ORIGINAL ARTICLE

The association between sport nutrition knowledge, nutritional intake, energy availability, and training characteristics with the risk of an eating disorder amongst highly trained competitive road cyclists

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Abstract

Purpose To determine the association between sport nutrition knowledge, nutritional intake, energy availability, and training characteristics with the risk of an eating disorder amongst highly trained competitive cyclists.

Methods Using an observational cohort study design, 36 male cyclists (age $= 23.1 \pm 3.9$ years) provided information on personal characteristics, training history and functional threshold power. The cyclists completed the sports nutrition knowledge questionnaire (SNKQ) and brief eating disorder in athletes questionnaire (BEDA-Q) before submitting a three-day food diary to quantify energy and macronutrient intake, and calculate energy availability.

Results The estimated lean body mass, years training, weekly on-bike training and functional threshold power were 57.6 ± 3.9 kg, 5.9 ± 3.0 years, 16.4 ± 3.2 h and 355 ± 33 W, respectively. The mean score for the SNKQ was $60.0 \pm 8.4\%$ whilst the BEDA-Q score was 4.3 ± 4.1 AU. Training and rest day energy availability was 16 ± 18 kcal·kg eLBM^{-1} and 44 ± 14 kcal·kg eLBM^{-1}, respectively. Associations between SNKQ with energy intake ($r = 0.13$, $P = 0.553$) and availability ($r = 0.21$, $P = 0.345$) were trivial to small. There was a large, negative association between SNKQ and BEDA-Q ($r = -0.55$, $P = 0.006$) suggesting that for every correct answer on the SNKQ, the BEDA-Q score reduced by 0.3 AU. All other association with the BEDA-Q were trivial to small ($r = -0.29$–0.27, all $P > 0.05$).

Conclusion The results indicate that sport nutrition knowledge and energy intake was insufficient to match their training demand on training days. The large, negative association between SNKQ and BEDA-Q suggests that those highly trained cyclists with less sport nutrition knowledge may be at a greater risk of an eating disorder.

Keywords Athlete health · Performance · Relative energy deficiency in sport (RED-S) · Sport nutrition · Endurance athletes

Introduction

Road cyclists, along with other endurance athletes, are a population potentially at high risk of being in a state of low energy availability (LEA) [1] due to the large training volumes and associated daily exercise energy expenditure [2]. It is common for cyclists to expend between 1000 and 4500 kcal during a single training session or race [2], and if this is not matched by sufficient energy intake, then the rider may be in a state of LEA [3]. Insufficient energy intake

may be a subconscious decision because the athlete is not aware of the vast energy expenditure or how to alter their nutritional intake accordingly. Alternatively, the athlete may consciously choose to limit their energy intake to reduce their body mass. Indeed, cyclists often strive to reduce their body mass due to the perceived importance of their power to weight ratio, which is an important performance consideration in cycling [4]. Body mass is the most modifiable component of the power to weight ratio and can result in some cyclists trying to reduce their body mass to maximise performance [5]. This perceived importance of having a low body mass may have unintended consequence, one of which is LEA [6].

LEA has received considerable interest over recent years given its association with sporting performance and the health of an athlete [7, 8]. LEA occurs when an individual

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has insufficient energy to support normal physiological function after the cost of energy expended during exercise has been removed [9]. The impaired physiological function caused by LEA has been identified as relative energy deficiency in sport (RED-S) [3, 10] and can have a negative impact on bone, reproductive and cardiovascular health as well as endocrine function [7–9]. Much of the research on LEA has examined the risk in female athletes, and various energy availability thresholds have been identified to determine the risk to health and performance. Current recommendations suggest that energy availability values for healthy physiological functioning is ~ 45 kcal·kg LBM^{-1}·day^{-1}, and is impaired at < 30 kcal·kg LBM^{-1}·day^{-1} [3, 6, 11, 12]. Whilst there is some uncertainty regarding the suitability of these thresholds [13], particularly in male cyclist, they offer guidelines to evaluate the risk in male athletes against, thus supporting the interpretation of nutrition diaries and eating behaviour.

