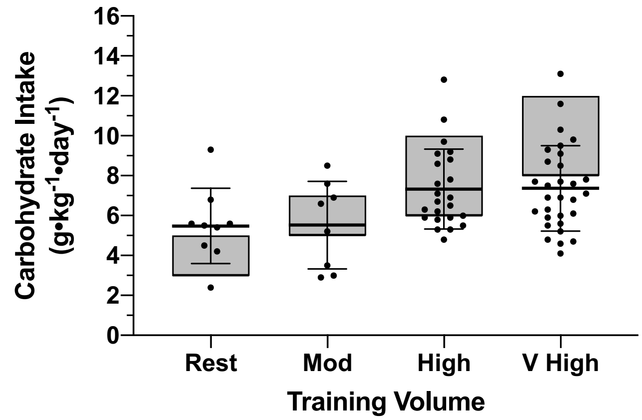

Figure 4. Relative carbohydrate intake of the cohort of elite male road cyclists, stratified by daily training volume (*Rest*: < 45 min training; *Mod (moderate)*: 45–90 min training; High 90–210 min training; V. High (Very High): >210 min training). Shaded grey boxes denote recommended carbohydrate intake for the daily training load, based upon the guidelines of Thomas et al. (2016). Individual dots represent daily values, central line average and error bars standard deviations.

insufficient carbohydrate on 30% of "High" and 70% of "Very High" training volume days, relative to guideline recommendations (Thomas et al., 2016). Therefore, in the majority of the cases, our cohort failed to adequately match their carbohydrate intake to their training volume in accordance with contemporary nutrition guidelines (Burke, Hawley et al., 2018; Impey et al., 2018; Stellingwerff, 2018; Thomas et al., 2016). Collectively, these findings suggest that when elite endurance athletes are left to their own means in relation to their nutrition, they fail to ingest carbohydrates in line with current guidelines, resulting in lower energy (and carbohydrate) availability when undertaking a higher training volume. Whilst the findings of this study are based upon observations from 1 group of individuals, the data may be underpinned by their philosophy, eating patterns and culture. In line with the Capability, Opportunity and Motivation Behaviour (COM-B) model of behaviour change (Michie et al., 2011), we speculate that if high carbohydrate availability and energy balance are desired, then the right fuelling culture and philosophy must be present in the team. Similarly, ease of access to carbohydrate-rich foods is important, alongside motivating athletes to increase their carbohydrate intake during heavy training load, as has been suggested previously (Burke, Lundy et al., 2018). In support of this, Charlot et al. (2021) recently demonstrated that the provision of familiar and hyper-palatable foods, in conjunction with extra-time allowance for eating, lead to augmented caloric intake that maintained energy balance in a cohort of 12 soldiers completing a 15-day cold-weather expedition. Facilitating food access (both physical and temporal) therefore appears to positively influence energy intake, despite high daily EEE.

Whilst we consider that the current research provides clear results and new insights into the daily patterns of EA of athletes under free-living conditions, we acknowledge some limitations in the assessment of EI and EEE. Despite providing insights into a rarely accessible elite population of tier-4 athletes (McKay et al., 2022), care should be taken in drawing conclusions from some data (e.g., changes in bodyweight) given the relatively low number of athletes recruited. Specifically, we are aware of the tendency for individuals to under-eat and under-report when dietary intake is assessed by participant dietary reports (Stubbs et al., 2014). Similarly, we acknowledge the noise introduced by the assumptions we have used to estimate body composition (we estimate this induces an uncertainty of ~3–6 kcal · kg FFM^{-1} · day^{-1} in the EA values, compared to the "real" EA) and to extrapolate gross efficiency during exercise for the sake of the accuracy of measurements (Haakonssen et al., 2013). We have therefore taken care with our data so as not to over-interpret our findings, as well as not to classify specific daily EA values as "low" or "adequate"/"normal". This is partly because what represents "low" energy availability in males, or for how long this state is required to result in a physiological response, is not yet established (Areta et al., 2021). Additionally, we also acknowledge that there may be some discrepancies from the values estimated herein and the "actual" energy availability had this been measured under laboratory conditions as originally defined. Nonetheless, the high ecological validity of the assessments, such as the direct measurement of mechanical power output and the considered assessment of EI using the RFPM provide a solid methodological foundation. Whilst this approach may have introduced some error, this is likely to be systematic in nature. The methodology employed therefore provides an adequate framework to determine the relationship between EEE and EI, and the resultant daily patterns of EA in this cohort. Furthermore, beyond the use of weighed food intakes, we are unaware of alternative methodologies that would result in drastically improved estimates of the daily EA of athletes in free-living conditions.

In conclusion, our findings provide a clear message for future laboratory-based research on energy availability as well as for applied fieldwork with athletes. To increase ecological validity, laboratory-based studies investigating the impact of LEA upon athlete health and well-being should seek to investigate the impact of heterogenous EA patterns during periods of LEA on its endocrine, metabolic and physiological effects. In relation to fieldwork, athletes and support personnel should be conscious that periods with high training loads can be more susceptible to reduced energy availability. At present, the endocrine, metabolic and physiological effects of periods of "low" energy availability are poorly characterised in males and it is also unclear to what extent they are necessary to exert an adaptative stimulus. However, a greater understanding of the EA patterns observed during periods of increased EEE with *ad libitum* EI, as shown in this study, will facilitate the development of strategies that optimise athlete training and nutrition practices. Future studies should aim to determine the effect of intermittent "low" energy availability on physiological responses in well-controlled settings.

Acknowledgments

The authors would like to thank the cyclists for their efforts during data collection for this study and to Emmy Campbell, Mitchell Challinor, Tobias Graham, Clark Grantmyre, Daniel Makison and Stella Miric for their technical assistance during data collection. We would also like to thank Professor Greg Atkinson for his assistance with data processing, statistics and the writing of these elements of the manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study was undertaken without external funding support.

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