Whilst early identification of LEA is important to reduce health-related issues or performance-related impairments [3], it is also essential to consider potential identifiable risk factors. Sport nutrition knowledge may be considered risk factors that, when insufficient, could contribute to state of LEA. Determining the extent to which knowledge is associated with LEA, and then developing strategies to increase an athlete's knowledge and awareness of LEA, may be an effective way to prevent health and performance impairments. A recent study by Keay et al. [14] examined the effects of a 6-month nutritional education intervention on 50 competitive cyclists who were at risk of RED-S. The cyclists were paired, based on Z-scores for lumbar spine bone mineral density (BMD), and the results indicated that cyclists who acted as controls saw a 2.3% reduction in lumbar BMD between scans over the 6-month interval. In contrast, those who received the nutritional education reported a 2.2% increase in lumbar BMD after 6 months. The findings of this study suggest that there may be a link between the nutritional knowledge of cyclists and lumbar BMD, which is likely reflected in energy availability. Whilst this study offers useful insight into a strategy to improve knowledge, further research is needed to reinforce the association between nutritional knowledge and LEA.

Other potential risk factors could include the racing category of the cyclists and the additional demands faced whilst progressing through categories and the need to accumulate racing points. Highly trained, competitive cyclists typically have a larger training volume and energy expenditure compared to lower-level cyclists. This increased exercise energy expenditure needs to be supported with adequate energy intake otherwise the cyclist will be at risk of LEA [9]. Furthermore, highly trained, competitive cyclists may experience pressure from their coaches or performance staff to match the performance and body composition goals set throughout the racing season [15]. This external pressure could place a psychological burden on the cyclist and put them at risk of LEA, and potentially lead to greater risk of disordered eating or even a diagnosis of an eating disorder [16]. Research has found that there is a greater prevalence of eating disorders in elite athletes compared to the general public, especially those competing in endurance sports [17], although there is limited research to distinguish the prevalence within different categories of the same sport such as cycling.

Therefore, the aim of this study was to assess the association between sports nutrition knowledge, nutrition intake, energy availability, and training characteristics with the risk of an eating disorder amongst highly trained, competitive male cyclists.

Materials and methods

Participants

Male competitive cyclists aged 23.1 ± 3.9 years participated in the study. After considering their involvement and providing informed consent, cyclists submitted a complete food diary for the assessment of energy intake, macronutrient intake and, with insight into the training characteristics, energy availability. Participants were ranked as elite, category 1 and category 2 by their respective national governing bodies and needed to complete a minimum of 6 h training (cycling) per week. All participants must have completed at least two competitive seasons and gained sufficient points (25 to 300) in the previous season to maintain their category status. Participants were excluded if they experienced an injury within the past 6 months that had prevented them from training for a period of 2 weeks or more. Participants that have previously been diagnosed with an eating disorder at any timepoint were not included. A minimum sample of between 35 and 40 participants was deemed appropriate [14] and provided an acceptable margin of error when generalising the findings to a relatively small cohort (i.e., international/national competitive cyclists).

Study design

Using a cohort study design, participants completed a combination of questionnaires during the preparatory period of the season to assess their sports nutrition knowledge and risk of an eating disorder. Cyclists also completed a three-day food and training diary which was used to assess their energy and macronutrient intake as well as energy availability when combined with training characteristics. All questionnaires were combined into one online survey using JISC Online Survey (Bristol, United Kingdom) with the hyperlink

distributed to potential participants. The questionnaire was accessible for two months. Ethics approval was granted by the Faculty of Health, Psychological and Social Care ethics committee at Manchester Metropolitan University (22,527). All procedures were conducted in accordance with the Declaration of Helsinki.

Procedures

Estimates of energy and macronutrient intake, expenditure, and availability

Participants recorded nutritional intake for three consecutive days, including two training days and one rest day. A training day was defined as one where the participant engaged in purposeful exercise including cycling or non-cycling activity. A rest day involved no purposeful exercise. Participants were given in-depth written instructions and provided with examples of how the diary should be completed. The participants were instructed to record the food as they were consuming it rather than retrospectively, and were asked to weigh their food to improve the accuracy of the analysis. Participants were also instructed not to change their habitual diet during the three days. The food diary was analysed using Nutritics (Version 5.5, Dublin, Ireland) to derive energy intake and macronutrient content. A Sport and Exercise registered (SENr) nutritionist input the food diary into the software and the exported information was analysed. Participants were also asked to give a written description of their training in as much detail as possible across the same three days.

To determine energy expenditure, participants were asked to report the duration, distance, mean power output and meters climbed for all cycling activity, and duration for any other forms of exercise, which were used to allocate a metabolic equivalent (MET) value taken from the compendium of physical activities [18]. However, due to one MET underestimating the true resting metabolic rate (RMR) most of the time [19], which would subsequently underestimate energy expenditure, METs were corrected for each individual across activities performed on training days. This was done by multiplying the original MET value (e.g., 3) by 3.5/RMR, with RMR estimated using the Harris–Benedict equation for men [20]. Despite all participants being able to determine their power output during cycling activity which could be used to determine kilojoules, we note that considerable between-power meter variation exists, and that several deviate from a mathematical model by over 5% due to factory calibration or torque-to-signal characteristics [21]. Furthermore, activities performed on training days that were non-cycling could not be estimated in the same manner. Thus, to standardised this across all participants and removed potential sources of equipment error, corrected METs was deemed a feasible alternative.

When completing the online survey, participants were asked to report their racing category, training history, weekly training volume and their 60 min functional threshold power (FTP), which is a common metric used by cyclists to set their training zones [22]. The participants were also asked to record their stature and body mass at the time. In accordance with previous research using cyclists, triathletes and runners [1], and based on the methodological approach used, the Boer formula for men was used to estimate the participant's lean body mass (eLBM) using the following equation: $eLBM = (0.407 \times bodymass[kg]) + (0.267 \times stature[cm]) - 19.2$ [23]. The validity of this equation for athletes is currently unknown; however, the concurrent validity of Boer's formula against dual-energy X-ray absorptiometry has been reported as strong ($r > 0.80$) with a mean bias in region of 2.6 kg amongst older healthy and diseased adults with similar body mass and percentage body fat to our sample [24, 25]. Estimates of energy availability were done using the following equation: $energyavaiability = (energyintake - exerciseenergyexpenditure)/eLBM$ [10].

Sports Nutrition Knowledge Questionnaire (SNKQ)

The SNKQ is an 88-item questionnaire comprised of five sub-sections, which assessed the participant's knowledge of weight management, macronutrients and micronutrients, sports-specific nutrition knowledge, supplement use and alcohol intake. One point was awarded for each correct answer and a 'not sure' or incorrect response received zero points. The overall score was expressed as a percentage of the total possible score (79) and interpreted as "poor" knowledge (0–49%), "average" knowledge (50–65%), "good" knowledge (66–75%) and "excellent" knowledge (75–100%) based on previously published work [26]. Studies assessing the validity and reliability of this questionnaire indicate a high construct validity ($P < 0.001$) and good test–retest reliability ($r = 0.92$, $P < 0.001$) [26].

The Brief Eating Disorder in Athletes Questionnaire (BEDA-Q)

The BEDA-Q version 2 is a brief questionnaire comprised of 9-items and was developed to identify symptoms of eating disorders in athletes [27]. The initial 6-items aimed to identify any potential symptoms of eating disorders, with the following responses available: "always", "usually", "often", "sometimes", "rarely", or "never". The responses are scored (3 = always, 2 = usually, 1 = often, 0 = sometimes, rarely, and never; scoring was reversed on the 4th item), and the theoretical final result for each participant ranged 0–18, whereby a higher score is indicative of greater risk of an

eating disorder. The second section of the BEDA-Q included 3 questions on dieting, which is often included when asking about disordered eating or an eating disorder.

Statistical analysis

Descriptive statistics included the means, standard deviation and percentage of the respondents. A paired sample t-test was used to compare energy intake, energy expenditure, energy availability and macronutrient intake between the training days and rest day. To determine difference in energy availability against 30 kcal·kg eLBM^{-1}, a one-sample t-test was used. Spearman's Rho correlation was used to determine the relationship between SNKQ and energy intake and availability as well as macronutrient intake. A linear mixed model was used to determine the association between the BEDA-Q score with participants included as a random factor to account for the individual slopes. The racing categories, weekly on-bike training, SNKQ score, macronutrient intake, and mean energy intake, expenditure and availability were included as fixed factors. All scale factors were grand-mean centred to shift the intercept to correspond with a meaningful value rather than the estimated intercept when a fixed factor is assumed to be 0. The model specification is presented in Supplement 1. The t-value for each parameter was included regardless of the significance and subsequently converted into an effect size correlation with 95% confidence intervals [28]. The size of the effect correlation was interpreted as: < 0.10, trivial, 0.11–0.30, small; 0.31–0.50, moderate; 0.51–0.70, large; 0.71–0.90, very large; 0.91–0.99, almost perfect, 1.0, perfect [29]. All data was analysed using SPSS (IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp).

Results

A total of 36 cyclists completed the online questionnaire and 3 day food diary. The sample comprised elite category racers ($n=8$), category 1 races ($n=9$) and category 2 racers ($n=19$), including a national criterium champion, a track world cup winner and five riders from Union Cycliste Internationale Continental or Pro Tour teams. The characteristics and training-related information are presented in Table 1.

Responses to the SNKQ were summed for all cyclists with a mean score of 47.4 ± 6.6 AU (range 31–58 AU). When expressed as a percentage to the total score, the mean score was $60 \pm 8\%$ (range = 39–73%). For the BEDA-Q, the mean score was 4.3 ± 4.1 AU, with 4 cyclists reporting a score that would suggest they are at risk of an eating disorder using this assessment tool (Fig. 1).

Mean energy intake, expenditure and availability across the three days was 3205 kcal, 1835 kcal and 25 kcal·kg

Table 1 Participant characteristics and cycling information

Characteristic/information	Mean ± SD (range)
Age (years)	23.1 ± 3.9 (18–30)
Stature (cm)	180.5 ± 6.1 (168–194)
Body mass (kg)	70.4 ± 7.1 (58–88)
Body mass index (kg/m^2)	21.6 ± 1.8 (18.7–27.4)
Resting metabolic rate (kcal)	1781 ± 111 (1569–2058)
Estimated lean body mass (kg)	57.6 ± 3.9 (49.3–68.4)
Years training (years)	5.9 ± 3.0 (2–13)
Mean weekly on-bike training (h)	16.4 ± 3.2 (10–22)
Mean weekly off-bike training (h)	2.0 ± 1.4 (0–5)
Functional threshold power (W)	355 ± 33 (287–430)
Functional threshold power (W·kg^{-1})	5.1 ± 0.3 (4.2–6.1)

eLBM^{-1}, respectively (Table 2). Mean energy intake ($t=3.519$, $P=0.002$) and expenditure ($t=8.411$, $P<0.001$) were substantially higher on training days compared to the rest day, but energy availability was much lower ($t=-5.322$, $P<0.001$) (Table 2). Compared to 30 kcal·kg eLBM^{-1} as a minimum reference point, energy availability was higher on rest days ($t=4.520$, $P<0.001$) and lower ($t=-3.823$, $P=0.003$) on training days. Macronutrient intake across the three days is presented in Table 2. Mean CHO ($t=3.266$, $P=0.004$) and protein ($t=2.680$, $P=0.14$) were substantially higher on a training day when compared to the rest day, whilst there was minimal difference for fat ($t=1.139$, $P=0.202$).

There was a trivial and small positive correlation between the SNKQ score with the mean 3-day energy intake ($r=0.13$, $P=0.553$) and availability ($r=0.21$, $P=0.345$), respectively. A small correlation was observed between SNKQ and mean carbohydrate intake ($r=0.28$, $P=0.204$); however, correlations were trivial for protein ($r=0.09$, $P=0.697$) and fat ($r=-0.01$, $P=0.978$). Results from the linear mixed model are presented in Fig. 2 with the entire model output in Supplement 2. There were trivial to small negative associations between cycling category and BEDA-Q score (r –0.19 to –0.03) indicating that as the racing standard increase, the risk of an eating disorder appeared to decrease slightly compared to category 2 cyclists. Mean weekly on-bike training volume was negatively associated with BEDA-Q, albeit was small in magnitude ($r=-0.18$, $P=0.396$). The SNKQ score had a moderate negative association ($r=-0.55$, $P=0.006$) with BEDA-Q score, indicating that for every correct answer in the sports nutrition knowledge questionnaire, the risk of an eating disorder decreased by 0.3 AU (see Supplement 2). There were small association between BEDA-Q and energy intake, expenditure, and availability ($r=-0.29$ to 0.27, all $P>0.05$). Macronutrient intake was negatively associated with BEDA-Q ($r=-0.23$ to -0.05, all $P>0.05$) (Fig. 2).
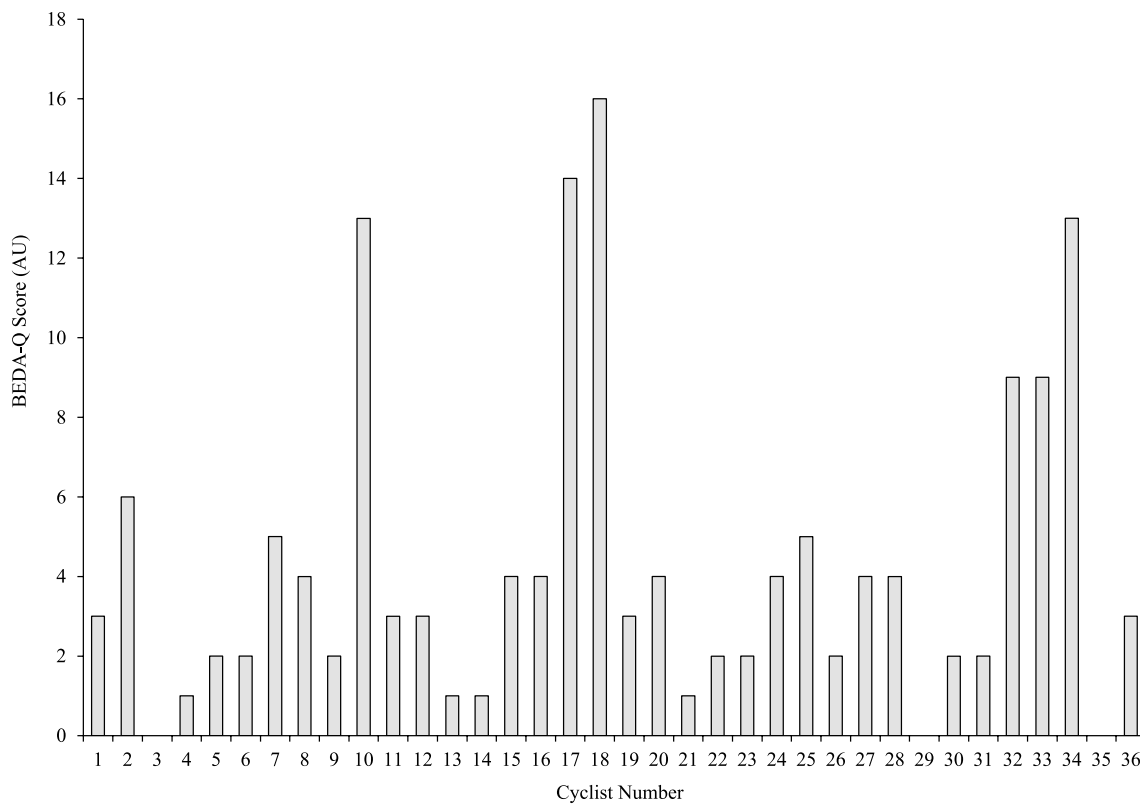
Fig. 1 Individual responses to the BEDA-Q

Table 2 Energy availability, energy intake and macronutrient intakes of the participants

	Rest day	Training days*	Three-day Mean
Energy intake (kcal)	2789 ± 811	3378 ± 856	3205 ± 743
Exercise energy expenditure (kcal)	313 ± 397	2521 ± 1266	1835 ± 890
Energy availability (kcal·kg eLBM^{-1})	44 ± 14	16 ± 18	25 ± 13
Carbohydrate intake (g·kg^{-1}·day^{-1})	4.8 ± 1.5	6.3 ± 2.1	5.8 ± 1.6
Protein intake (g·kg^{-1}·day^{-1})	1.8 ± 0.7	2.1 ± 0.6	2.0 ± 0.6
Fat intake (g·kg^{-1}·day^{-1})	1.4 ± 0.7	1.6 ± 0.4	1.6 ± 0.5

Data expressed as mean and standard deviation, and in brackets, the percentage of total energy intake. *mean value from two training days which including any cycling and non-cycling activities

Discussion

This study aimed to determine the association between sport nutrition knowledge, nutritional intake, energy availability, and training characteristics with the risk of an eating disorder amongst highly trained competitive cyclists. The results demonstrated that the cyclists possess an "average" level of nutritional knowledge, achieving a mean score of 60%, with a range of 39 to 73%. BEDA-Q scores indicate a low risk of an eating disorder when considering the group, though 4 (11%) individuals did appear to be at a higher risk. The negative association between SNKQ and the BEDA-Q suggests that better sport nutrition knowledge may reduce the risk of an eating disorder in highly trained, competitive cyclists. From the food diary analysis, it was evident that the cyclists' energy availability was substantially lower than the threshold often considered the lower bound that causes physiological impairment (~ 30 kcal·kg eLBM^{-1}) on training days and slightly below across the three-day observation period.

The cyclists recruited for this study were highly trained cyclists who competed at national or international events. The standard of the cyclists is reflected in their 60-min functional threshold power as well as their weekly training volume. The results show that the cyclists recruited for this
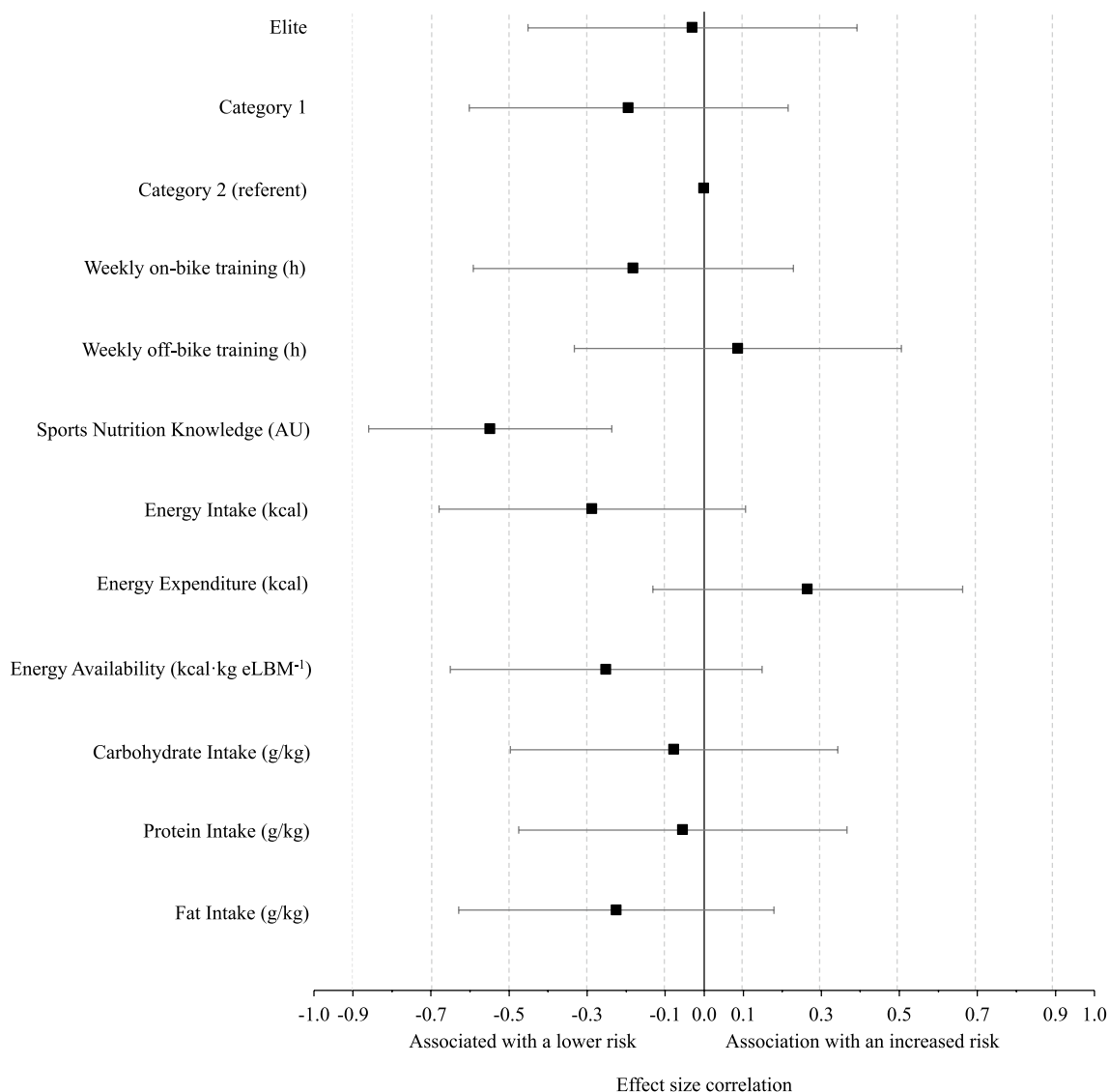
Fig. 2 The association between cyclist category, sport nutrition knowledge, energy intake, availability and expenditure, and macronutrient intake with risk of an eating disorder

study possess an "average" level of sport nutrition knowledge. This level of sport nutrition knowledge was higher than that reported in other sports, such as collegiate athletes (57%) [30] and Australian rules football players (54%) [31], but there was scope to improve this with some individuals scoring within the "poor" range. The results from the regression demonstrated that there was moderate negative association between the SNKQ score and BEDA-Q score, indicating that as sport nutrition knowledge increases, the risk of an eating disorder decreases. Using the estimate from the model, it appears that for every correct answer on the SNKQ, the BEDA-Q score was reduced by 0.3 AU (on a 0-18 scale). This supports the notion that sport nutrition knowledge may play an important role in preventing or reversing the negative health consequences of an eating

disorder and potentially LEA. Indeed, a study by Keay et al. [14], which examined the effect of a 6-month nutritional education intervention on competitive cyclists who were in a state of LEA, reported the educational intervention group observed a mean increase of 2.2% in lumbar BMD compared to a 2.3% reduction in the control group. Further, a recent study that implemented a year-long education intervention in soccer, involving taught lessons, grocery shopping and cooking lessons, improved sport nutrition knowledge by 16%. An improvement of 16% or 13 marks on the SNKQ would reduce the BEDA-Q score by ~4.8 AU. Our results, combined with those of Keay et al. [14], suggest that there might be a need to assess cyclist's sport nutrition knowledge, and deliver education programmes to moderate the risk of an eating disorder and the accompanying health risks.

That said, further research is needed to confirm the association reported in this study as well as determining the effectiveness of various education strategies within the cycling community.

The prevalence of clinical eating disorders varies greatly within the literature, possibly due to the various screening tools and methods available. The prevalence of eating disorders within male and female endurance athletes ranges from 9 to 19% [17, 32, 33], whilst the prevalence of eating disorders in female collegiate athletes ranges from 6 to 45% [34]. Of the participants surveyed in the present study, 4 (11%) were at risk of having an eating disorder, and if the data is extrapolated across all cyclists of a similar standard as those used in this study, the number of cyclists potentially at risk could be large. Whilst the 'true' population at risk is unknown and extrapolating results in this manner requires a degree of caution, these additional individuals at risk of an eating disorder has potential implications from a sporting, economic and health standpoint. However, one point of note here is that the risk did not appear to be influence to any great extent by the cyclist grade, though a larger sample across various other categories of cyclists would be needed to confirm this. Weekly on-bike and off-bike training also appeared to have minimal influence on the risk BEDA-Q scores, suggesting that the link between excessive training and BEDA-Q may not be a key driver in the development of an eating disorder within this sample.

Another key finding of this study was the LEA on training days despite energy intake being in excess of 3000 kcal on average, and CHO intake corresponding with the lower threshold recommended in the literature of 6 g/kg. Given the volume of training that our sample complete per week, these findings might have important implications when consider the risk of LEA and potentially RED-S. Indeed, on training days, the mean energy availability was considerably lower than the 30 kcal·kg eLBM^{-1} noted as a lower limit [6]. In fact, 4 (11%) of our participants were in a negative energy availability because of the large energy expenditure during training days (~4000 kcal). These finding agree with those of Melin et al. [35] who noted a similar proportion of weight-bearing endurance athletes were in a state of LEA with values of 28.5 ± 2.0 kcal·kgFFM. Furthermore, the results of Melin et al. [35] also demonstrated that those in the reduced (~30.5 kcal·kgFFM) and low (28.5 kcal·kgFFM) energy availability groups had a resting metabolic ratio below 0.90, a value that has been associated amenorrhea and low serum triiodothyronine, both common in RED-S [36].

When considering the rest day, participants appeared to have sufficient energy availability because of the balance between energy intake and exercise expenditure. Indeed, on the rest day, energy intake corresponded with that previously observed in elite-level cyclists [35, 37] and energy expenditure associated with exercise was minimal. However,

it's also important to note the mean results across the three-day observation period, with the data suggesting that over this period, energy availability might be slightly lower than the 30 kcal·kg eLBM^{-1} previously noted. However, a longer observation period is needed before drawing firm conclusions on the variability across days/weeks and long-term effect. The results of the regression highlight that energy intake and availability are negatively associated with the BEDA-Q scores, though we do acknowledge that a null and even positive effect is observed in the 95% confidence limits. This association potentially suggests that as energy intake increases, and by extension energy availability, the risk of developing an eating disorder decreases. This is intuitive because a characterising feature of an eating disorder is restricting energy intake to lose body mass, or in the fear of gaining, mass [38]. Also, the perceived importance of having a low body mass on cycling performance, i.e., power to weight ratio, may also play a role in the development of eating disorder in cyclists [39]. Exercise energy expenditure was positively associated with the risk of developing an eating disorder due to increasing exercise energy expenditure being one such strategy used to reduce body mass by purposively creating an energy deficit [17]. Our finding suggest that a clear understanding of exercise energy expenditure is likely to be extremely important in this group, especially in-light of the adjustment observed in energy intake from rest to training day.

There was no difference in the protein and fat intake between the rest and training days, and these were largely within the recommended range advocated within current position statements [40, 41]. CHO intake was slightly higher on average on training days (~1.5 g/kg) and was within the current recommendations for CHO intake (6 to 10 g/kg; [40]) for prolonged training (>90 min) such as that commonly completed by endurance athletes. Interestingly, only two of our participants achieved this upper limit of 10 g/kg, both of whom had an energy availability above 30 kcal·kg eLBM^{-1}. Whilst caution is needed when considering only two individuals, our own calculations using the mean data within this study suggest that 9 to 10 g/kg would have resulted in an energy availability of 30 and 35 kcal·kg eLBM^{-1}, with even higher recommendations of 12 g/kg [40, 41] resulting in an energy availability of 44 kcal·kg eLBM^{-1}. These finding may have important implications for cyclists like those used in this study, with a recommendation of approximately 10-12 g/kg ensuring that energy availability was more appropriate for basic physiological function and repair throughout a week.

This study provides new insight into the risk of ED in highly trained cyclist. There are, however, several limitations that need acknowledgment. The data collected in this study was self-reported by the participant due to this being conducted during a pandemic, therefore the data may have been

misreported by the participants. This is particularly important with the food dairy where participants could, either deliberately or accidentally, fail to record certain foods on the food diary. That said, the one of the authors is themselves a highly trained cyclist and reviewed all documentation to check or potential outliers or mis-reported data. Also, the participants may have altered their habitual diet to improve the perception of what they are eating and therefore altering their energy intake [42]. Another limitation is the various methods to calculate each component (intake, expenditure, lean muscle mass) of the energy availability formula used in this study, as each of these may bring about a degree of error when compared to a criterion measure (e.g., indirect calorimetry, DXA). We note that the method used to estimate lean body mass has not been validated in athlete populations such as cyclists where lean mass is likely to constitute a larger proportion of total mass. Finally, we did not ask about the participants educational background, previous or current socioeconomic status or currently living arrangements—all of which might be important when considering educational resources or developing workshops to improve knowledge and energy availability.

Conclusion

In this study, we have explored the association between sport nutrition knowledge, nutritional intake, energy availability, and training characteristics with the risk of an eating disorder amongst highly trained competitive cyclists. Our results have several important implications for cyclist and those working with them. The result indicates the cyclists possess an "average" level of nutrition knowledge, with this being positively correlated with energy availability. Also, the results show that most of the cyclist included in this study were at risk of LEA on training days and across three-day monitoring period. Furthermore, the moderate negative association between the SNKQ score and BEDA-Q score indicate that as sport nutrition knowledge increases, the risk of developing an eating disorder decreases. These cyclists could benefit from educational resources on energy availability and appropriate nutrition intake (e.g., higher CHO intake) whilst training, especially in those with the lowest sport nutrition knowledge scores or negative energy availability. Educational resources which improve the cyclist's sport nutritional knowledge may increase the awareness of the negative health consequences of LEA and reduce the risk of developing an eating disorders.

Declarations

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